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Effectiveness of the Guidelines for the Non-Operative Management of Knee Osteoarthritis
Is There any Difference in the Survival of Conversion TKA After Previous HTO In Compare to Previous UKA? Factors to be Considered When Offering a Surgery

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MEDICAL unicompartamental knee arthroplasty (UKA) and valgus high tibial osteotomy (HTO) are reliable treatments for medial unicompartamental knee osteoarthritis, which are often indicated in relatively young patients. However, if they fail or the osteoarthritis progresses, both will have to be converted to total knee arthroplasty (TKA) (1, 2).

Valgus HTO has the advantage of preserving the native joint, although its influence on TKA survival after failure of the HTO is still controversial (3). Some authors have mentioned that a TKA after HTO failure is technically more demanding with higher risk of intra- and post-operative complications in compare to a primary TKA (4).

With respect to the UKA, a significantly higher revision rate has been reported following a UKA than a primary TKA. Given this finding, most surgeons are selectively offering a UKA to only a small number of patients (5%) who meet the criteria (5). Other authors have reported good clinical results after a medial UKA, although its survival is shorter than that of a primary TKA (6).

The aim of this Editorial is to review the survival of the converted TKA after a previous HTO and previous UKA with special attention to the risk of revision of a TKA after previous HTO and previous UKA.

In 2015, Robertsson et al assessed the risk of revision of a converted TKA after previous close-wedge HTO (CW-HTO) or UKA and compared it with the risk of revision after a primary TKA (level of evidence III, therapeutic study) (1). They included 920 TKAs after previous UKA, 356 TKAs after CW-HTO, and 118,229 primary TKAs. They found a significantly higher risk of revision after a converted TKA than primary TKA (risk ratio, 2.8; confidence interval [CI], 2.2-3.5; P<0.001, and 1.7 CI, 1.1-2.6; P<0.001, respectively). However, the difference was not significant when compared to 482 converted TKA after open-wedge HTO (OW-HTO) (risk ratio, 1.2; CI, 0.8-1.8; P=0.44). Of note, stemmed components was used in 663 of 117,566 primary TKAs (0.6%), 22 of 809 conversions from HTO (4%), 22 of 809 conversions from HTO (4%) and 136 of 920 conversions from UKA (17%) (1).

In a series of 41,986 patients from the National Joint Registry for England and Wales (NJR), Liddle et al studied the optimal use of UKA, which was defined as the percentage of UKA out of overall knee arthroplasty (5). It was showed that acceptable results were achieved in practices that 20% or more is comprised of UKA. Optimal results were achieved with when this comprised 40% to 60% of the practice. Surgeons with the lowest number (up to 5% of the practice) had the highest revision rates. With optimal use, five-year survival rate was 96% (95% CI: 95-96), compared to 90% (95% CI 88 to 92) with low use (5).

In 2018, El-Galaly et al compared 1,044 TKAs after prior HTO with 63,763 primary TKAs (3). The TKA after prior HTO had a lower survival (estimated 10 year survival was 91% compared to 94% for primary TKAs). However, after adjusting for gender and age, the difference in the risk of revision was not significant (Hazard Ratio- HR 1.19, P = .09) (3).

In another study, El-Galaly et al compared survival of the TKA after previous UKA with survival of a primary TKA and revision TKA (evidence level III) including 1,012 TKA after previous UKA, 73,819 primary TKA, and 2,572 RTKA (6). The converted TKA after UKA was mobile-bearing in 85% of the patients. In addition, compared to primary TKA and RTKA, UKA to TKA conversion patients were younger with a mean age of 66 years and were classified healthier with 55% in Charnley class A (mean age of 70 years with 35% class A in primary TKA group and 70 years with 42% class A in RTKA group, all P < 0.001). The survival of the converted TKAs after
previous UKA was comparable to that of RTKA (P = 0.42, HR=0.94, 95% CI=0.74-1.2) whereas significantly lower than the primary TKA (P < 0.001, HR=3.00, 95% CI=2.5-
3.7) after being adjusted for other variables. Moreover, survival of the TKA after previous UKA was not influenced by implant type (P = 0.47), experience (all P ≥ 0.06), and indications for conversion from UKA to TKA (all P ≥ 0.27). Instability (26%) and pain of unknown origin (13%) were the most common indications revision of a TKA after previous UKA (P < 0.001). This showed that the TKA after UKA has 3 times higher chance of revision than primary TKA. Survival of TKA after UKA was similar to that of RTKA, although it was associated with increased frequency of pain and instability of unknown origin (6).

In 2020 Sasaki et al analyzed the survival of ČW-HTO with high valgus correction after a mean of 14 ± 5 (4-20) years follow-up and investigated factors related to poor outcome in 120 knees of 96 patients (7). Out of this group, 16 knees of 15 patients (13.3%) underwent TKA surgery. The survival rate was 99.2% after 5 years, 96.7% at 10 years, 92.5% at 15 years, and 86.7% at the final follow-up (18 years). Based on the Japanese Orthopaedic Association (JOA) score, 44 patients (36%) had a poor result with risk factors being obesity (P=0.018), low femorotibial angle (P = 0.019), low JOA score (P = 0.040), low knee extension angle (P = 0.045), and low knee flexion angle (P = 0.046) (7).

In a case-control study, Batailler et al compared the survival of 41 uncemented TKA after HTO with 82 primary TKAs with the mean follow-up of 8 ± 2.4 (range, 5-14) years (4). At the last follow-up, there were no significant differences in either functional outcomes or radiographic findings particularly in the rate of radiological signs of loosening. There was no significant difference in the rate of complications in the TKA after HTO (9 patients; 22%) in compare to the control group (14 patients; 17%). The survival rate with a mean follow-up of 8 years was 97.6% in the TKA after HTO vs. 100% in the control group. In the medium term follow-up, uncemented TKA after HTO showed no significant difference in functional and radiological outcomes, and survival (4).

In 2020 El-Galaly et al compared TKA survival after previous UKA and the survival of TKA after previous HTO (2). Kaplan-Meier method and the Cox proportional hazards regression were used to estimate survival and the HR for revision, considering confounding by indication utilizing propensity-score based inverse probability of treatment weighting (PS-IPTW). PS-IPTW yielded a well-balanced pseudo-cohort (standard mean difference (SMD) < 0.1 for all covariates, except implant supplementation) of 963.8 TKAs following UKA and 1139.1 TKAs following HTO. Survival of TKA after previous UKA was significantly lower than the survival of TKA after previous HTO, with an estimated survival at 5 years of 0.88 (95% CI: 0.85-0.90) versus 0.94 (CI: 0.93-0.96), respectively. The differences in survival corresponded to an implant-supplementation adjusted HR of 2.7 (CI 2.4-3.1) for TKA following UKA compared with TKA following HTO (2). However, this study has three main limitations: At first, the national registries are susceptible to misclassifications. Secondly, although the PS-IPTW usually balances many covariates with great success, some confounding variables are inevitable in non-randomized studies. Third, more HTOs were converted prior to 2008. This lack of balance may have exaggerated the jeopardy of revision related to TKA after UKA compared to TKA after HTO.

Given the above findings, we have to bear in mind other predictive factors such as age and perception of pain for satisfaction following UKA and HTO (8). According to Koh et al, severe osteoarthritis (P<0.01) was related to an augmented risk of dissatisfaction following HTO, but young age (P<0.01) and severe varus deformity (P=0.045) were associated with dissatisfaction after UKA. Besides, in patients with higher demands of physical activity, satisfaction was better after UKA in compare to HTO. All other patient-reported outcomes were favoring UKA, except pain intensity (8).

In conclusion, although the chance of TKA conversion after UKA is about twice as the TKA after HTO, there might be other hidden factors including perception of pain, socioeconomic status of the patients, and availability of resources which has to be taken into consideration with great caution. In some countries based on the healthcare system, the burden of the expenses on the patient is higher for UKA than the HTO which might influence the primary indication in offering one surgery based on patient’s affordability and insurance coverage. Subsequently, UKA patients might be less concerned about the costs after being offered a revision surgery after UKA than HTO. This might influence the survival of each stage of the conversion surgeries that has to be taken into account.

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The Delivery of Orthopaedic Care amidst COVID-19 and Social Distancing

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Abstract

In this paper we present the findings of a literature review covering articles published in the last three decades describing the application of telemedicine in orthopaedics. A review of the PubMed Central and Medline provided 75 articles studying the role of telemedicine, the majority directly examining the application of telemedicine in orthopaedic patients. We report the summarized findings of these studies, the financial and HIPAA considerations of using telemedicine, and provide an example of our single urban level-1 trauma center’s strategy for incorporating telemedicine into the clinical practice of orthopaedic surgeons during the COVID-19 pandemic.

Level of evidence: V

Keywords: COVID-19, Orthopedics, Social distancing, Telehealth, Telemedicine

Introduction

The COVID-19 pandemic has placed an unprecedented burden on healthcare systems across the globe (1). In efforts to mitigate transmission and spread of the virus, social distancing, the act of maintaining at least six feet from another individual, has been recommended for all individuals, but the impact of this will take weeks if not months to appear (2). Social distancing efforts have far reaching implications in the delivery of medical care to all patients, both with and without COVID-19. Despite the recommendations for social distancing, patients will still require non-Covid-19 related care in the midst of this pandemic. This has grave implications in terms of stressing the healthcare system and alternative treatment methods need to be explored, especially those that limit direct physician to patient contact whenever possible. Telehealth provides orthopaedic surgeons a viable alternative to in-office visits for patients requiring postoperative follow ups or triage to determine if the patient requires an in-office visit, and in some instances potentially replace routine clinical follow-ups (3–5).

Telehealth is defined as the delivery of preventive, diagnostic, and curative health services over distance (3). There are three primary forms of telehealth including: video conferencing, telephone calls, and instant messaging including text messages, email, or health system messaging services (5–7). The ideal form of communication is the use of video conferencing with telephone calls a second option. Both of these are readily accessible to many patients in 2020. Studies prior to the global pandemic found that a 75% of patients would prioritize having access to care in place of an in-person office visit (6).

Due to the hands-on nature of orthopaedic practice, telemedicine has not been heavily incorporated into the everyday practice of surgeons until this global pandemic started (7). The most common utilization of telemedicine in delivery orthopaedic care is in teleconsultations, and the results have been favorable with reductions in cost, emergency room visits, and misdiagnoses (8–15). Considering social distancing and the most recent guidelines from the American College of Surgeons (ACS) and Centers for Medicare and Medicaid Services (CMS), orthopaedic practices should move towards delivering care via through telemedicine and virtual clinic.

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Given the current state of the U.S healthcare system, we provided a review of the most recent recommendations from the ACS and CMS regarding the practice of Orthopedic surgery during the COVID-19 Pandemic (16,17). Furthermore, we have conducted a review of the literature specific to the role of telemedicine in the practice of orthopaedics, and the changes incorporated to deliver care to orthopaedic patients at a single, level-1 urban trauma center.

Materials and Methods
We searched PubMed and the Cochrane databases for studies published from January 1990 to April 1, 2020 for randomized clinical trials, meta-analyses, systematic reviews, observational studies, and retrospectives involving the use of telehealth in the delivery of orthopaedic care. Furthermore, the references of each selected article were reviewed for additional references. Articles were included following review and agreement amongst the authors, with a goal of creating a comprehensive review of the role of telemedicine in orthopedics, and its use during COVID-19 within each orthopaedic subspecialty.

Results

Patient Selection: Emergent, Nonemergent, Elective, and the Undiagnosed Patient
Emergent orthopaedic cases are potentially life or limb threatening emergencies require immediate intervention, including both surgical and medical therapies. Injuries and pathologies qualifying as orthopaedic emergencies include open fractures and traumatic amputations, crush injuries, compartment syndromes and limb ischemia as well as certain nerve and tendon injuries, infection (periarticular joint infections, osteomyelitis, septic joints, etc), spinal cord compression, post-traumatic dislocations, hip fractures and unstable or intraarticular fractures (18). Delays in definitive intervention for these injuries can have a dramatic impact on the patient’s outcome, resulting in permanent disability, loss of limb, or even death. Inpatient and outpatient evaluation for these patients should be a priority in the acute setting but can increase the mortality and morbidity in the inpatient setting and place unnecessary strain on the healthcare system.

Nonemergent orthopaedic injuries require prompt attention but can often tolerate delayed surgical intervention. These include sprains, strains, certain ligament and tendon injuries, arthritic conditions, biopsy and resection of bone or soft tissue tumors, malunions, some nerve and tendon injuries, mechanical loosening of prosthesis, etc (19–21). While not all of these injuries and pathologies require immediate intervention, delay can lead to increased pain and discomfort, anxiety, and decreased patient satisfaction (21).

Eelective procedures can be delayed for weeks, months, or possibly even years in some cases. Common elective procedures in orthopaedics include arthroplasty for painful arthritic conditions, chronic tendon rupture such as rotator cuff pathology, nerve compression (carpal tunnel, cubital tunnel), and many arthroscopic procedures. These procedures alleviate significant pain and can dramatically improve a patient’s quality of life.

While not ideal, delay in time to surgery is unlikely to result in irreversible harm to the patient and may be necessary in instances of extreme strain on the healthcare supply chain and system.

In new or undiagnosed patients, the mechanism of injury and history should be utilized to triage patients as emergent, nonemergent, or elective. The initial triage can be performed by incorporating telehealth strategies; telephone calls with new patients can not only appropriately triage the patient, but also increase patient satisfaction as their concerns will still be heard (21).

The need for an in-office evaluation can be difficult to assess even with telemedicine, which depends on the comfort level both the patient and surgeon as important considerations. The current guidelines from the American College of Surgeons (ACS) for the triage of orthopaedic patients details recommendations for each Orthopaedic subspecialty, both for elective and nonelective procedures (17). In broad strokes, patients with emergent and urgent musculoskeletal injuries should be scheduled for an in-office visit. Indications for scheduled office visits include acute joint pain in the setting of an injury, acute traumatic injury, the inability to bear weight, wound drainage or other cause for infection, osteomyelitis, new neurological deficits (cervical myelopathy, acute radiculopathy, scoliosis, weakness of the upper or lower extremities, acute loss of function or change in sensation), acute tendon laceration or rupture, acute loss of function, any dislocation or new fracture, and musculoskeletal oncology patients undergoing chemotherapy or radiation, with impending pathological fracture, or aggressive benign lesions.

The Center for Medicare and Medicaid Services (CMS) has released tiered guidelines for surgical procedures amidst the COVID-19 pandemic: tier 1 – postpone, tier 2 – consider postponing, tier 3 – do not postpone (16). As it relates to orthopaedics, the recommendation is in line with classifying patients as emergent, nonemergent, and elective. Tier 1 procedures are outpatient, low acuity surgeries, for non-life or limb threatening injuries. Tier 2 procedures are moderate acuity, requiring in-hospital stay, and performed in healthy patients. Delays in the surgery are non-life threatening in the immediate setting but can increase the mortality and morbidity in the future. These procedures include total hip and total knee arthroplasty, spinal fusions, and laminectomies. Finally, tier 3 procedures are high acuity surgeries in patients where delay would significantly increase the chance of morbidity and mortality. This includes surgical intervention for hip fractures, acute limb ischemia or compartment syndrome, and intervention for spinal cord compression.

Injuries and pathologies not recommended for scheduled in office visits may be appropriate for telemedicine. The experience of using telemedicine can vary greatly depending on the clinical practice, the resources available to the practice, the patient volume, and the financial and legal consideration.

Shoulder and Elbow
In shoulder and elbow patients, the incorporation of
electronic completion of validated scoring indices has been shown to be a simple, yet effective way for patients to be evaluated (22). Furthermore, patient’s completing the indices themselves may provide a more accurate score due to the elimination of potential sources of bias (23). In patients undergoing arthroscopic rotator cuff surgery, telehealth provided more efficient postoperative evaluations, with equivocal levels of pain and satisfaction (24). Substantial research has been performed evaluating the effectiveness of telemedicine in measuring range of motion, with studies finding telemedicine measurement comparable to clinical measurements (25–28). In instances where smartphone photography apps are unavailable to the patient, surgeons may be able to use screen-capture to create photographs use in the applications.

**Spine**

The high rates of complications following spine surgery pose a difficult challenge for surgeons to balance with the current risk of COVID-19 (29). However, several studies have outlined potential navigation of the postoperative care of these patients utilizing telemedicine. A study following patients undergoing lumbar discectomies reduced postoperative visits while retaining the ability to identify postoperative complications through a web based app (30). Clinical evaluation of patients can also be performed via telehealth, with video conferencing allowing for patient interviews, and the existence of standardized procedure for evaluating conditions like scoliosis using photography (31).

**Pediatrics**

Telemedicine has been utilized in virtually every pediatric specialty with success, but the use in orthopaedics is not well described in the literature. In pediatric orthopaedics, telehealth has been used both for initial evaluations and follow-up/preoperative evaluations, providing to be especially effective in patients with known disabilities or barriers to transportation (32). These patients can often be treated without the need for in person follow up or evaluation (33). Furthermore, as with the evaluation of adult patients suffering traumatic orthopaedic injuries, the evaluation of pediatric fractures and other pediatric orthopaedic problems, can also be performed via telehealth consultation (13,15).

**Oncology**

Musculoskeletal oncology unique subspecialty, with few fellowship-trained specialists, caring for patients whose survival is greatly impacted by timely treatment (34). More than 40% of patients are referred to another institution for their care after their initial diagnosis, causing significant delays time to treatment (35). The use of telemedicine in orthopaedic oncology was demonstrated as a viable and cost-effective model in first time appointments. Aponte-Tinao et al. performed a cost analysis, utilizing an $80-dollar charge per telemedicine appointment, and found a decrease in healthcare cost of 12% if appointments were not in-office (36). Furthermore, more than 52% of the patients in the study were diagnosed during their first visit and did not require any additional orthopaedic oncology care. Other applications of telemedicine in the field of musculoskeletal oncology are limited, but parallels can be drawn to medical and surgical oncology (37–39). Primarily used in follow-up patients, studies have demonstrated significant increase in follow up rates, as high as 1000%, especially in rural settings where patients must travel long distances and may not have access to reliable transportation (40). Telemedicine appointments for preoperative evaluation as well as postoperative follows up have been successful in surgical oncology clinics (41–43). Additionally, tumor boards are a vital component of the multidisciplinary approach to providing comprehensive cancer care, and can be performed virtually using video conferencing and screen sharing for radiographic and histologic images (44). While oncology would, and should, be evaluated in-person, these patients are at increased risk of complications and mortality from COVID-19 due to the severity of their illness and potentially compromised immune systems. Current CMS and ACS guidelines recommend scheduled visits to be maintained, and surgical interventions continue as scheduled in orthopaedic oncology patients (16, 17). However, in low-risk patients or those with benign/stable tumors, telemedicine may be a more appropriate modality for their clinical evaluations.

**Trauma**

In orthopaedic trauma patients, telemedicine has been used for the routine follow ups of patient sustaining closed fractures (45). Following their 2-week follow up appointments, the remainder of the follow ups were performed via videoconference at the 6-, 12- and 24-weeks mark. Patients with both upper and lower extremity fractures, treated operatively and nonoperatively, were included with no difference in complications. Within the hospital, video conferencing orthopaedic consults allowed for patients to be evaluated without increases in adverse outcomes, and provides an opportunity for surgeons to deliver high quality care to patients while minimizing exposure to patients potentially infected with COVID-19 (8–11,46,47). Orthopaedic consults via telemedicine are best accomplished through the use of not only video conferencing with the consulting clinician and patient, but also benefit from the use of teleradiology technology to effective send clinical and radiographic images (12). Incorporation of readily available technology, such as an iPad, to provide the inclusion of multimedia during point of care consults further reduces resource utilization resulting from orthopaedic consults (13–15). The use of telemedicine has also been shown to reduce unnecessary patient transfers following orthopaedic trauma, fewer unnecessary emergency room visits and fewer missed fractures (48–50).

**Hand, Foot and Ankle**

In rural settings, telemedicine has been especially effective in the evaluation and management of hand trauma, significantly reducing unnecessary transfers and escalations of care (7). As with other orthopaedic
subspecialties, telehealth and smartphone applications may be a viable alternative to in-office range of motion measurements of the wrist, hands, feet and ankle, allowing for comparable assessment of the patients’ function and progress (51,52).

Sports and Adult Reconstruction
In sports and adult reconstruction patients, telemedicine has shown to be an incredibly effective tool, with high rates of patient satisfaction (53). Telem medicine can be used to not only evaluate osteoarthritis in new patients, but also in the postoperative follow up care of patients undergoing TJA (54–56). In sports, the initial follow up period after ACL reconstruction has shown to benefit from telem medicine, allowing surgeons to follow their patients’ progress remotely with daily updates and identification of possible complications (57,58). The use of telemedicine in TJA patients has been shown to reduce the number of in-clinic visit and calls to the office and improve follow-up efficiency without compromising patient outcomes (59,60). Sharareh et al. found patients with five scheduled skype calls in addition to their in-office visits, found significant time saved due to a decrease in unscheduled appointments and calls (59). A virtual clinical is particularly useful for patients with routine follow up visits. Postoperative follow up visits can be performed via telemedicine without compromising patient care (59). One area of concern with telemedicine is the implementation of imaging modalities in assessing a patient’s progress. This is addressed by Wood et al. who had patients undergoing the imaging study, and then have the imaging reviewed electronically by the surgeon. Review of radiographic images in this manner resulted in no increases in complications, with equivocal time spent in the radiology department (60). Furthermore, similar to shoulder and elbow patients, the electronic delivery of validated scoring indices following TJA can eliminate potential sources of biases and provide more accurate scores (23). Regarding the measurement of range of motion following knee surgery, as with other orthopaedic subspecialties, smartphone applications and telehealth have been shown to be comparable to clinical measurements (61,62). Postoperative rehabilitation is another consideration for all orthopaedic patients, especially those undergoing knee surgery (63). Numerous telerehabilitation and at home rehabilitation programs are available to provide patients with the essential therapy they need, without increasing their risk of exposure to COVID-19 and maintain social distancing practices (63,64). Telem medicine provides arthroplasty patients a simple and safe way to communicate with their surgeon in the postoperative period, reducing in-person contact, and the number of unnecessary hospitalizations following TJA (65).

Single Institution Experience
Prior to the onset of the COVID-19 pandemic, telemedicine was not something that was used at our institution. As soon as social distancing recommendations were implemented across the state and region, the institution responded promptly by scheduling telemedicine visits for patients. Providers were asked to “scrub” their schedules to determine which patients could be offered a telemedicine visit. In general, patients were very receptive to the idea of touching base with their physician over the phone. Furthermore, due to the high level of anxiety within the general public related to exposure to the novel coronavirus strain, most patients were relieved to “touch base” with their physician or provider over the phone.

In just a brief period of time, the capabilities of our telemedicine visits have expanded from audio to an audiovisual platform, allowing a more interactive visit in which a limited physical exam can be performed, and face-to-face contact can be made. While COVID-19 has no obvious end in sight, we should continue to explore and improve our utilization of telemedicine within the field of orthopaedics. In general, it is an important platform for both patient satisfaction and safety and helps limit resource utilization, especially in times of dire need.

Discussion
The telemedicine model of healthcare delivery has evolved tremendously over the last three decades, with the most dramatic changes occurring in the last fifteen years with the widespread availability and accessibility of smartphones and novel technologies (66). The current global pandemic due to a novel coronavirus strain, COVID-19, has placed an unprecedented burden on the health system as hospitals and clinicians struggle to find balance between flattening the curve and minimizing exposure with the needs of their patients (1,67).

While the role of telemedicine in the field of orthopaedics has slowly grown in recent years, hospitals and orthopaedic groups must dramatically change their practice models to a virtual clinic and telehealth care delivery model. While limited in certain subspecialties, this review of the literature regarding the application of telemedicine in orthopaedics has demonstrated telemedicine to be a more than sufficient care model in the initial, routine, preoperative evaluations, and postoperative follow up visits (4,8,32,36,38,59).

Surgeons should be diligent when stratifying patients between in-office and telehealth visits and utilize CMS and ACS guidelines to reduce unnecessary travel and patient exposure, especially in the elderly who are particularly vulnerable (68). As the pandemic continues, patient can still have their orthopaedic needs met high quality and accessible care without diminishing patient satisfaction or causing undo harm (7,24).

In practice, this may allow for physician assistant and nurse practice nurses to have play a significant role in telemedicine visits. This advanced practice providers can be effective in assessing a patient’s progress postoperatively, or in their initial injury evaluation. The utilization of physician assistants to perform medical screening examinations via telemedicine has gained traction during the COVID-19 pandemic with multiple urban medical centers employing these systems in their emergency rooms (69). Such a practice not only ensures the patient undergoes a thorough screening with a highly trained provider, but also provides the healthcare
worker with an extra degree of protection. This point of care telemedicine screening and triage process can not only identify the appropriate level of care a patient will require, but also if there is any concern over the patient potentially having COVID-19, an exposure that would place all of the healthcare staff at risk.

One of the largest concerns regarding telehealth is physician reimbursement. In a procedure driven specialty, the financial impact of CMS and ACS recommendations to restrict elective surgeries can be crippling. The current payment model codes visits on multiple factors including level of care, time, procedures, and imaging performed. There is simply no feasible way for orthopaedic surgeons to generate equivalent relative value units using telemedicine as with performing total hip and total knee arthroplasties, which with Medicare and Medicaid are approximately $838 and $1515 for THA and $903 and $1514 for TKA, respectively (70). Telehealth reimbursement is complicated by current CMS and state laws. In California, reimbursement rates for in-office postoperative visits costs $55 to $75 dollars per visit, while asynchronous telehealth payment is between $25 to $30 per visit (66). However, this is argued to be balanced by increased efficiency allowing more patients to be seen, with multiple studies evaluating the use of telehealth in orthopaedics showing a dramatic reduction in the time spent by the clinician evaluating each patient (45,47,60). While CMS payments for telehealth under normal circumstances is limited to patients with Medicare residing in particular geographic areas and requires real time, interactive, communication between the clinician and patient, the global pandemic has resulted in expansion of telehealth payments (66,71). Among other changes, the expansion has removed the geographic restriction, and will allow for physicians to be reimbursed for Medicare patients regardless of their geographic location (72). Furthermore, state specific changes are being implemented as the pandemic progresses in order to remove barriers to care, optimize delivery of telehealth, and reduce potential exposure of patients to COVID-19 (73).

Another limitation of telemedicine is the medic-legal and HIPAA requirements. Legal guidelines and regulations surrounding telehealth are strict and has previously limited the utility of telemedicine (74). As a result of the COVID-19 pandemic in the United States, the Department of Health and Human Services has relaxed regulations and penalties of HIPAA violations using telehealth, communicating through common products like Facetime and Skype (75). The use of these modes of communication can provide clinicians with easy to use and readily accessible devices, as well as dramatically decrease the cost of overhead and implementation of telehealth. Currently, there are multiple HIPAA compliant telemedicine platforms that physicians may utilize and incorporate into their practice with relative ease. These platforms include “Zoom”, “WebEx”, “Healthie”, and “Doximity”. Other platforms exist, and it is of the utmost importance that physicians evaluate the platform of their choice for both HIPAA compliance and ease of use. While hospitals often opt for HIPAA approved methods of communication (i.e., Webex), there is no citable evidence that their encryption is more secure than that of WhatsApp or Apple’s FaceTime. The recent shift to online classrooms and work meetings due to the pandemic has brought up doubts about which software may be most secure as classes have been ‘hacked’ and disrupted by external parties. Most notably, the videoconference software Zoom, a reportedly HIPAA compliant software, has been hacked numerous times with the intruder taking over the meeting(76,77). Additionally, almost all these programs are easily recordable, meaning encounters and protected health information can be saved or leaked to the internet. The risks and benefits of each software are something that must be decided internally.

With the appropriate precaution and care given to maintaining a patient’s privacy, clinicians should feel comfortable using telehealth in its various forms during the COVID-19 pandemic.

Telehealth has the potential to be a crucial mode of care delivery during the COVID-19 pandemic. While historically under-utilized in the field of orthopaedics, telemedicine has proven to be a more than adequate method of providing all levels of outpatient care to orthopaedic patients. While the telemedicine with mitigate the financial impact to a small degree, there is no way for it to make up for the revenue generated by procedures. During this time of global crisis, it is essential for all clinicians, but within and outside of orthopaedics, to feel comfortable with telemedicine and know their patients are still receiving high quality care.

References

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CURRENT CONCEPTS REVIEW

Patient Satisfaction Following Primary Total Knee Arthroplasty: Contributing Factors

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Abstract

The reported dissatisfaction rate after primary total knee arthroplasty (TKA) ranges between 15% and 25%. The purpose of this article is to perform a narrative review of the literature with the aim of answering the following question: What are the main factors contributing to patient dissatisfaction after TKA? A review of the literature was performed on patient satisfaction after TKA. The search engines used were MedLine (PubMed) and the Cochrane Library. The keywords used were “TKA” and “satisfaction”. The main reported preoperative factors positively contributing to patient satisfaction were the following: fulfillment of preoperative expectations, preoperative complete joint space collapse, increasing patellar and lateral compartment osteophyte size, and TKA communication checklist. The principal preoperative factors negatively contributing to patient satisfaction included female sex, comorbidities, and Hispanic race. The chief perioperative factor positively contributing to patient satisfaction was cosmetic closure, whereas the fundamental perioperative factors negatively contributing to patient satisfaction included joint laxity, anterior tibial component slope, and greater femoral component valgus angle. The principal postoperative factors positively contributing to patient satisfaction were the following: ameliorated walking distance, improved range of motion, and improvements in pain. The most important postoperative factors negatively contributing to patient satisfaction included poor postoperative knee stability and soft-tissue balance, functional limitation, surgical complication and reoperation, staff or quality of care issues, and increased stiffness.

Level of evidence: III

Keywords: Arthroplasty, Knee, Patient satisfaction, Total knee arthroplasty

Introduction

Total knee arthroplasty (TKA) is one of the most commonly performed surgical procedures in the United States, with approximately 2% of the population having had a primary TKA, and soon to be well above 1 million procedures performed annually. Some studies have reported the rate of satisfied patients following their primary TKA to range from 85% to 90%, but with considerable variability. The capability to identify patients at risk for dissatisfaction would be paramount to counsel, educate, and possibly diminish the overall rate of dissatisfied patients (1). TKA is a treatment alternative for severe osteoarthritis (OA), and most patients profit from this surgical procedure by experiencing reduced knee pain, ameliorated function, and augmented quality of life. Despite these factual improvements, a high dissatisfaction rate after TKA has been reported (15%–25% of patients) (2).

Materials and Methods

A review of the literature was performed on patient satisfaction after TKA. The search engines used were MedLine (PubMed) and the Cochrane Library. The keywords used were “TKA” and “satisfaction.” The time period searched included all available literature on the Internet up to January 16, 2020. Of the 1187 articles...
found (821 in PubMed, 366 in the Cochrane Library). 39 were selected and reviewed because they were especially focused on the topic (inclusion criteria). In other words I reviewed those articles on the subject that I found particularly important. Figure 1 shows our search strategies.

**Results**

In this article, the following issues relating to patient satisfaction after primary TKA will be reviewed: prevalence, factors contributing to patient satisfaction, differences between OA and rheumatoid arthritis (RA), satisfaction changes over time, predictors of patient satisfaction for the second TKA (6 weeks apart or more) in bilateral primary asynchronous TKA, and predictive models for satisfaction after primary TKA.

**Prevalence**

In 2017, Huang et al retrospectively analyzed 46 patients who experienced simultaneous bilateral TKA. They stated that up to 20% of Asian patients who underwent TKA reported dissatisfaction with the surgical result. Minimum duration of follow-up was 2 years, with an overall patient satisfaction rate of 91.3% (3). In a systematic review published by Gunaratne et al in 2017, approximately 20% of patients reported dissatisfaction following primary TKA (4).

In 2018, Alosh et al reviewed a consecutive series of primary TKAs carried out by a single surgeon with a minimum 2-year follow-up (5). They analyzed 151 TKAs with a minimum 2.3 years’ follow-up. Eleven (7.28%) were not satisfied, 9 (5.96%) were satisfied, with minor objections, and 131 (86.75%) were fully satisfied after TKA. In a retrospective cohort of 2589 patients who had undergone a primary TKA, at 1 year, Walker at al found 1740 (67.5%) patients very satisfied, 572 (22.2%) satisfied, 190 (7.4%) dissatisfied, and 76 (2.9%) very dissatisfied (6).

**Factors contributing to patient satisfaction**

There are a number of preoperative, perioperative, and postoperative factors contributing to patient satisfaction.

**Preoperative factors**

According to the systematic review of Gunaratne et al, patient expectation before surgery is the principal preoperative factor of patient dissatisfaction (4). They searched six literature databases published between 2005 and 1 January 2016. In a study of 3069 TKAs, the most important preoperative factors for dissatisfaction were female sex and lesser improvement in knee flexion (3).

Alosh et al found that the augmenting size of patellar and lateral compartment osteophytes, specifically, greater than 5 mm, was significantly associated with amelioration in Knee Society Score (KSS). Patient satisfaction was also...
clearly associated with these parameters and seemed independent of mechanical axis alignment (5).

In the study by Hasegawa et al, patient satisfaction after TKA correlated negatively with old age (7). They analyzed 109 patients (130 knees) with knee osteoarthritis who experienced primary TKA with navigation. However, Lange et al found that satisfaction with TKA was 86% among younger patients and 91% among older patients. Distribution of satisfaction answers was shifted toward greater satisfaction in older patients (8). Patient-reported outcomes were recorded before surgery and 2 years after surgery.

According to Clement et al, overall satisfaction was influenced by diabetes, depression, back pain, and short form 12 (SF-12) physical and mental components (9, 10). A retrospective cohort of 2521 patients undergoing a primary unilateral TKA were identified from an established regional arthroplasty database. Walker et al had encountered that patients with lung disease, diabetes, gastric ulcer, kidney disease, liver disease, depression, back pain, and those with poorer preoperative functional scores [WOMAC (Western Ontario and McMaster Universities Osteoarthritis Index) and SF-12] had a significantly lower level of satisfaction (6, 11). A retrospective cohort consisting of 2589 patients undergoing a primary TKA were identified from an established arthroplasty database.

In 2019, in a prospective cohort study, Gautreau et al reported that the use of a TKA communication checklist augmented patient satisfaction. In this study, 60 patients had received the checklist in TKA appointments with orthopedic surgeons between 6 weeks and 6 months postoperatively, and their satisfaction ratings were compared with 67 patients who had received the standard of care communication (12).

Halawi et al performed a satisfaction survey. They analyzed 551 patients undergoing TKAs and total hip arthroplasties with a minimum of 1-year follow-up, who responded to a satisfaction survey. Hispanic race was found to be the most significant predictor of dissatisfaction (13). A study by Deakin et al showed a clear correlation between achievement of preoperative expectancies and patient satisfaction after TKA (14). It was a prospective analysis of 200 patients.

In the study by Felix et al they analyzed a German prospective cohort study. They found that 61% of the patients reported satisfactory outcomes; patients were mainly satisfied with the results if postoperative WOMAC was ≥82.49 and the postoperative EuroQol 5-dimension visual analog scale (EQ-5D VAS) was ≥75. In particular, patients with high absolute preoperative patient related outcome (PRO) scores were more likely to remain dissatisfied (15).

Liebensteiner et al found that patient satisfaction after TKA was better in patients with preoperative complete joint space collapse. Patients with preoperative complete joint space collapse (0- to 1-mm minimal joint space width - mJSW) attained a significantly better WOMAC result from TKA than did those with an mJSW equal to or greater than 2 mm. From these findings, it was advised that “complete joint space collapse” could especially be used as an indication for TKA (16). It was a retrospective comparative analysis.

Johnson et al, in a randomized study, compared 3 education methods in the informed consent and their association with patient satisfaction (17). No difference in satisfaction with the consent process between the 3 groups was found; 92%–97% of the patients considered the consent process as good to excellent. Satisfaction was not influenced by reinforcement approaches, such as video or nurse education; they might hence not be necessary (17).

According to Jain et al (prospective multicenter study), greater patient expectations anticipate greater PROs, but not satisfaction, in TKA patients (18). Higher Hospital for Special Surgery Knee Replacement Fulfillment of Expectations Survey scores predicted greater satisfaction at 6 months and 1 year. In TKA patients, preoperative expectations were not affected by patient demographics or preoperative function. Greater preoperative expectations anticipated higher postoperative amelioration in PROs and accomplishment of expectations. The findings of this paper emphasized the significance of preoperative patient expectations on postoperative results. Table 1 summarizes the main preoperative factors contributing to patient satisfaction.

**Perioperative factors**

In simultaneous bilateral TKA Huang et al evaluated whether patients have different satisfaction levels between the first and second knee in the early stage after simultaneous bilateral TKA. They found that there was better patient satisfaction with the second knee in the early stage (first, third, and seventh postoperative days) (5).

In a case series, Tsukiyama et al found that medial rather than lateral knee instability correlated with lower patient satisfaction. Knee laxity was measured with postoperative stress X-rays in flexion and extension, and patient satisfaction and knee function were assessed by the 2011 Knee Society Knee Scoring System. The scores for satisfaction were significantly better in medially tight than in medially loose knees (19). In computer-assisted TKA (case series), Hasegawa et al had found that midflexion instability was associated with poorer expectations and satisfaction (7). In 2018, Azukizawa (case series) had reported that excessive intraoperative medial joint laxity of ≥4 mm at 90° flexion progressively decreased patient satisfaction for 1 year (20).

In a case series of cruciate-retaining TKA, postoperative medial stability had an important positive influence over patient satisfaction at 1 year (21). In a prospective, single-arm audit, Agarwala et al stated that concealed cosmetic closure was an efficacious method for skin closure in TKA, producing superior cosmetic healing with minimal complications, leading to ameliorated long-term patient satisfaction (22). Meanwhile, in a prospective trial Sundaram et al reported that skin closure with 2-octyl cyanoacrylate and polyester mesh after primary TKA offered better cosmetic results and patient satisfaction than skin closure with staples (23).

In a prospective multicenter investigation by Khlopas
et al, at 4 to 6 weeks postoperatively, patients who had undergone robotic-arm-assisted TKA were found to have a greater satisfaction score than those who had undergone manual TKA (24). In 2019, Reimann et al compared patient-specific implants (PSIs) and conventional TKA. The PSI TKA achieved higher global patient satisfaction (25).

In a case series, a significant improvement in patient satisfaction was shown by Smith et al when they compared robotic-assisted TKA with TKA using conventional manual jig-based instruments (26). In 2020, Galea et al found that anterior (vs neutral or posterior) tibial component slope, greater femoral component valgus angle, less severe OA, and lower preoperative health state were related to inferior levels of satisfaction (27). Data were sourced from 2 prospective international, multicenter studies. In a randomized clinical trial, local infiltration analgesia for pain mitigation and patient satisfaction in the early postoperative period after TKA (28).

In a case series, Hitt et al found that the use of a flexible intramedullary rod influenced patient satisfaction and femoral size in TKA (29). Those patients who had undergone TKA using a flexible IM rod had better ameliorations in their PROs and diminished risk of oversizing the femoral component. The use of such a rod was not detrimental to outcomes and could have a positive effect on results. Table 2 summarizes the main perioperative factors contributing to patient satisfaction.

### Postoperative factors

In 2017, in a regional registry study Shannak et al reported that the principal reason for continued dissatisfaction was persistent pain (30). According to Kamenaga et al, postoperative knee stability and soft-tissue balance affected patient satisfaction after cruciate-retaining TKA (21). In 2018, in a case series Van Onsem et al observed that ameliorated walking distance and range of motion (ROM) foretell patient satisfaction after TKA. In their study, male patients improved on the 6-min walk test by 50 m or more and had an augmented ROM of 5° or more, compared with the preoperative situation, and were 6–8 times more likely to be satisfied after TKA (31). Walker et al observed that patients with less improvement in the WOMAC and SF-12 scores had a significantly inferior level of satisfaction (6). In 2018, in a retrospective cohort Bryan et al had stated that the patient will be less satisfied if the TKA does not produce ameliorations in pain and physical health (32). According to Halawi et al (satisfaction survey), the most common reasons for dissatisfaction after TKA were unceasing pain (41%), functional limitation (26%), surgical adverse event and reoperation (17%), staff or quality of care issues (11%), and unmet expectations (4%) (13). In 2019, in a retrospective study Clement et al reported that augmented symptoms of stiffness 1 year after TKA were related to an inferior rate of patient satisfaction (33).

In a randomized controlled trial Moffet et al compared the degree of patient satisfaction following in-home telerehabilitation after TKA with that of patients following a usual face-to-face home visit rehabilitation (34). The satisfaction degree of both groups was similar and was very high (over 85%). Satisfaction was rather found to be associated with walking and stair-climbing ability. Moffet et al firmly supported the use of telerehabilitation to ameliorate access to rehabilitation services and effectiveness of service delivery after TKA.

Table 3 summarizes the main postoperative factors contributing to patient satisfaction.

### Table 1. Preoperative factors contributing to patient satisfaction positively (+) or negatively (-).

<table>
<thead>
<tr>
<th>AUTHORS</th>
<th>YEAR</th>
<th>PREOPERATIVE FACTORS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gunaratne et al (4)</td>
<td>2017</td>
<td>Excessive patient expectations prior to surgery (-)</td>
</tr>
<tr>
<td>Huang et al (3)</td>
<td>2017</td>
<td>Female sex (-)</td>
</tr>
<tr>
<td>Huang et al (3)</td>
<td>2017</td>
<td>Better knee flexion (-)</td>
</tr>
<tr>
<td>Alosh et al (5)</td>
<td>2018</td>
<td>Increasing size of patella and lateral compartment osteophytes, particularly greater than 5 mm (+)</td>
</tr>
<tr>
<td>Hasegawa et al (7)</td>
<td>2018</td>
<td>Old age (-)</td>
</tr>
<tr>
<td>Lange et al (8)</td>
<td>2018</td>
<td>Old age (+)</td>
</tr>
<tr>
<td>Clement et al (10)</td>
<td>2018</td>
<td>Diabetes, depression, back pain, SF-12 physical and mental components (-)</td>
</tr>
<tr>
<td>Walker et al (6)</td>
<td>2018</td>
<td>Lung disease, diabetes, gastric ulcer, kidney disease, liver disease, depression, back pain, with worse pre-operative functional scores (WOMAC and SF-12) (-)</td>
</tr>
<tr>
<td>Gautreau et al (12)</td>
<td>2019</td>
<td>TKA communication checklist (+)</td>
</tr>
<tr>
<td>Halawi et al (13)</td>
<td>2019</td>
<td>Hispanic race (-)</td>
</tr>
<tr>
<td>Deakin et al (14)</td>
<td>2019</td>
<td>Fulfilment of preoperative expectations (+)</td>
</tr>
<tr>
<td>Felix et al (15)</td>
<td>2019</td>
<td>High absolute preoperative PRO scores (-)</td>
</tr>
<tr>
<td>Liebensteiner et al (16)</td>
<td>2019</td>
<td>Preoperative complete joint space collapse (+)</td>
</tr>
</tbody>
</table>

WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index; SF-12 = Short-form 12; PRO = patient related outcome
In a case series, Kobayashi et al. showed that patient satisfaction was better but functional activity was lower in RA than in OA (35). In a regional registry study, Shannak et al. found that patient satisfaction after TKA changed over a period of 5 to 20 years. The main conclusion was that half of the patients who stated that they were not satisfied with their TKA at 1 year went on to be satisfied with their knee (30). In 2020, Galea et al. found that patients with anterior tibial component slope improved in satisfaction level over time (27). In a prospective randomized study, Lützner et al. stated that fulfillment of expectations influences patient satisfaction 5 years after TKA (36).

Clement et al. had analyzed a retrospective cohort of 454 patients undergoing an asynchronous (6 weeks apart or more) bilateral primary TKA. They observed that amelioration of pain and function was less with the second TKA, but the rate of satisfaction remained much the same. Patients who were dissatisfied with their first TKA were more likely to be dissatisfied with their second TKA (37).

**Predictive models for satisfaction after primary TKA**

Tools designed to predict patient satisfaction following TKA have the potential to guide patient selection. In 2019, in a case series, Kunze et al. internally validated a predictive model for postoperative patient satisfaction after TKA analyzing 484 TKAs. This knee survey showed a 97.5% sensitivity and 95.7% negative predictive value in identifying at-risk patients for postoperative dissatisfaction after primary TKA (38). Zabawa et al. aimed to validate a model that predicts

### Table 2. Perioperative factors contributing to patient satisfaction positively (+) or negatively (-)

<table>
<thead>
<tr>
<th>AUTHORS</th>
<th>YEAR</th>
<th>PERIOPERATIVE FACTORS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moghtadaei et al (28)</td>
<td>2013</td>
<td>Local infiltration analgesia (+)</td>
</tr>
<tr>
<td>Hitt et al (29)</td>
<td>2015</td>
<td>Use of a flexible intramedullary rod (+)</td>
</tr>
<tr>
<td>Huang et al (3)</td>
<td>2017</td>
<td>First-side TKA in simultaneous bilateral TKA (-)</td>
</tr>
<tr>
<td>Tsukiyama et al (19)</td>
<td>2017</td>
<td>Medial rather than lateral joint laxity (-)</td>
</tr>
<tr>
<td>Hasegawa et al (7)</td>
<td>2018</td>
<td>Midflexion instability (-)</td>
</tr>
<tr>
<td>Azukizawa et al (20)</td>
<td>2018</td>
<td>Excessive intraoperative medial joint laxity of ≥4 mm at 90° flexion (-)</td>
</tr>
<tr>
<td>Kamenaga et al (21)</td>
<td>2018</td>
<td>Medial stability and lateral laxity (-)</td>
</tr>
<tr>
<td>Agarwala et al (22)</td>
<td>2019</td>
<td>Concealed cosmetic closure (+)</td>
</tr>
<tr>
<td>Khlopas et al (24)</td>
<td>2019</td>
<td>Robotic-arm-assisted TKA (+)</td>
</tr>
<tr>
<td>Reimann et al (25)</td>
<td>2019</td>
<td>Patient-specific implants (+)</td>
</tr>
<tr>
<td>Sundaram et al (23)</td>
<td>2019</td>
<td>Skin closure with 2-octyl cyanoacrylate and polyester mesh (+)</td>
</tr>
<tr>
<td>Smith et al (26)</td>
<td>2019</td>
<td>Robotic-assisted TKA (+)</td>
</tr>
<tr>
<td>Galea et al (27)</td>
<td>2020</td>
<td>Anterior vs neutral or posterior tibial component slope, greater femoral component valgus angle, less severe OA, and lower preoperative health state (-)</td>
</tr>
</tbody>
</table>

TKA = Total knee arthroplasty; OA = Osteoarthritis

<table>
<thead>
<tr>
<th>AUTHORS</th>
<th>YEAR</th>
<th>POSTOPERATIVE FACTORS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shannak et al (30)</td>
<td>2017</td>
<td>Persistent pain (-)</td>
</tr>
<tr>
<td>Kamenaga et al (21)</td>
<td>2018</td>
<td>Poor postoperative knee stability and soft-tissue balance (-)</td>
</tr>
<tr>
<td>Van Onsem et al (31)</td>
<td>2018</td>
<td>Improved walking distance and range of motion (+)</td>
</tr>
<tr>
<td>Walker et al (6)</td>
<td>2018</td>
<td>Poor improvement in WOMAC and SF-12 (-)</td>
</tr>
<tr>
<td>Bryan et al (32)</td>
<td>2018</td>
<td>Improvements in pain, mental health, and physical health from 6 to 12 months, predicted improvements in satisfaction (+).</td>
</tr>
<tr>
<td>Halawi et al (13)</td>
<td>2019</td>
<td>Persistent pain, functional limitation, surgical complication and reoperation, staff or quality of care issues, and unmet expectations (-)</td>
</tr>
<tr>
<td>Clement et al (33)</td>
<td>2019</td>
<td>Increased stiffness (-)</td>
</tr>
</tbody>
</table>

WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index; SF-12 = Short-form 12
PATIENT SATISFACTION FOLLOWING TKA

The capacity to recognize patients at risk for dissatisfaction would be valuable to counsel, educate, and potentially diminish the overall rate of dissatisfied patients. Tools (predictive models) intended to anticipate patient satisfaction following TKA have the potential to guide patient selection. Nonetheless, further research is required to develop a simple, but robust questionnaire that consistently foretells patient satisfaction after primary TKA.

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References


patient satisfaction following TKA. Phone surveys were administered to 203 patients who underwent TKA. The satisfaction in their study was 65%. Comparing satisfied and dissatisfied groups, there was a significant difference with respect to pain before TKA and body mass index (39).

Calkins et al aimed to determine the external validity of a prediction model for patient satisfaction (PMPS), with the hypothesis that it would achieve similar predictive success in their study group. They found that their prediction model was incapable to anticipate patient satisfaction after TKA (1).

Discussion

TKA is one of the most frequently performed surgeries in the world. The vast majority of patients profit from primary TKA by experiencing diminished knee pain, ameliorated function, and augmented quality of life. In spite of these fact-based ameliorations, a high dissatisfaction rate after TKA has been reported (15%–25% of patients); however, other studies have stated that the rate of patients satisfied following primary TKA ranges from 85% to 90%.

A number of preoperative, perioperative, and postoperative factors contribute to patient satisfaction.

Recurrence of Ganglion Cysts Following Re-excision

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Abstract

Background: The recurrence of ganglion cysts after surgical excision has a reported rate of 4% to 40%. Recurrence rate after revision surgical excision is unknown. The purpose of this study was to define the incidence of recurrent ganglion cysts in patients who underwent a secondary excision procedure.

Methods: With Institutional Review Board approval, we retrospectively identified by CPT code and reviewed charts of patients who had recurrent ganglion cyst excision performed over a five-year period (2010 – 2014). Recurrence was defined as reappearance of a cyst in the same area as it was previously. Demographic information including recurrences and revision surgeries was collected in addition to outcome variables such as patient satisfaction, pain levels, and functional limitations.

Results: Out of the 42 revision cases identified 20 patients were reached. Mean time to recurrence of the cyst after the first ganglion cyst excision was 2.5 years (range: 1 month - 12 years). After the second ganglion cyst excision, three patients (15%) had a recurrence, each occurring within one year (mean: 11 months; range: 9-12). One of the three patients underwent a third successful ganglion cyst excision. The other two patients declined surgical intervention to date. Patients without a second recurrence (n=17) reported an average pain score of 0.1 (range: 0-2) on a scale of 1-10. Three (18%) reported some difficulty with day-to-day activities due to their scar. Seven (41%) patients reported at least transient numbness or tingling. Mean satisfaction was 9.8 on a scale of 1-10, and 100% reported that they would undergo another ganglion cyst excision should they ever have another recurrence.

Conclusion: Patients should be advised about the risk of recurrence after re-excision of ganglion cysts, which was noted to be 15% in our cohort. This rate of recurrence is similar to that of primarily excised cysts.

Level of evidence: III

Keywords: Ganglion cyst, Recurrence, Surgical excision, Wrist surgery

Introduction

Ganglion cysts are the most common masses afflicting the hand and wrist. Although these masses are benign, they can cause pain, weakness, and loss of function due to irritation of the branches of the posterior interosseous nerve, tendon, or capsular tissues (1). Ganglion cysts usually overlie joints or tendons and are typically located on the dorsal side of the wrist. To date, the exact pathogenesis of ganglion cysts remains unknown. However, several theories exist, including synovial herniation, mucoid degeneration of periarticular structures, and/or a result of stressing the joint capsule and ligaments which simulates the production of hyaluronic acid (2). Ganglion cysts have the potential to resolve spontaneously, and given the limited morbidity associated with these lesions, nonsurgical interventions, such as observation or needle aspiration, represent the primary treatment approaches (3,4). Surgery is often reserved for patients with persistent

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or recurrent symptoms who have failed conservative therapy. Surgical removal can be performed using an open or endoscopic approach (5-8). During the procedure, removal of both the cyst and its stalk is necessary. If this is not done properly, postoperative recurrence may be more likely. There are several additional risk factors for recurrence after dorsal wrist ganglion excision, including presence on the dominant hand or wrist, female gender, and age of 24 years or younger (1,7). Rates of ganglion cyst recurrence following surgery have been reported to be in the range of 4% - 40% (9). However, following a second surgical excision, there are no published data on the incidence of another recurrence and the symptoms associated with it.

The present study can impact surgical decision-making and further define the surgical risks and benefits of revision ganglion cyst excision, as well as guide patient expectations.

Materials and Methods

In this retrospective study, which was approved by the Institutional Review Board at our institution, our patient cohort was identified by searching electronic medical records data for Current Procedural Terminology (CPT) code 25112, which pertains to revision ganglion cyst excision. Specifically, this query encompassed all CPT codes over a five-year period (2010 – 2014). Recurrence of the ganglion cyst was defined as reappearance of a cyst in the same area as prior. The study adhered to the Strengthening the Reporting of Observational studies in Epidemiology (STROBE) guidelines. Of the 42 patients identified using this CPT code, 20 patients were reached by phone or email. These patients were asked to complete a questionnaire, which included demographic information, duration between primary and revision surgeries, surgical technique for each procedure (open vs. arthroscopic), and specifics regarding any third recurrences and/or second revision surgeries. Additionally, outcome data pertaining to patient satisfaction, pain levels, and functional limitations was collected.

Results

Of all 42 patients identified with a ganglion cyst recurrence and subsequent revision surgery, 20 patients (48%) completed the questionnaire via phone call or email. The study cohort consisted of 12 women (60%) and 8 men (40%), with an average age of 46.2 years (range: 15 – 76; standard deviation: 17.8) [Table 1]. Distribution of ganglion cyst laterality was similar between the right (55% of cases) and left (45% of cases) hand/wrist. The dominant side was affected 55% of the time, and volar ganglion cysts were more common (60% of cases) than dorsal ganglion cysts (40% of cases). The primary surgical excision was performed using an open technique in 18 cases. Two ganglion cysts were excised using an arthroscopic technique.

Time to recurrence of the cyst after primary surgical excision ranged from one month to 12 years with an average of 2.5 years [Table 2]. The duration between the primary and revision surgeries ranged from two months to 14.6 years, with an average of 4.2 years between procedures. All 20 revision surgeries were performed using an open technique. After the second ganglion cyst excision, three patients (15%) had a third recurrence. Demographic data from these three patients is available in [Table 3]. Each of these patients had a volar ganglion cyst, and all three recurred within one year of the revision procedure (mean: 11 months; range: 9 – 12 months). Only one of these three patients opted for a third ganglion cyst excision due to pain (pain level 3 on a scale from 1-10) and transient paresthesias which limited day-to-day activities. One patient did not seek additional treatment because they experienced no pain or functional limitations. The other patient cited the previous two recurrences as reasoning not to seek additional treatment, despite the ganglion cyst interfering with day-to-day activities.

Of the patients without a second recurrence (n=17), only one reported pain of 2 out of 10 attributed to scarring. Three patients (18%) reported some difficulty with day-to-day activities due to scarring. Seven patients (41%) reported transient numbness or tingling of the hand or wrist. On average, these patients reported a satisfaction level of 9.8 on a scale from 1-10.

Discussion

Patients with a ganglion cyst recurrence more often presented with a lesion on the volar side of the wrist. Symptoms and limitations may be less well-tolerated on the volar side of the hand and wrist as compared to the
dorsal side. Volar cysts are technically more difficult to surgically manage because there is a risk of damage to the radial artery and the stalk of the cyst may be more difficult to identify.

In three out of 20 patients (15%) there was a second recurrence of the ganglion cyst. Patients should be informed about the risk of recurrence after re-excision of ganglion cysts. The rate of ganglion cyst recurrence observed in this study is similar to the recurrence of primarily excised cysts (9). All patients reported that they would undergo another ganglion cyst excision if, hypothetically, the cyst were to recur. However, in the three patients who had a true third recurrence, only one had pursued a second revision surgery to date.

This is the first report in the literature that gives insight into the incidence and outcomes of a second recurrence of ganglion cysts in the hand and wrist. Even so, there are limitations to this study. Only 48% of the patients identified responded via phone or email to the questionnaire. We are not certain in why our response ratio is so low. Geographic and demographic factors may play a role in this. Due to the small sample size we cannot provide conclusive recommendations based on the results.

<table>
<thead>
<tr>
<th>Procedure technique, N (%)</th>
<th>After 1st surgery (N=20)</th>
<th>After 2nd surgery (N=3)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open</td>
<td>18 (90)</td>
<td>1 (100)</td>
</tr>
<tr>
<td>Endoscopic</td>
<td>2 (10)</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time to recurrence, months</th>
<th>After 1st surgery (N=20)</th>
<th>After 2nd surgery (N=3)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;12</td>
<td>10 (50)</td>
<td>1</td>
</tr>
<tr>
<td>12-60</td>
<td>6 (30)</td>
<td>2</td>
</tr>
<tr>
<td>&gt;60</td>
<td>4 (20)</td>
<td>0</td>
</tr>
<tr>
<td>Mean</td>
<td>30.3</td>
<td>11.0</td>
</tr>
</tbody>
</table>

Ganglion cysts have a high incidence, and additional research on the subject is warranted. Although these lesions are benign, most patients desire resolution of the cyst by means of aspiration or resection. Further research should be performed with a larger population sample to offer conclusive recommendations regarding secondary recurrence of ganglion cysts after re-excision.

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References

Five Year Follow up of Retrospective Cohort Comparing Structural and Functional Outcome of Arthroscopic Single-row versus Double-row Suture Bridge Repair of Large Posterosuperior Rotator Cuff Tear in Patients Less than or Equal to 70 Years

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Abstract

Background: High re-tear rates after repairing large-sized posterosuperior rotator cuff tears remain a significant concern which may affect the clinical outcome. The most optimal type of repair (single versus double-row suture bridge) suited for large size tear remains debatable.

Methods: In a retrospective cohort study with a minimum of five years follow up, the structural and functional outcome of 103 patients with large size cuff tear repaired with single row (SR) or double row suture bridge (DRSB) were evaluated. The structural outcome was assessed with ultrasonography whereas functional outcome was evaluated with Constant Murley (CM) and American shoulder elbow score (ASES).

Results: There were 55 patients in the SR group and 48 patients in the DRSB group with a mean follow-up of 74.2 months (range, 60-96 months). While comparing the structural integrity in two groups, we found significantly lower re-tear rates in the DRSB group as compared to the SR group (10.4% vs. 32.7%; \( P=0.006 \)). Also, there were more focal defects in the SR group (25.4%) than the DRSB group (8.3%). Overall, there was no significant difference in CM and ASES scores when the SR group was compared to DRSB. However, subgroup analysis between those with intact and retorn tendon revealed significant difference \( (P=0.0001) \) in the clinical scores.

Conclusion: At a minimum of five years follow-up, the DRSB repair of large posterosuperior cuff tear resulted in superior structural healing over SR repair. Nevertheless, overall there was no significant functional difference between both the techniques. However, the functional outcome of the healed tendon subgroup was superior to retear tendon subgroup.

Level of evidence: III

Keywords: Large size, Outcome, Posterosuperior, Repair, Rotator cuff tear, Single row, Suture bridge

Introduction

Retear or failure to heal after the rotator cuff repair remains a significant concern as it may affect the functional outcome (1-3). The retear rates of the repaired rotator cuff continue to be varying from 5 % to 90 % (4-9). Multiple factors are responsible for failure to heal on to the footprint after the repair of the rotator

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cuff, such as the age of the patient, size of the tear, quality of the tendon and repair techniques (10, 11). Among various factors, tear size (especially large tear) remains a major concern resulting in a retear rate of up to 50% after the repair of large tears (11-13).

Currently, most surgeons either use arthroscopic single row (SR) or double row suture bridge (DRSB) technique to repair the torn cuff. Biomechanically, DRSB repair is superior over SR repair in restoring near-complete footprint, higher load to failure, and lesser gap formation on cyclic loading (14-16). Hence, it is logical to conclude that rotator cuff repair by the DRSB technique would result in better structural and clinical outcomes as compared to SR repair. However, a superior structural footprint restoration in DRSB as compared to SR has not always translated into better clinical and structural outcomes in the former group. The evidence in the literature remains conflicting regarding the clinical and structural outcome after the repair of large rotator cuff tears with two techniques. To date, there has been no consensus regarding the superiority of either technique which would provide a superior outcome in large tears.

Many authors gave different conclusions like similar structural and clinical outcome in both techniques or better clinical results with DRSB but no structural difference between the two or superior structural healing with DSRB but no superiority in the clinical outcome as compared to SR (17-20) or better clinical and structural outcome in double row technique in large tears (21). A recent meta-analysis by Xu et al concluded that the double-row technique results in improved functional outcomes in tear size more than 30 mm (22).

Nevertheless, most individual studies had mixed data of small-medium, medium-large, large to massive, or mixed type tears with a fewer number of patients in each group and subgroup.

The objective of our study was to evaluate the clinical and structural outcome after the repair of large size rotator cuff tear with either SR or DRSB technique. We hypothesized that there would be no difference between the two techniques while comparing structural integrity and clinical outcomes.

**Materials and Methods**

**Study Design and patient selection**

This is a retrospective cohort study (Institutional ethical committee approved) of arthroscopic rotator cuff repair of large size posterosuperior cuff tear by SR or DRSB (transosseous equivalent), which were performed between 2011 to 2014, and the data were collected prospectively for a minimum of five years.

The demographic data, history, preoperative clinical, preoperative magnetic resonance imaging (MRI) and intraoperative details of each patient who was operated for large size RC tear between 2011 and 2014 were obtained from offline and online medical records. A total of 128 patients were selected who matched the criteria. Twenty-five patients were excluded as they were lost to follow up, leaving 103 patients for the final assessment.

**Inclusion and Exclusion criteria**

The inclusion criteria were (1) patients between 40 years to 70 years, (2) presence of large, full-thickness posterosuperior cuff tear [tear size 3-5 cm in anteroposterior plane measured by a graduated probe] confirmed during arthroscopy which were either crescent, ‘L’ or ‘reverse-L’ shape, [3] repair technique either by SR or DRSB, (4) postoperative ultrasonographic imaging of repaired cuff at 3, 12 months and at a minimum final follow-up of five years and [5] clinical follow up at a minimum of five years. The exclusion criteria were [1] patients with partial tears, medium and massive size tear, [2] radiographic features of cuff arthropathy, [3] mini-open repair of the cuff [4] associated frozen shoulder which required capsular release, [5] Lafosse Type 4 and 5 Subscapularis repairs as these repairs required different rehabilitation protocol, and would have affected the overall outcome, [6] irreparable cuff or partial repair of the cuff or cases where more than 80% of mediolateral footprint coverage could not be performed after the repair, and [7] ‘Deep U’ shape tears were excluded from the study as coverage of the repaired tendon after the repair was often less than 80% of the footprint and Goutallier grade IV fatty infiltration and severe atrophy of the Supra- and Infraspinatus muscles (23-25).

**Choice of Repair technique**

The repair technique, SR or DRSB, performed for large tear, was dependent on two factors. If the patient was insured, rotator cuff repair was performed with the DRSB technique. However, if the patient was not insured and where the patient had to pay for the surgery, the decision to perform SR or DRSB repair was preoperatively decided by the patient based upon the information provided to him by the treating senior surgeon. The surgeon discussed the variable nature of structural and clinical outcomes after the SR and DRSB repair reported in various studies (retrospective, prospective, or randomized trials), which existed before 2014 (26-29). The final decision had to be taken by the patient as uninsured patients had to pay for the higher cost involved with more anchors required in DRSB. Mihata et al too adopted a similar policy wherein repair technique (SR or Double row) was decided by the patient after the operating surgeon gave a detailed account of previously published data (29).

**The minimum sample size**

The minimum sample size calculation was performed taking the data from conclusions of Park et al, wherein a statistically significant difference in constant score among single row and double row repair of only large-massive rotator cuff tears has been reported to be 7.75 (21). Power analysis suggested that the total sample size required for detecting an anticipated difference of at least six in the constant score among two groups of repair technique (SR and DRSB) would be a total of 96 (48 patients in each group) to provide a statistical power of 0.8 with a 5% level of significance.

**Operative Technique**

All cases were operated by the single senior surgeon.
The patients were operated under general anaesthesia or interscalene block or both in sloppy lateral decubitus position with the affected upper limb attached to the limb positioner (Spider 2 limb positioner, Smith and Nephew, USA). After standard skin preparation and draping, diagnostic arthroscopy of the affected shoulder joint was performed from the standard posterior portal. The anterior portal was made just above the subscapularis tendon in the rotator interval. The Biceps tendon was tenotomised if it was found to be significantly frayed, flat, split, or damaged. Open Subpectoral tenodesis was performed if the patient had demanded it preoperatively, in a manual laborer; or when the patient was less than 50 years. Regarding subscapularis tendon, Lafosse Type 1 tear was debrided while Type 2 and 3 tears were repaired with a single anchor (double or triple loaded) by modified Mason allen repair. After completing subscapularis repair and evaluation of the glenohumeral joint, the scope was shifted to the subacromial space. Standard subacromial bursa excision was done using a power shaver and radiofrequency device. Bony acromioplasty was performed only if there was an acromial spur or Bigliani type III acromion. After bursectomy and acromioplasty, supra- and infraspinatus tendons were assessed for the following characteristics (shape, size, retraction, and reparability on to the footprint) before the repair. Tear size was measured in an anteroposterior direction using a graduated probe and categorized as per the DeOrio and Cofield classification (30). Then, margin of the cuff was held with a suture retriever (Arthrex, Naples, Florida, US) to assess its reducibility, adequate coverage, and repairability over the footprint. If the cuff was found to be retracted, the standard releases were performed until optimum coverage of the footprint (>80%) was obtained. Apical traction suture was applied in the L or reverse L shape cuff tear for traction while releasing the tendon from subacromial adhesions or paralabral capsule. The sclerosed bone over the greater tuberosity was gently dusted using burr till minimal bleeding ensued.

**Single Row (SR) Repair technique**

For single-row repair, double-loaded suture anchors (4.5 mm Cork screw anchor or 5.0 mm PEEK, Arthrex, Naples, Florida) were deployed in the middle of the tuberosity. Two or three suture anchors were used depending on the size of the tear. The tear was repaired in a standard, modified Mason-Allen fashion. In case of L- or reverse-L shape tear, one to three side to side intratendinous sutures were placed and tied, and traction suture was removed.

**Double Row Suture bridge (DRSB) repair [transosseous equivalent technique**

For DRSB repair, two to three double-loaded suture anchors (4.5 mm Corkscrew anchor or 5.0 mm PEEK, anchor, Arthrex, Naples, Florida) were used for the medial row and were inserted just lateral to the cartilage margin. Mattress bite was taken in the cuff just lateral to the musculotendinous junction. Once sutures were passed, it was tied in a mattress fashion. These limbs were then brought laterally down to the lateral aspect of the greater tuberosity to create a suture bridge construct (transosseous equivalent) using one or two lateral row knotless anchors (4.75 mm Swivel lock, Arthrex, Naples, Florida) in the standard fashion. In the case of L- or reverse-L shape tear, one to three side to side intratendinous sutures were placed and tied.

All the intraoperative findings were recorded in a standardized form.

**Postoperative Rehabilitation**

All the patients were started on a structured rehabilitation protocol after repairing large cuff tear. Post-operatively, the shoulder was immobilized in an arm sling for six weeks, and only elbow and finger movements were encouraged along with scapular isometrics. After six weeks, passive mobilization of the shoulder was started. At the end of eight weeks, active assisted movements were initiated, followed by active movements. At the end of three months, an ultrasound of the shoulder was performed in all the cases to ascertain the healing status of the cuff over the footprint. Further, cuff strengthening exercises were initiated with theraband. Return to full and sports activity was reserved at the end of 6-8 months.

**Post-Operative tendon integrity**

The assessment of the healing status of the repaired tendon was performed using ultrasound (US) examination at the end of three months, 12 months, and then at the final follow-up. The final follow-up ultrasonography was performed on Philips epic 5G (The Netherlands) with a linear probe (12-5 Mhz) by a single qualified senior musculoskeletal radiologist. We classified the ultrasound report broadly into three categories. Type I, normal thickness with homogeneously hyperechoic tendon or partial hypoechogenicity or heterogenicity or insufficient thickness without discontinuity indicating ‘complete healing’; type II, the presence of a minor discontinuity or a focal partial defect indicating ‘partial tear’; and type III, the presence of a significant discontinuity or a ‘full-thickness tear’. While performing statistics, Type I was considered healed and type II and III were considered torn. Gartsman et al and Gwark et al also deployed similar criteria for ultrasound assessment of postoperative healing status of the cuff (31, 32). Gilat et al proved that the US showed a sensitivity of 80.8% and specificity of 100% in the diagnosis of rotator cuff retear (33). Further, excluding partial rotator cuff retears resulted in an increase in sensitivity to 94.7%, with 100% specificity.

**Functional outcome analysis**

At a minimum follow-up of five years, the functional outcomes were assessed with Constant Murley (CM) and American Shoulder and elbow score (ASES) by an independent assessor who was not aware of the technique used in each case.

**Statistical Analysis**

Statistical analysis was performed using SPSS 16.0 software (IBM, USA). Descriptive analysis was performed to assess the various demographic factors. Chi-square test was used to compare tendon integrity, whereas student
t-test to compare the differences in clinical scores (ASES and CM score) between groups. The level of significance was set at $P < .05$.

**Results**

A total of 103 patients with large rotator cuff tears were included in the study. There were 55 patients in the SR group and 48 patients in the DRSB group. The primary demographic details including age, gender, side, type of posterosuperior tear (Crescent, L or reverse L shape), number of anchors used, mean preoperative clinical scores (CM and ASES), mean follow up in both groups, and type of subscapularis tear are mentioned in Table 1, and are well-matched. The overall mean follow-up of patients in both groups was 74.2 months (range, 60-96 months).

While comparing the structural integrity, there were significantly lower retear rates in the DRSB group than the SR group (10.4% vs. 32.7%; $P = 0.006$) [Table 2]. Further, there were more focal defects in the SR group than in the DRSB group (25.4% vs. 8.3%) [Table 3].

<table>
<thead>
<tr>
<th>Basic characteristics</th>
<th>SR group (n=55)</th>
<th>DRSB group (n=48)</th>
<th>$P$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean age (Range), y</td>
<td>60.2 (43-69)</td>
<td>57.14 (40-70)</td>
<td>0.2</td>
</tr>
<tr>
<td>Sex, Male: female, n</td>
<td>39, 16</td>
<td>26, 22</td>
<td>0.07</td>
</tr>
<tr>
<td>Side, Right:Left</td>
<td>45, 10</td>
<td>42, 6</td>
<td>0.42</td>
</tr>
<tr>
<td>Mean Constant Murley Score (±SD)</td>
<td>31.42 (5.39)</td>
<td>29.70 (5.42)</td>
<td>0.11</td>
</tr>
<tr>
<td>Mean ASES Score (±SD)</td>
<td>42.36 (5.25)</td>
<td>39.76 (4.18)</td>
<td>0.11</td>
</tr>
<tr>
<td>Mean follow up (in months)</td>
<td>78.7</td>
<td>69.7</td>
<td>0.2</td>
</tr>
<tr>
<td>Shape of tear</td>
<td>Crescent 43</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td></td>
<td>L- or reverse- L 12</td>
<td>15</td>
<td>0.37</td>
</tr>
<tr>
<td>Size of tear (mean in cm)</td>
<td>4.2</td>
<td>4.4</td>
<td>0.42</td>
</tr>
<tr>
<td>Number of anchors used</td>
<td>2-3</td>
<td>3-5</td>
<td></td>
</tr>
<tr>
<td>Subscapularis tear</td>
<td>None 22</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Type 1 11</td>
<td>09</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Type 2 16</td>
<td>10</td>
<td>0.48</td>
</tr>
<tr>
<td></td>
<td>Type 3 06</td>
<td>03</td>
<td></td>
</tr>
</tbody>
</table>

ASES, American shoulder and elbow; SD, standard deviation; SR, single row; DRSB, double row suture bridge

<table>
<thead>
<tr>
<th>Healed tendon (Type I) (n=80)</th>
<th>Return tendon (Type II, III) (n=23)</th>
<th>$P$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR group (55)</td>
<td>37 (67.3%)</td>
<td>18 (32.7%)</td>
</tr>
<tr>
<td>DRSB group (48)</td>
<td>43 (89.6%)</td>
<td>5 (10.4%)</td>
</tr>
</tbody>
</table>

Note: Type I was considered healed whereas Type II and III were considered torn. SR, Single row; DRSB, double row suture bridge

<table>
<thead>
<tr>
<th>Type I (Completely Healed tendon) (n=80)</th>
<th>Type II (Focal defect) (n=18)</th>
<th>Type III Complete tear (n=5)</th>
<th>$P$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR group (55)</td>
<td>37 (67.3%)</td>
<td>14 (25.4%)</td>
<td>4 (7.3%)</td>
</tr>
<tr>
<td>DRSB group (48)</td>
<td>43 (89.6%)</td>
<td>4 (8.3%)</td>
<td>1 (2.1%)</td>
</tr>
</tbody>
</table>

SR, Single row; DRSB, double row suture bridge
OUTCOME OF ARTHROSCOPIC REPAIR OF LARGE POSTEROSUPERIOR CUFF TEAR

Table 4. Summary of the Postoperative Clinical Outcome Scores

<table>
<thead>
<tr>
<th>Functional Scores</th>
<th>SR group (n=55)</th>
<th>DRSB group (n=48)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM (±SD)</td>
<td>82.65 (8.43)</td>
<td>83.93 (5.15)</td>
<td>.38</td>
</tr>
<tr>
<td>ASES (±SD)</td>
<td>86.87 (8.75)</td>
<td>88.31 (4.88)</td>
<td>.31</td>
</tr>
</tbody>
</table>

SD, standard deviation; CM, Constant Murley; ASES, American shoulder and elbow; SR, Single row; DRSB, double row suture bridge

Table 5. Summary of postoperative clinical scores in healed versus re-tear group

<table>
<thead>
<tr>
<th>Functional score</th>
<th>Healed Tendon (n=80)</th>
<th>Retorn Tendon (n=23)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM (±SD) score</td>
<td>85.11 ± 5.71</td>
<td>76.78 ± 9.04</td>
<td>.0001</td>
</tr>
<tr>
<td>ASES (±SD) score</td>
<td>89.24 ± 5.32</td>
<td>81.65 ± 9.22</td>
<td>.0001</td>
</tr>
</tbody>
</table>

Type II and III is grouped as return tendon group. SD, standard deviation; CM, Constant Murley; ASES, American shoulder and elbow

Discussion

Our study demonstrated that the DRSB repair offers superior healing potential compared to SR repair in large tears and that the clinical scores are better in the healed tendon group versus the retear group.

Structural healing of large cuff tears after repair

Despite advancements in the understanding of the biology and improved rotator cuff repair techniques, the healing of the cuff over the footprint remains an Achilles heel, especially of the large size tears. Many authors have reported varying retear rates after the repair of a large tear ranging from 4.5% to 62.5% depending upon the type of repair [SR or DRSB] (12, 19, 20, 29, 34-36). Our study included patients with ‘only large cuff tears’ as recent systemic reviews and meta-analysis are inconclusive regarding the superiority of one technique over the other in this subgroup (22, 27, 37). In a systematic review of 23 studies incorporating a total of 1252 repairs, Duquin et al did not find any difference between the type of repair and any size of the tear (27). On the other hand, in a systematic review of 32 studies comprising 2048 repairs, Hein et al reported that double row or suture bridge repair resulted in lower retear rates for any tear size (27). Analyzing nine studies in a meta-analysis, Xu et al concluded that double-row repair produced superior healing outcomes compared to a single row for tear size more than three cm (22). Similarly, Mascarenhas et al analyzed three concordant high-quality meta-analyses and concluded that DR repair results in superior structural healing compared to a single row (38).

While reporting on clinical and structural outcomes of large tear repairs, almost all individual studies in the literature have considered the mixed type of tears; small-medium or medium-large or large to massive or all types of tear combined healed [type I] and re-torn tendons [type II, III] (irrespective of repair type) revealed that there was a significant difference (P=0.0001) in the clinical scores (CM and ASES) between the two group [Table 5]. The type of subscapularis tear and its repair did not influence the clinical outcome at the final follow-up.

To our knowledge, ours is the only study that considered large posterosuperior tears managed by SR or DRSB technique in large numbers (n=103) at a mean follow-up of 74.2 months. Our results indicate that the DRSB technique results in significantly lesser re-tear rates of large posterosuperior tears (10.4 %) than the SR technique (32.7 %). The retear rate after repair of the large tear (managed by DRSB) reported by Choi et al was 18.4% (7 out of 38 patients), which was slightly higher than our results (35). However, their series had 147 patients with medium, large and massive tears managed by the DRSB technique without any comparison with a single row. In another study, Jeong et al reported a retear rate of 45.5% in large tears managed by SR technique but lacked a comparison with DRSB (36). Hantes et al in a randomized controlled trial comprising 66 patients (younger than 55 years), reported that DR repair resulted in superior structural outcome than SR. However, they also had compared medium (n=37) and large size tear (n=29) with fewer in each subgroup of single row and DRSB technique. Furthermore, their study group had relatively younger patients. Mihata et al reported retear rates of 62.5% in a single row and 4.7% in the DRSB technique in large-massive size tear group (29). However, eight patients in the SR group and 40 patients in the DRSB technique were not equally balanced. In another recent retrospective study published by Jeong et al comprising of partial (n=44), small (n=48), medium (n=224), and large tears (n=50); DRSB was found to be superior to the SR technique for large tears regarding better healing potential, and lesser retear rate (20). However, this study also considered repairing of the cuff into type I and type II, further bringing down the number of actual anatomical repairs for comparison.
Furthermore, our study revealed that partial re-tears are more common than complete retear in the SR group (25.4%, n=14) compared with the DRSB group (8.3%, n=4). It indicates a poor tendency of the cuff to heal completely over the footprint in the SR group as compared to the DRSB group. Noyes et al reported 29% partial healing in a group of 17 patients with a large and massive tear when repaired with a single row technique (39). In their systematic review of seven studies, Millet et al concluded that SR repair results in statistically significant higher retear rates, especially the partial thickness tears (40). Since single-row repair results in lesser footprint contact, a partial thickness tear may also indicate an unhealed part of the cuff over the tuberosity. So, the partial thickness tear or an unhealed cuff could be considered an intermediate stage before it might become a full-thickness tear in the long-term follow-up, as suggested by Kartus et al (41). Hence, many studies conclude that DRSB repair results in superior structural healing in large tears, while SR repair resulting in higher rates of partial re-tears. However, one must remain cautious about catastrophic type 2 failure with the over-enthusiastic DRSB repair. In a systematic review of 40 cadaveric studies, Shi et al concluded that a higher number of suture limbs and transosseous equivalent repair increases construct's chance of type 2 failure (42).

**Functional outcome after large cuff tear repair**

Our analysis of functional scores revealed no difference between either score (CM or ASES) of the two groups, SR and DRSB. In a recently conducted randomized controlled trial (RCT) by Nicholas et al in patients with medium (n=15), large (n=12), and massive tears (n=9), no difference was observed between ASES scores of SR and DRSB group (43). However, separate subgroup analysis was not performed for each type of tear repaired due to fewer patients in each subgroup. In another RCT in patients with medium and large size tears managed by SR and DR, Carbonel et al concluded that clinical scores (CM and ASES) were similar in two groups (single versus double row) in patients with tear size less than 3 cm, whereas superior in patients with tear size more than 3 cm managed by double row technique (44). However, Millet et al in their systemic review of seven studies, concluded that clinical scores are similar in both groups (40).

However, we encountered statistically superior clinical results in patients with intact tendons compared to retear ones when both groups were combined. Many studies have reported inferior clinical outcome scores in return tendons compared to healed tendons (19, 20, 29).

**Strengths and limitations of the study**

We had a single senior operating surgeon for all the patients, and hence the operational conditions and the skill remains the same in each case. The biggest strength of the study is the inclusion of only large posterosuperior rotator cuff tear with a large number of patients (103) and a reasonable mean follow-up of 74.2 months, enabling a robust statistical analysis. Another strength of the study is the utilization of an independent clinical score assessor and a single sonologist assessing the integrity of the tendon throughout the study.

However, this study, too, carries several limitations. One, this is a retrospective cohort study. Potential bias, including patient’s occupation, hand dominance, physical demands, smoking, diabetes mellitus, and its influence on the clinical outcome cannot be ignored. Most of it could not be considered as some of the data was missing. Two, selection bias would have occurred while the patient chose the type of repair as a single or double row suture bridge according to what they understood after discussing with the surgeon. Also, the higher cost involved with the DRSB technique would have forced some patients to opt for the SR technique as many patients were paying for their treatment. Third, the use of ultrasonography (USG) to assess postoperative cuff healing status may raise questions regarding operator dependence, sensitivity and specificity in detecting a retear as most other studies have performed MRI for the diagnosis of post-operative re-tear (45). However, Lee et al in their review have found both MRI and US to be comparable in the diagnosis of the postoperative full-thickness retear. Still, both carry lower sensitivity for partial tears (46). Magee et al reported that the USG carries 100% sensitivity and 87% specificity for the diagnosis of full or partial thickness re-tear (47). Motamedi et al concluded that MRI could over-diagnose the postoperative retears while Schroder et al concluded that the presence of metal anchors could adversely affect the diagnosis of the rotator cuff retear by artifacts during MRI (48, 49). Hence, the USG remains a validated tool for the diagnosis of postoperative retear of the rotator cuff with similar sensitivity and specificity to the MRI. It also has an added advantage of the dynamic component to diagnose impingement and is free from ‘artifacts.’

Despite a robust conclusion of the superiority of DRSB repair versus SR repair of a large cuff tear, given potential limitations and biases in the study, we recommend a randomized controlled trial on the repair of only large posterosuperior tears by the single and DRSB technique with clinical and MRI evaluation of patients. The conclusion of such a study would benefit a surgeon in decision-making regarding the type of repair of large repairable posterosuperior tears.

Our study revealed that double-row suture bridge repair of large posterosuperior rotator cuff tears resulted in superior structural healing compared to single-row repair without any functional superiority. Furthermore, the healed tendons resulted in superior functional results over the return tendons.

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Reference


26. Cho NS, Yi JW, Lee BG, Rhee YG. Retear patterns...


Factors Predicting Postoperative Range of Motion and Muscle Strength one Year after Shoulder Arthroplasty

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Abstract

Background: Shoulder arthroplasty improves shoulder range of motion (ROM), strength and function in patients with advanced shoulder disease. However, clinical outcomes vary and are not always predictable among patients. Pre-operative factors and patients’ characteristics may influence improvement after surgery. This study examined the impact of the pre-operative objective measures range of motion (ROM) and strength, age, sex, and comorbidities on shoulder ROM, strength status and the amount of improvement one year following shoulder arthroplasty.

Methods: 140 patients were assessed pre-operatively and one year after shoulder arthroplasty in this prospective cohort study. Pearson’s correlations and multiple regression analyses were performed to test the impact of potential predictors on abduction, flexion, internal rotation and external rotation ROM as well as on shoulder abductors, flexors, internal rotators and external rotators strength at one year.

Results: Pre-operative ROM significantly predicted 10% - 37% of the improvement in ROM after surgery. Less pre-operative ROM was associated with a greater improvement in ROM. Less pre-operative muscle strength was associated with a greater improvement in strength after surgery. Pre-operative shoulder muscles predicted 28% - 38% of the strength status at one year, and 24% - 43% of the improvement in strength postoperatively. Older age was associated with less improvement in ROM and strength at one year. With other predictors, age explained 37% of the change in ROM and 36% of the change in strength. Male sex was associated with greater improvement in muscle strength. Sex significantly predicted 24% - 36% of the change in strength.

Conclusion: Pre-operative ROM and strength, age, and sex are significant predictors of the improvement in the shoulder ROM and strength one year after shoulder arthroplasty. The improvement in these measures is expected to decline with age and men are expected to gain more strength than women following this surgical intervention.

Level of evidence: II

Keywords: Muscle strength, Range of motion, Shoulder arthroplasty

Introduction

Shoulder arthroplasty is a surgical procedure that involves replacing either part (partial) or all (total) of the articular surface. When considering all shoulder arthroplasty procedures currently recorded by the Australian Orthopedic Association registry (2018), total shoulder arthroplasty (TSA) was the most common procedure (75.5%), followed by hemiarthroplasty (HA) (14.5%) and revision procedures (10.0%) (1). Shoulder arthroplasty is more commonly undertaken in females (64%) with the majority between the ages of 65 and 84 years (1). The primary diagnosis for HA is fracture (45%) followed...
by osteoarthritis (40%) while the primary diagnosis for TSA is osteoarthritis (65%) followed by rotator cuff arthropathy (21%) (1).

The effect of shoulder arthroplasty on improving range of motion (ROM) is well documented (2). However, the degree of improvement in these objective measures varies among patients and is not always predictable. The factors contributing to this variability are not well investigated and little information is available regarding the pre-operative characteristics of the patients that may affect the quality of the outcomes (3).

Pre-operative ROM in all directions were shown to be predictive of postoperative forward flexion (FF), abduction, external rotation (ER) and internal rotation (IR) ROM one year following TSA (4). Further, pre- and intra-operative FF were found to be strong predictors of postoperative FF ROM one year after reverse shoulder arthroplasty (5). Furthermore, pre-operative ER ROM of less than 10 degrees was associated with less post-operative ER ROM in 118 patients four-years following HA but not TSA (6). However, pre-operative loss of FF did not predict postoperative FF following HA and TSA (6).

While age did not affect postoperative ROM, male sex was associated with increased postoperative ROM one year following reverse shoulder arthroplasty (4, 5). The presence of comorbidities, including diabetes and hypertension, did not predict postoperative ROM, except for IR ROM, which was decreased with diabetes (4). Lastly, humeral head subluxation was associated with lower active ER ROM following HA and TSA (6).

As shown above, few studies examined factors that influence postoperative ROM and muscle strength outcomes following shoulder arthroplasty. Further, there is a lack of reporting regression coefficients that illustrate the degree of change in outcomes after shoulder arthroplasty. This makes it difficult for surgeons and health care professionals to provide patients with realistic expectations of their postoperative outcomes and treatment plans. The purpose of this study was to analyze pre-operative factors that affect postoperative shoulder ROM and muscle strength.

Materials and Methods

Study design and patients

Institutional Review Board approval was obtained for this prospective study. All patients who underwent shoulder arthroplasty at our tertiary care hospital and followed up for a minimum of one year were included in this analysis. A consent form was obtained from all patients.

A computerized database was available for 477 patients. The inclusion criteria for this cohort were the presence of comorbidity data and prospectively collected measurements of shoulder ROM and muscle strength at baseline (pre-operative) and at one year follow-up visit.

This cohort included all patients treated with shoulder arthroplasty regardless of the type of surgery based on our previous study, which showed non-significant differences in ROM and muscle strength among patients who underwent TSA, reverse TSA, and HA (7). A total of 140 patients met these inclusion criteria. Patients whose shoulder ROM and muscle strength data were not available pre-operatively and at one-year follow-up visit were excluded from this study.

Instrumentation

Dependent variables included shoulder ROM and muscle strength. Shoulder ROM was assessed in flexion, abduction, and ER and IR using a standard goniometer. Shoulder ROM was measured using standardized procedures with known high reliability (Intraclass Correlation Coefficients (ICCs) > 0.97) placed along the joint axis by the therapist, was read by an independent assistant (8–10).

Isometric muscle strength was assessed for shoulder flexors, abductors, and lateral rotators (LR) and medial rotators (MR) using the JTech PowerTrack handheld dynamometer (JTech; JTech Medical, Salt Lake City, UT, USA). This device has known validity and reliability (ICCs 0.89–0.98) (11, 12).

Measurements of ROM and strength were recorded pre-operatively and at one year follow-up visit. These data were averaged and compared between patients based on their age, sex, and the presence of comorbidities [Table 1].

Independent variables

The predictive variables of interest included patients’ demographics: age, sex, and comorbidities (diabetes, hypertension, depression), and the pre-operative ROM and muscle strength data. The prediction effect of these variables was assessed for the final ROM and strength measurements at one year and on the change of ROM and strength from pre-operative to one year postoperative visit, aiming to estimate the clinical benefits of shoulder arthroplasty.

Statistical analysis

Statistical analyses were performed using SPSS software, version 23 (SPSS Inc., Chicago, IL, USA). A P value of <0.05 was considered statistically significant. An independent sample t-test was used to detect differences in the ROM and strength between patients based on age, sex and the presence of comorbidities (diabetes, hypertension, depression). All values are reported as mean and standard deviation (SD). Pearson’s correlation coefficients (r) were calculated between the dependent and predictive variables and between the predictive variables. The effect size (ES) of Pearson’s correlations were classified as follow: 0.1 ≤ r < 0.3 = small effect, 0.3 ≤ r < 0.5 = medium effect, r ≥ 0.5 = large effect (13).

A multivariable regression analysis was performed to examine the effect of the predictive variables on the improvement in ROM and strength one year after shoulder arthroplasty. To predict the clinical benefits of shoulder arthroplasty, we calculated the change in ROM and strength measurements by subtracting one year measures from pre-operative measures. Then, a second multivariate regression analysis was performed on the change values.
Results

Descriptive statistics

Within this cohort, measures of ROM were available for 140 patients and measures of muscle strength were available for 127 patients. The average age of patients was 71 years (range, 47–89 years). The influence of age, sex, and comorbidities on ROM and strength measures one year after shoulder arthroplasty are summarized in Table 1. Patients with depression were younger (64±7 years) than patients without depression (72±8 years), men were stronger (5±3, 6±3, 5±3, & 6±3 kg for flexors, abductors, LR & MR, respectively) and had greater abduction ROM (124 degrees ±34) than women (4±2, 4±2, 3±1, 5±2 kg, & 113 ± 36 degrees, for flexors, abductors, LR, MR muscle strength, & abduction ROM, respectively). Diabetic patients had weaker MR (5±2 kg) than non-diabetes patients (6±3 kg), and hypertensive patients were older (74±7 years) and had weaker muscle strength (4±2, 4±1, & 5±2 kg for abductors, LR and MR, respectively) than non-hypertensive patients (5±3, 5±3, & 6±3 kg, for abductors, LR and MR, respectively) [Table 1].

Pearson’s correlations

Pearson’s correlation between pre-operative ROM and muscle strength at one year was significant ($P < 0.001$) with medium to large ES (0.4 to 0.6) for flexors, abductors, LR, and MR muscle strength. The greater pre-operative strength was associated with greater strength at one year. However, the lesser pre-operative strength was associated with greater change in strength after surgery with significant ($P < 0.001$) medium to large ES (-0.3 to -0.64) for flexors, abductors, LR and MR strength.

Pearson’s correlations between ROM and strength and predictors (age, sex, and comorbidities) are summarized in Table 2. The coefficients (ES) ranged from -0.4 to 0.01. There were significant correlations ($P < 0.05$) with medium to small ES among shoulder ROM and age (-0.3 to -0.2), and muscle strength and age (-0.3 to -0.2); indicating that these measures decrease with age. Male patients had significant greater abduction ROM (small ES: -0.2) and stronger shoulder muscles (medium ES: -0.3 to -0.4) when compared to female patients. Diabetic patients had weaker flexors, abductors, and MR muscle strength (small ES: -0.2) when compared to non-diabetic patients. Lastly, hypertensive patients had weaker abductors, LR, and MR muscle strength (small ES: -0.2) when compared to non-hypertensive patients [Table 2].

Multivariable regression analysis

Regression models of ROM

We controlled for the pre-operative flexion, abduction, ER, and IR ROM by adding these measures to the regression models as shown in Table 3. In predicting flexion, age was the only significant predictor of flexion ROM at one year; indicating that with each one year increase in age, flexion decreases by one degree. Together, all predictors (age, sex, diabetes, hypertension, depression, and pre-
operative flexion ROM) explained 10% of the variability of flexion at one year. In predicting the change in flexion, both age and pre-operative flexion were significant predictors. Lower pre-operative flexion was associated with greater improvement in flexion at one year. All predictors explained 37% of the improvement in flexion ROM [Table 3].

Age was the only significant predictor for abduction ROM indicating that with each one year increase in age, abduction ROM decreases by 0.9 degree. All predictors explained 8% of the variability in abduction ROM at one year. In predicting the change in abduction, both age and pre-operative abduction were significant predictors of the improvement in the abduction ROM at one year. Less pre-operative abduction ROM was associated with a greater improvement in abduction. All predictors explained 30% of the improvement in abduction ROM [Table 3].

For ER and IR ROM, pre-operative IR ROM was a significant predictor of IR ROM. With each one degree increase in pre-operative IR, there was a 0.5 degree increase in IR at one year. All predictors explained 5% of the variability in ER and IR ROM. In predicting the change in ER and IR ROM, pre-operative ER and IR ROM were significant predictors of the improvement in ER and IR ROM at one year, respectively. Less pre-operative rotational ROM was associated with greater improvement in ER and IR ROM. Together, all predictors explained 20% and 10% of the improvements in ER and IR ROM, respectively [Table 3].

**Regression models of muscle strength**

We controlled for the pre-operative flexor, abductor, LR, and MR muscle strength by adding these measures to the regression models as shown in Table 4. In predicting flexor strength at one year and the change in flexor strength, pre-operative flexor strength was the

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**Table 2. Pearson’s correlations between predictors and dependent factors one year following shoulder arthroplasty**

<table>
<thead>
<tr>
<th>Shoulder ROM variables</th>
<th>Predictors</th>
<th>Age</th>
<th>Sex</th>
<th>Diabetes</th>
<th>Hypertension</th>
<th>Depression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion</td>
<td>-0.3*</td>
<td>-0.1</td>
<td>0.01</td>
<td>-0.04</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>Abduction</td>
<td>-0.2*</td>
<td>-0.2*</td>
<td>0.02</td>
<td>-0.05</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>External rotation</td>
<td>-0.2*</td>
<td>-0.1</td>
<td>0.1</td>
<td>-0.04</td>
<td>-0.04</td>
<td></td>
</tr>
<tr>
<td>Internal rotation</td>
<td>0.02</td>
<td>0.1</td>
<td>-0.03</td>
<td>-0.04</td>
<td>-0.1</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Muscle strength variables</th>
<th>Predictors</th>
<th>Flexors</th>
<th>Abductors</th>
<th>Lateral rotators</th>
<th>Medial rotators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexors</td>
<td>-0.2*</td>
<td>-0.3*</td>
<td>-0.2*</td>
<td>-0.2*</td>
<td>-0.2*</td>
</tr>
<tr>
<td>Abductors</td>
<td>-0.3*</td>
<td>-0.3*</td>
<td>-0.2*</td>
<td>-0.2*</td>
<td>0.04</td>
</tr>
<tr>
<td>Lateral rotators</td>
<td>-0.3*</td>
<td>-0.4*</td>
<td>-0.1</td>
<td>-0.2*</td>
<td>0.02</td>
</tr>
<tr>
<td>Medial rotators</td>
<td>-0.2*</td>
<td>-0.4*</td>
<td>-0.2*</td>
<td>-0.2*</td>
<td>-0.1</td>
</tr>
</tbody>
</table>

* Significant at $P < 0.05$. ROM: range of motion.

**Table 3. Regression model summary for shoulder ROM one year following shoulder arthroplasty**

<table>
<thead>
<tr>
<th>Dependent variables</th>
<th>$R$</th>
<th>$R^2$</th>
<th>Adj. $R^2$</th>
<th>SE</th>
<th>$F$</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion</td>
<td>0.31*</td>
<td>0.10</td>
<td>0.06</td>
<td>31</td>
<td>2.4</td>
<td>0.03</td>
</tr>
<tr>
<td>Change in flexion</td>
<td>0.61*</td>
<td>0.37</td>
<td>0.34</td>
<td>31</td>
<td>13</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Abduction</td>
<td>0.28*</td>
<td>0.08</td>
<td>0.04</td>
<td>35</td>
<td>2.0</td>
<td>NS</td>
</tr>
<tr>
<td>Change in abduction</td>
<td>0.55*</td>
<td>0.30</td>
<td>0.27</td>
<td>34</td>
<td>9</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>External rotation</td>
<td>0.22c</td>
<td>0.05</td>
<td>0.005</td>
<td>22</td>
<td>1.1</td>
<td>NS</td>
</tr>
<tr>
<td>Change in external rotation</td>
<td>0.45c</td>
<td>0.20</td>
<td>0.17</td>
<td>22</td>
<td>5.7</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Internal rotation</td>
<td>0.22d</td>
<td>0.05</td>
<td>0.004</td>
<td>18</td>
<td>1.1</td>
<td>NS</td>
</tr>
<tr>
<td>Change in internal rotation</td>
<td>0.31d</td>
<td>0.10</td>
<td>0.06</td>
<td>18</td>
<td>2.4</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Dependent variables: one-year status and change in ROM from pre-operative to one-year following shoulder arthroplasty

a Predictors: (constant), age, sex, hypertension, diabetes, depression, pre-operative flexion ROM

b Predictors: (constant), age, sex, hypertension, diabetes, depression, pre-operative abduction ROM

c Predictors: (constant), age, sex, hypertension, diabetes, depression, pre-operative external rotation ROM

d Predictors: (constant), age, sex, hypertension, diabetes, depression, pre-operative internal rotation ROM

ROM: range of motion
only significant predictor of these dependent variables; indicating that patients with stronger pre-operative flexors had less improvement in flexor strength at one year postoperatively. All predictors explained 43% of the improvement of flexor strength one year postoperatively [Table 4].

In predicting abduction strength at one year and the change in abductors strength, age, sex, and pre-operative abductor strength were the only significant predictors. With each one year increase in age, abductor strength decreases by 0.06 kg; men had stronger abductors (0.9 kg) than women; and patients with stronger pre-operative abductors had less improvement in abductor strength at one year. All predictors explained 36% of the improvement in abductors strength one year postoperatively [Table 4].

Age, sex, and pre-operative LR strength were significant predictors of LR strength at one year and the change in LR strength. Each one year increase in age was associated with a 0.05 kg decrease in LR strength, men had stronger LR (one kg) than women, and patients with stronger pre-operative LR had less improvement in LR strength. All predictors explained 24% of the variability in LR muscle strength one year after surgery [Table 4].

Lastly, sex and pre-operative MR strength were significant predictors of MR strength at one year and the change in MR strength. Men were stronger (1.4 kg) than women, and stronger pre-operative MR was associated with less improvement in MR strength. Together, all predictors explained 38% of the improvement in MR muscle strength at one year postoperatively [Table 4].

Discussion
This study found that pre-operative ROM and muscle strength measures are important factors (ES=0.3 for ROM & 0.64 for muscle strength ) in determining the overall improvement in shoulder ROM and muscle strength one year following shoulder arthroplasty. Greater pre-operative ROM and muscle strength are associated with greater ROM and strength one year after shoulder arthroplasty. Further, less pre-operative ROM and strength are associated with greater postoperative change and improvement in ROM and muscle strength. This indicates that patients with worse pre-operative ROM and strength have more room to improve; however, those patients are not expected to achieve the same results as patients who have better ROM and muscle strength pre-operatively.

In this study, younger age is associated with greater flexion and abduction ROM and stronger abductors and LR muscles as well as greater change or improvement in these measures one year postoperatively. Further, males are expected to get stronger abductors, LR, and MR muscle strength and greater change in strength from preoperative to one year after shoulder arthroplasty.

Indeed, although pre-operative flexion, abduction, and ER are not significant factors in predicting shoulder ROM status at one year, these measures predicted the change in shoulder ROM following shoulder arthroplasty; suggesting that patients with lesser pre-operative flexion, abduction, and ER ROM are expected to gain greater improvements in shoulder ROM postoperatively. However, pre-operative IR ROM is significantly associated with greater IR at one year status but with less change in IR ROM after surgery.

These findings are consistent with the study of Iannotti & Norris (n=118) who found that pre-operative flexion ROM did not predict postoperative flexion four years after shoulder arthroplasty (6). Further, Levy et al. (n=230) reported that pre-operative IRROM significantly predicted postoperative IR ROM one year following TSA (4). On the contrary, previous research found that pre-operative flexion, abduction and ER ROM were significantly associated with greater postoperative ROM (4, 5). These contradictions might be related to the differences in the inclusion criteria and the various

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Table 4. Regression model summary for shoulder muscle strength one year following shoulder arthroplasty

<table>
<thead>
<tr>
<th>Dependent variables</th>
<th>R</th>
<th>R²</th>
<th>Adj. R²</th>
<th>SE</th>
<th>F</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexors</td>
<td>0.62*</td>
<td>0.38</td>
<td>0.35</td>
<td>2</td>
<td>12</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Flexors change</td>
<td>0.65*</td>
<td>0.43</td>
<td>0.40</td>
<td>2</td>
<td>15</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Abductors</td>
<td>0.55*</td>
<td>0.31</td>
<td>0.27</td>
<td>2</td>
<td>9</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Abductors change</td>
<td>0.60*</td>
<td>0.36</td>
<td>0.33</td>
<td>2</td>
<td>11</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Lateral rotators</td>
<td>0.54*</td>
<td>0.29</td>
<td>0.25</td>
<td>2</td>
<td>8</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Medial rotators</td>
<td>0.49*</td>
<td>0.24</td>
<td>0.20</td>
<td>2</td>
<td>6</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Change in medial rotators</td>
<td>0.53*</td>
<td>0.28</td>
<td>0.24</td>
<td>2</td>
<td>8</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Change in laterial rotators</td>
<td>0.61*</td>
<td>0.38</td>
<td>0.35</td>
<td>2</td>
<td>12</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

Dependent variables: one-year status and change in muscle strength from pre-operative to one-year following shoulder arthroplasty

Predictors a Predictors: (constant), age, sex, hypertension, diabetes, depression, pre-operative flexors strength

Predictors b Predictors: (constant), age, sex, hypertension, diabetes, depression, pre-operative abductors strength

Predictors c Predictors: (constant), age, sex, hypertension, diabetes, depression, pre-operative Lateral rotators strength

Predictors d Predictors: (constant), age, sex, hypertension, diabetes, depression, pre-operative Medial rotators strength

---
Although Iannotti & Norris found that pre-operative ER ROM is a significant predictor of the change in ER ROM after surgery, which concurs with our study, the authors reported that pre-operative ER ROM of less than 10 degrees was associated with less improvement in postoperative ER ROM (6). Our results show the opposite; less pre-operative ER ROM is associated with greater improvement in ER ROM one year after shoulder arthroplasty. In our previous paper, we summarized the improvements in ROM following shoulder arthroplasty, the average of pre-operative ER ROM was (22 ±12 degrees), indicating that the majority of our patients had an ER ROM greater than 10 degrees (7). This might explain the conflicting findings.

In our previous research, we reported a significant improvement in shoulder strength one year following shoulder arthroplasty (7). In this paper, we showed that pre-operative muscle strength is a significant predictor of postoperative strength, and stronger pre-operative muscles are associated with less improvement. We could not find previous research examining the prediction effect of pre-operative muscle strength on the postoperative strength; therefore, no comparisons are made.

Previous research has demonstrated a loss of shoulder ROM and muscle strength with age (14, 15). Age-related sarcopenia or loss in muscle mass can be compounded by disuse atrophy due to arthritis or an incomplete resolution of symptoms following surgery. In the present study, older age is associated with less shoulder flexion and abduction ROM as well as a lower strength in the abductors and LR strength status at one year. Besides, older age is associated with smaller improvements in flexion and abduction ROM as well as less improvement in strength following shoulder arthroplasty. The association of age with strength, motion and the amount of improvement at one year suggests that both direct and indirect age-related mechanisms are involved. Not all studies concur with ours, as Schwartz et al. study who reported that diabetes was a significant factor in predicting shoulder IR ROM (4). However, we found a significant correlation between diabetes and flexors, abductors and MR strength as well as between hypertension and abductors, LR, and MR strength, suggesting that diabetic and hypertensive patients may suffer from weaker muscles following shoulder arthroplasty. Previous research had reported a higher prevalence of chronic diseases among older people (17). Hence, weaker muscles after shoulder arthroplasty could be related to ageing rather than to the actual presence of comorbidities.

Possible implications of these associations include investigating the benefits of pre-rehab approaches that attempt to improve strength and motion pre-operatively. Alternatively, older adults with arthritic symptoms that limit the effectiveness of pre-rehab may require longer or appropriately targeted rehabilitation. The clinical implications of these findings are speculative since only clinical trials comparing different solutions can identify if predictors are modifiable. Otherwise, the predictors can only be confidently used to help patients understand the probability they will achieve a specific outcome.

Strengths and limitations

Our study provided new insights about the effect of pre-operative ROM, pre-operative strength, age, sex, and comorbidities on one year postoperative shoulder ROM and strength status and clinical benefits after shoulder arthroplasty. This study was a large prospective cohort of patients who underwent shoulder arthroplasty. Shoulder ROM and strength were objectively measured using validated and reliable instruments. Further, in some of our models, the explained improvements in shoulder ROM and strength were large, which makes them useful for clinical prognostication. However, our study has some limitations. The data was collected in a single-specialty upper extremity program and may not be generalized to other practices. In addition, we did not control for other factors such as the quality and types of implant, postoperative complications, and neck ROM that might affect the improvement in shoulder ROM and muscle strength after shoulder arthroplasty. Lastly, controlling for age and body weight may provide a better estimate of the differences in muscle strength between men and women. In our study, we measured and reported absolute but not relative muscle strength (dividing muscle strength by body weight).

This study found that less pre-operative ROM and weak shoulder muscles are significantly associated with greater improvement and surgical benefits one year after shoulder arthroplasty. Further, young age and male sex are associated with greater surgical benefits. Furthermore, the presence of comorbidities does not
impact the final ROM and strength status at one year postoperative and the amount of improvement gained with surgery. Detecting factors that affect clinical outcomes can assist clinicians in providing realistic expectations about the expected final outcome following shoulder arthroplasty. Studies are required to examine the effect of these factors, such as muscle strength, on clinical outcomes after surgery.

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References

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Comparing Relative Value Units among Shoulder Arthroplasty, Hemiarthroplasty, and ORIF for Proximal Humerus Fractures in the Elderly: Which is Most Worth Your Time?

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Abstract

Background: Relative value units (RVUs) are assigned to Current Procedural Technology (CPT) codes and give relative economic values to the services physicians provide. This study compared the RVU reimbursements for the surgical options of proximal humerus fractures in the elderly, which include arthroplasty (reverse [RSA] and total [TSA]), hemiarthroplasty (HA), and open reduction and internal fixation (ORIF).

Methods: Using the National Surgical Quality Improvement Program, a total of 1,437 patients of at least 65 years of age with proximal humerus fractures between 2008 and 2016 were identified. Of those, 259 underwent RSA/TSA (CPT code 23472), 418 underwent HA (CPT codes 23470 and 23616), and 760 underwent ORIF (CPT code 23615). Univariate analysis compared RVU per minute, reimbursement rate, and the average annual revenue across cohorts based on respective operative times.

Results: RSA/TSA generated a mean RVU per minute of 0.197 (SD 0.078; 95%CI [0.188, 0.207]), which was significantly greater than the mean RVU per minute for 23470 HA (0.156; SD 0.057; 95%CI [0.148, 0.163]), 23616 HA (0.166; SD 0.065; 95%CI [0.105, 0.156]), and ORIF (0.135; SD 0.048; 95%CI [0.132, 0.138]; P<0.001). This converted to respective reimbursement rates of $6.97/min (SD 2.78; 95%CI [6.63, 7.31]), $5.48/min (SD 2.56; 95%CI [5.22, 5.74]), $5.83/min (SD 2.28; 95%CI [5.49, 6.16]) and $4.74/min (SD 1.69; 95%CI [4.62, 4.87]). After extrapolation, respective average annual revenues were $580,386, $456,633, $475,077, and $395,608.

Conclusion: RSA/TSA provides significantly greater reimbursement rates compared to HA and ORIF. Orthopaedic surgeons can use this information to optimize daily procedural cost-effectiveness in their practices.

Level of evidence: III

Keywords: Geriatric population, Humeral fracture, Relative value analysis, Surgical management

Introduction

Proximal humerus fractures are a common injury pattern sustained by the elderly as they are the third most common osteoporotic fracture, after the distal radius and vertebrae (1). In addition, they make up about 6% of all fractures in the Western world (2). While different surgical management options for
proximal humerus fractures exist, such as arthroplasty (reverse [RSA] and total [TSA]), hemiarthroplasty (HA), and open reduction and internal fixation (ORIF), there is no consensus on the best treatment option (3, 4). Additionally, the comparative economic value of these procedures, in terms of relative value units per time, has not been studied (5). Given the persistent surge in the population over 65 years of age, management of proximal humerus fractures are of continued importance (6).

The Centers for Medicare & Medicaid Services use the resource-based relative value scale (RBRVS). The RBRVS utilizes Relative Value Units (RVUs) to give relative economic value to different Current Procedural Terminology (CPT) codes (7). Each CPT code has a preset number of RVUs that are calculated based on physician work (wRVU), practice expense (pRVU), and malpractice (mRVU). The physician work component, which makes up the largest portion of the total RVUs, is based on relative level of time, skill, intensity, effort, and training to provide a specific service. The practice expense component is based on practice costs such as rent, equipment, supplies, and non-physician staff costs. The malpractice component, which normally makes up the smallest portion of the total RVUs, is based on professional liability expenses. Each of these components are also multiplied by a geographic practice cost index (GPCI), which serves to adjust component values based on differing costs across geographic areas. Ultimately, a conversion factor is used to convert RVUs to dollar amounts to determine compensation (8). While the RVU attempts to incorporate all relevant reimbursement factors, the literature has shown that there are still discrepancies in relative time and effort spent versus the amount of RVUs allocated in various other surgical procedures (9-13). Knowledge of potential discrepancies can lend to a better understanding of the economic worth of a physician’s time. In turn, orthopaedists can optimize procedural cost-effectiveness in their practice when multiple treatment options exist for a specific condition.

These discrepancies have not been evaluated in the setting of proximal humerus fractures, thus an exploration into the assigned RVUs between different surgical options for proximal humerus fractures is warranted. The purpose of this study is to compare relative value parameters in RSA/TSA, HA, and ORIF for proximal humerus fractures in the elderly to determine which surgical choice has higher proportional reimbursements. Specifically, we focused on the mean operative time, average RVU per minute, reimbursement rate, revenue per day, and average annual revenue differences between the three different surgical options.

**Materials and Methods**

The American College of Surgeons National Surgical Quality Improvement Program (NSQIP) database was employed to identify all patients older than 65 years who underwent RSA/TSA, HA, and ORIF for proximal humerus fractures between 2008 and 2016 (14). Institutional Review Board approval was obtained. RSA/TSA, HA, and ORIF procedures were identified based on their CPT codes, which were 23472, 23470 and 23616, and 23615 respectively (15). Arthroplasty using hemiarthroplasty (23470) and proximal humerus fracture hemiarthroplasty (23616) were both included in this analysis as both CPT codes were billed for proximal humerus fracture cases. Proximal humerus fractures were identified via International Classification of Diseases, 9th revision, Clinical Modification (ICD-9-CM) codes and the following codes were included: 812.00, 812.01, 812.09, 812.02, 812.03 (16). Operative times for each patient were extracted from NSQIP. Raw wRVU values and conversion factors were obtained from the CMS and American Medical Association website (15, 17). Since wRVU and conversion factors differ based on year, the respective wRVU and conversion factors were used based on the patient’s operation year. To convert RVUs to dollars, wRVUs were multiplied by their respective conversion factors. wRVUs were used instead of total RVUs to maintain focus on the physician work portion of the total RVU formula in addition to preventing the effects of practice expense and malpractice on the analysis. An assumed 10-hour workday was used for daily revenue analysis. An assumed 160-day yearly operating schedule was used to account for weekends, holidays, vacation time, and clinic days as per past orthopaedic RVU analyses in the literature (12, 13, 18). Univariate analysis using SPSS Statistics version 25 (IBM Corporation, Armonk, NY) compared operative time as well as relative value parameters, such as RVU per minute, reimbursement rate, revenue per case, revenue per day, and the average annualized cost difference across cohorts.

**Results**

A total of 1,437 patients of at least 65 years of age were identified, 259 of whom underwent RSA/TSA, 418 of whom underwent HA, and 760 of whom underwent ORIF for proximal humerus fractures. The mean operative time for the RSA/TSA procedure was 130 minutes (SD 50.1; 95% CI [123.9, 136.2]). The mean operative times for the 23470 and 23616 HA procedure were 130 minutes (SD 47.8; 95% CI [124.1, 136.3]) and 127 minutes (SD 48.9%; 95% CI [120.2, 134.6]) respectively. The mean operative time for the ORIF procedure was 104 minutes (SD 41.8; 95% CI [101.2, 107.2]) [Table 1]. Mean operative times between RSA/TSA and 23470 and 23616 HA did not differ significantly, however, all were significantly longer than ORIF (P < 0.001). The number of each type of surgery per year is shown in [Figure 1], and the mean operative time per surgery per year is reported in [Figure 2].

RSA/TSA generated a mean RVU per minute of 0.197 (SD 0.078; 95% CI [0.188, 0.207]), which was significantly greater than the mean RVU per minute for 23470 HA (0.156; SD 0.057; 95% CI [0.148, 0.163]), 23616 HA (0.166; SD 0.065; 95% CI [0.154, 0.178]), and ORIF (0.135; SD 0.048; 95% CI [0.132, 0.138]; P = 0.007) [Table 1]. There was no significant difference between the RVU per minute for 23470 HA and 23616 HA (P = 0.088). Using respective conversion factors, reimbursement rates for RSA/TSA, 23470 HA, 23616 HA, and ORIF were found to be $6.97/min (SD 2.78; 95% CI [6.63, 7.31]), $5.48/min (SD 2.05; 95% CI [5.22, 5.74]), $5.83/min (SD 2.28; 95% CI [5.49, 6.16]) and $4.74/min (SD 1.69; 95% CI [4.62,
The mean RSA/TSA reimbursement rate was significantly greater than both HA and ORIF ($P<0.001$). There was no significant difference between 23470 HA and 23616 HA reimbursement rates ($P=0.101$). Using the respective operative times, mean revenue per case for RSA/TSA, 23470 HA, 23616 HA, and ORIF were $907$ (SD 361.194; 95%CI [862.657, 951.049]), $713$ (SD 267.908; 95%CI [679.392, 747.585]), $742$ (SD 290.068; 95%CI [699.644, 784.971]), $495$ (SD 176.574; 95%CI [481.937, 507.084]), respectively [Table 1]. The mean revenue per case for RSA/TSA was significantly greater than for both HA and ORIF ($P<0.001$). There was no significant difference between 23470 HA and 23616 HA mean revenues per case ($P=0.293$).

Using mean operative time and assuming a 10-hour workday, a physician can perform 4 RSA/TSA or HA procedures or 5 ORIF procedures per day. Based on this, revenue per day for RSA/TSA, 234470 HA, 23616 HA, and ORIF would be $3,627, $2,854, $2,969, and $2,473 respectively [Table 1]. RSA/TSA generates a greater revenue per day in comparison to both HA and ORIF ($P<0.001$). There was no significant difference between 23470 HA and 23616 HA revenues per day ($P=0.293$).

Using revenue per day across 160 operating days, the average annual revenues generated for RSA/TSA, 234470 HA, 23616 HA, and ORIF were $580,386, $456,633, $475,077, and $395,608 respectively [Table 1]. When combining 23470 HA and 23616 HA, the average annual revenue was $3,627, $2,854, $2,969, and $2,473 respectively [Table 1].

Figure 1. Number of each type of surgery per year.

Figure 2. Mean operative time per type of surgery per year.
Table 1. Relative value analysis of reverse or total shoulder arthroplasty (RSA/TSA), hemiarthroplasty (HA 23470 and HA 23616), and open reduction and internal fixation (ORIF) for proximal humerus fractures in the elderly (>65 years old).

<table>
<thead>
<tr>
<th></th>
<th>RSA/TSA</th>
<th>HA (23470, 23616)</th>
<th>ORIF</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>259</td>
<td>418 (238, 180)</td>
<td>760</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Operative Time</td>
<td>130</td>
<td>130, 127</td>
<td>104</td>
<td></td>
</tr>
<tr>
<td>RVU 2010-2013</td>
<td>22.65</td>
<td>17.8, 18.37</td>
<td>12.30</td>
<td></td>
</tr>
<tr>
<td>RVU 2014 and after</td>
<td>22.13</td>
<td>17.89, 18.37</td>
<td>12.30</td>
<td></td>
</tr>
<tr>
<td>RVU/min</td>
<td>0.197</td>
<td>0.156, 0.166</td>
<td>0.135</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Reimbursement rate</td>
<td>6.97</td>
<td>5.48, 5.83</td>
<td>4.74</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Revenue per case (USD)</td>
<td>907</td>
<td>713, 742</td>
<td>495</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Cases per day</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Revenue per day (USD)</td>
<td>3627</td>
<td>2854, 2969</td>
<td>2473</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Average Annualized Difference (USD)</td>
<td>580,386</td>
<td>464,718</td>
<td>395,608</td>
<td></td>
</tr>
</tbody>
</table>

Revenue was $464,718. This revealed an average annual difference (AAD) of $115,667 between RSA/TSA and HA and an AAD of $184,777 between RSA/TSA and ORIF, both in favor of RSA/TSA in elderly patients. Between 23470 HA and 23616 HA, the AAD was $18,444 in favor of 23616 HA.

Discussion

RVUs are a basis of reimbursement for physicians. The physician work portion of RVUs includes factors such as time, skill, intensity, effort, and training (7). While reflective of the physician work portion, RVU compensation exhibited some discrepancies between procedures, even of similar lengths (10,11). In the case of proximal humerus fractures in the elderly, there are no current studies comparing the RVU reimbursement in a per time basis for the different surgical options. In this study, we found that RSA/TSA had the highest RVU/min and reimbursement rate in comparison to 23470 HA, 23616 HA, and ORIF in elderly patients. This was the case even with mean operative times between RSA/TSA and HA not differing significantly. These results show that more value is put on RSA/TSA in comparison to HA and ORIF in terms of RVU compensation.

In the case of a physician’s practice, operative time serves importance since it dictates the volume of operations that can be performed in a day. Operative time is also important in terms of infection rate as longer operative times are associated with increased infection rates. This trend has been shown across various orthopaedic procedures such as total knee arthroplasties, hip arthroplasties, arthroscopic rotator cuff repair, and spine surgeries (19-22). Cheng et al. conducted a systematic review that investigated operative time and infection rate across various surgical subspecialties. Their pooled analysis for orthopaedic surgeries found an 84% increased likelihood of SSI with increased operative time (P=0.0003) (22). Physicians should be wary of such factors when analyzing cost-benefit analysis of different surgical options.

Using the mean operative times in a hypothetical 10-hour workday, we found that physicians can perform either 4 RSA/TSA or HA procedures or 5 ORIF procedures in a single day. Even with higher daily volume of ORIF, RSA/TSA daily revenue was greater than 23470 HA, 23616 HA, and ORIF. When extrapolating to yearly revenues, RSA/TSA was found to have an AAD of $115,667 over HA and an AAD of $184,777 over ORIF.

While shoulder arthroplasty has the highest payment value per minute of all the surgical treatment options for proximal humerus fractures, it is associated with a range of postoperative complications. Glenoid component failure, rotator cuff tear, pain and stiffness, and instability are among the most common complications following shoulder arthroplasty (23). In a study of over 19,000 TSA and RSA cases, the complication rate was found to be 11% (24). One can therefore argue that although shoulder arthroplasty has better payment value, it may not be justified if complications are elevated. However, in our cohort, the complication rate was 6.1% for TSA, 8.4% for HA, and 5.7% for ORIF (not including transfusions), which were not significantly different. Therefore, based on our findings it does not seem like TSA/RSA is associated with a higher rate of complications. In the above study by Bohsali et al., the complication rate reported is not for TSAs that are specifically for the treatment of proximal humerus fractures, which can explain the difference in results.

While hemiarthroplasties for proximal humerus fractures are meant to be billed under the 23616 CPT code, our data found that both hemiarthroplasty CPT codes, 23470 and 23616, were used for the same indication. When comparing each group, the only significant difference existed in the mean RVU (17.87 vs. 18.36; P<0.001). While not significant, 23616 HA had a greater revenue per day than 23470 HA ($2969 vs. $2854) and a greater yearly revenue ($475,077 vs. $456,633).

Sodhi et al. conducted a similar RVU analysis on primary...
 vs revision total knee arthroplasties (TKA) and found that despite increased time and complexity of revision TKAs, primary TKAs had greater RVUs per min compared to revision TKAs (0.26 vs. 0.22; \( P<0.001 \)) (12). Sodhi et al. also conducted the same RVU analysis on primary vs revision total hip arthroplasties (THA). Similarly, despite increased time and complexity of revision THAs, primary THAs had greater RVUs per min compared to revision THAs (0.260 vs. 0.249; \( P<0.001 \)) (13). Results such as these showcase that the physician work portion of total RVUs may not accurately depict the perceived time, skill, and effort that goes into wRVUs.

Some limitations to this study are that it is a retrospective database study, limiting the data to the NSQIP database. However, national patient data is more generalizable than patient data from a single hospital. In addition, since RSA and TSA procedures had the same CPT code, we could not distinguish RVU data between the two procedures. Furthermore, ORIF procedures may vary with complexity. Despite these limitations, our results are valid. When using the RVU model for RSA/TSA, HA, and ORIF for proximal humerus fractures in the elderly, RSA/TSA had greater RVU/min compensation in comparison to 23470 HA, 23616 HA, and ORIF (0.197 vs. 0.156, 0.166, and 0.135; \( P<0.001 \)). This translates to an AAD of $115,667 in favor of RSA/TSA over ORIF. Additionally, it was found that all types of surgery had similar rates of postoperative complications, reoperations, and readmissions. Therefore RSA/TSA provides the highest payment value per minute with similar postoperative risks as the other surgical options. While this study shows discrepancies in compensation rates in favor of RSA/TSA, future studies showcasing why this disparity exists are needed. This study provides insight for orthopaedic surgeons to better understand the monetary value of their time. In addition, orthopaedic surgeons can utilize this information to increase the daily cost-effectiveness of their practice.

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RESEARCH ARTICLE

The Surgical Treatment of Deep Infection in the Native Shoulder Joint

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Research performed at The Rothman Orthopaedic Institute at Thomas Jefferson University, Philadelphia Pennsylvania, USA

Abstract

Background: The overall clinical picture surrounding native shoulder infections, and, in particular, the associated long-term functional outcomes of treatment are presently underreported. The purpose of this study is to examine the demographics, diagnostic and treatment strategies, and functional outcomes of isolated shoulder joint sepsis treated with surgical irrigation and debridement (I& D).

Methods: All patients treated with I&D for native shoulder sepsis between 2007 – 2017 were identified. Those without a minimum of one-year follow-up were excluded. Functional outcomes scores, reoperations, and predictors of poor outcome were evaluated.

Results: Twenty-three patients were included in the final study population. Mean age-adjusted CCI score was 4.1 (SD = 3.4, Range = 0 – 10). Twelve patients (52.2%) were treated with open I&D, while 11 patients (47.8%) were treated arthroscopically. Nine patients (39.1%) required multiple I&Ds (mean total number of I&Ds = 1.7, SD = 1.0, Range: 1 – 4). Five patients (21.7%) had at least one documented reinfection after their initial hospitalization, with the initial recurrence of infection occurring 2 – 15 months after the index procedure. Mean ASES score at final follow-up was 55.3 (SD = 26.7, Range: 5.8 – 98.3) and mean SANE score was 53.3 (SD = 30.6, Range: 0 – 100). Stepwise multiple linear regression modeling identified intravenous drug abuse as the most significant predictor for final ASES score [F(1,18) = 6.12, p = .024, adjusted $R^2$ = .254].

Conclusion: Following isolated shoulder joint sepsis, infection clearance and acceptable functional outcomes can be achieved using surgical I&D followed by a course of antibiotics, but outcomes are variable.

Level of evidence: IV

Keywords: Infection, Native, Outcomes, Sepsis, Shoulder, Treatment

Introduction

Deep infection of the native shoulder joint is a rare but serious condition that can carry substantial morbidity and mortality. It has been reported that the incidence of septic joint arthritis is between 4 and 12 cases per 100,000 patient-years, with 8 – 21% of these cases involving the shoulder joint (1, 2). While native shoulder infection can occur in otherwise healthy patients, it is often found in older, medically complex patients or those with easily identifiable risk factors, such as intravenous drug abuse (IVDA) or immunocompromised (1, 3, 4). Patients can present with varying severity shoulder pain, often of unknown etiology, with or without signs of local or systemic infection (5, 6). Diagnostic and treatment strategies also vary, but commonly include serum inflammatory markers, joint aspiration, blood cultures, and open
or arthroscopic irrigation and debridement (I&D). Both open and arthroscopic I&D have demonstrated acceptable infection eradication efficacy, with open I&D historically reserved for more chronic presentations, more virulent organisms, or more severe clinical pictures. Postoperatively, patients are often managed with extended courses of intravenous (IV) antibiotics. Lifelong suppressive antibiotic therapy may be required for immunocompromised patients or those with a history of recurrent infection (7).

Due to the medical complexity of many affected patients, the risk for disseminated infection leading to severe morbidity or mortality, and the often-ambiguous nature of clinical presentation, native shoulder infection is a challenging clinical scenario that requires prompt diagnosis and management. Reported treatment outcomes are highly variable and dependent on the age and comorbidity profiles of affected patients. It is therefore of critical importance to whole understand the variables associated with native shoulder infection that may impact or prognosticate outcomes (5, 6, 8-12). Although infection eradication and medical stabilization are of the most critical concern upon patient presentation, the potential for morbidity and functional limitations must also be considered within utilized treatment algorithms. The purpose of this retrospective cohort study is to examine the demographics, diagnostic and treatment strategies, and functional outcomes associated with surgically-managed native shoulder infection.

Materials and Methods
Following Institutional Review Board approval, a database search yielded 79 patients surgically treated for septic arthritis of a native shoulder joint between 2007 – 2017 within a single orthopaedic group. This cohort was established through an automated search for all shoulder I&Ds with a diagnosis code or description of septic arthritis, and excluded patients with any prior surgery or trauma to the affected shoulder through manual stratification. Study inclusion criteria required surgically managed patients with documented clinical follow-up and final survey completion at a minimum of one year after initial presentation. Patients with high clinical suspicion for infection despite negative cultures were included if they underwent surgery with a postoperative diagnosis of septic shoulder arthritis.

Thirty-eight patients lacked documented clinical follow-up after their index procedure and were excluded. Sixteen of the initially identified 79 patients (20.3%) were deceased by the time of data analysis. Twelve deceased patients lacked adequate clinical follow-up or survey completion and were also excluded. Of the remaining patients, final follow-up surveys, which included American Shoulder and Elbow Surgeons (ASES) score, Single Assessment Numerical Evaluation (SANE) score, Charlson Comorbidity Index (CCI) score, and the Veterans Rand 12-Item Health Survey scores for physical (VR-12P) and mental (VR-12M) functioning, were collected via telephone, electronic, or in-clinic survey. Six patients refused to participate. Demographic, preoperative, intraoperative, and postoperative variables were collected through electronic medical record review. For reporting purposes, final follow-up was considered to be the time of survey completion, and infection recurrence was considered to be any case in which a patient underwent unplanned reoperation for infection after their initial treatment and hospitalization, and after they had completed their initial course of antibiotic therapy.

Data was recorded and analyzed using the Statistical Package for the Social Sciences (SPSS Inc, Ver 26.0). Demographic variables, treatment characteristics, and overall outcomes were reported using descriptive statistics. Final survey scores were tested for normality using the Shapiro-Wilk test and mean differences between categorical variables were then compared using either the Student’s T-test or Mann-Whitney U test. Relative risks for ASES, SANE, VR-12M, and VR-12P scores of 50 or less, referred to as below average scores, were also calculated for the categorical demographic and treatment variables. Finally, multiple linear regression modeling was used to identify any potential predictors of final outcome scores. Statistical significance for all testing was established at P < .05.

Results
Twenty-three patients met full criteria. The mean time to final follow-up was 3.2 years (SD = 2.8 years, Range: 1.0 – 11.1 years). Thirteen patients (56.5%) were male and 10 patients (43.5%) were female. The mean age was 62.7 years old (SD = 15.5 years, Range: 31 – 86 years old). Mean CCI score was 2.2 (SD = 2.3, Range: 0 – 7) and mean age-adjusted CCI score was 4.1 (SD = 3.4, Range = 0 – 10). Six patients (26.1%) had a medical history significant for diabetes mellitus and seven patients (30.4%) had moderate to severe chronic kidney disease. Five patients (21.7%) had an active malignancy or prior history of cancer. Two patients (8.7%) had rheumatoid arthritis. Thirteen patients 56.5% were current or former smokers and four patients (17.4%) were active IV drug users. In the study population, five patients (21.7%) had a known history of prior joint infection (two metatarsophalangeal, one carpometacarpal, one knee, and one patient with a history of both metatarsophalangeal and carpometacarpal infections).

Inflammatory markers at initial presentation were documented for 14/23 patients (60.9%). Of these 14 patients, the mean erythrocyte sedimentation rate (ESR) was 75.9 mm/hr (SD = 26.1, Range: 38.0 – 113.0). Ten patients (71.4%) had an elevated C-reactive protein (CRP) (mean CRP = 48.7 mg/L, SD = 69.0, Range: 0.2 – 178.0), and four (28.6%) had an elevated white blood cell (WBC) count (mean WBC count = 9.1, SD = 3.7, Range: 4.9 – 18.8). Eleven patients (47.8%) had documented suspicion for systemic infection at initial presentation and five patients had positive blood cultures on initial presentation (21.7%) [Table 1]. There was a documented suspected factor contributing to infection in 19 patients (82.6%) [Table 2]. The joint was aspirated in 16 patients (69.6%) and the aspiration was culture-positive in seven of these cases (43.8%). The
mean WBC count from joint aspiration was 46,877.9 cells/µL (SD = 31,190.7, Range: 966 – 90,000). Mean time from initial presentation to operation was 3.2 days (SD = 2.5 days, Range: 1 – 8 days).

Twelve patients (52.2%) were treated with open I&D, while 11 patients (47.8%) were treated arthroscopically. Fourteen patients (60.9%) had a peripherally inserted central catheter (PICC) line placed for IV antibiotic administration. Patients receiving IV antibiotics without a PICC line did so through pre-existing hemodialysis access sites. Four patients (17.4%) required lifelong antibiotic suppressive therapy. In all cases, infectious disease specialists oversaw antibiotic therapy, and the specific regimen was selected through culture sensitivities or institutional protocol in culture negative cases. Results of intraoperative cultures were available for 11 patients. Of these, the mean number of cultures was 2.0 (SD = 1.5, Range: 1 – 6) and 57.1% of cultures were positive. Overall, methicillin-sensitive staphylococcus aureus (MSSA) was the most common causative organism [Figure 1].

Nine patients (39.1%) required more than one I&D (mean total number of I&Ds = 1.7, SD = 1.0, Range: 1 – 4). Four of these were planned, repeat I&Ds occurring during the initial hospitalization and within one month from presentation. A total of 11 patients (47.8%) required reoperation of any kind during the study period [Table 3]. Open debridement was associated with a significantly higher mean number of total surgeries required (2.3 versus 1.3, \( P=.019 \)). Three patients (13.0%) underwent reoperation after one year – two for infection recurrence, and one for a rotator cuff tear on the affected side. One patient (4.3%) in the cohort underwent conversion arthroplasty, which occurred five months after initial presentation. Five patients (21.7%) had at least one documented reinfection requiring reoperation after their initial hospitalization, with the
initial recurrence of infection occurring 2 – 15 months after the index procedure [Table 3].
Mean ASES score at final follow-up was 55.3 (SD = 26.7, Range: 5.8 – 98.3) and mean SANE score was 53.3 (SD = 30.6, Range: 0 – 100). The mean VR-12M score was 44.4 (SD = 12.8, Range: 17.6 – 65.0) and the mean VR-12P score was 44.4 (SD = 12.8, Range: 17.6 – 65.0) [Table 4]. The mean ASES score was significantly lower with IVDA (31.4 (Range: 5.8 – 48.3) versus 60.9 (Range: 20.0 – 98.3), P= .037]. IVDA also carried a significantly increased risk for below average ASES and VR-12P scores at final follow-up (ASES Relative Risk = 2.8, 95% Confidence Interval = 1.5 – 5.4, P= .002) (VR-12P Relative Risk = 1.4, 95% Confidence Interval = 1.0 – 1.9, P= .026). Stepwise multiple linear regression modeling identified IVDA as the most significant predictor for final ASES score [F(1,18) = 6.12, P = .024, adjusted R² = .254] among the variables tested (IVDA, age-adjusted CCI, positive smoking history, open versus arthroscopic procedure). Linear regression modeling did not identify any significant predictors for SANE, VR-12M, or VR-12P scores at final follow-up (all P > .05).

Discussion
Native shoulder joint infection often occurs in immunocompromised patients, or those with extensive medical comorbidities. Infection eradication can be reliably achieved through surgical I&D and postoperative antibiotic courses, although this often requires multiple surgeries. Functional outcomes are fair and may be associated with the comorbidity profile of affected patients. IV drug abuse is a particularly significant predictor of poor functional outcomes.
Sixteen of the 79 (20.3%) initially identified patients were deceased at the time of data analysis, underscoring the compromised medical complexity of this population. In our study, medical comorbidities did not reliably

| Table 3. Patients requiring reoperation during the study period. Note: Staged I&D is a planned I&D during the initial hospitalization, occurring within one month of initial presentation |
|---|---|---|---|---|
| Patient ID | Index Procedure | Causative Organism | Number of Reoperations | Reason for Reoperation |
| 1 | Open | Group B Strep | 1 | Staged I&D |
| 3 | Arthroscopic | Culture Negative | 2 | Rotator Cuff Repair and Revision |
| 4 | Open | MRSA | 2 | Infection Recurrence (x2) |
| 5 | Open | MSSA | 1 | Staged I&D |
| 6 | Open | CoNS | 1 | Conversion Arthroplasty |
| 10 | Arthroscopic | Multi-Organism | 1 | Infection Recurrence |
| 11 | Open | Unknown | 1 | Staged I&D |
| 13 | Open | MSSA | 2 | Infection Recurrence (x2) |
| 16 | Open | Serratia | 3 | Infection Recurrence, Wound Dehiscence, Distal Clavicle Osteomyelitis and AC Joint Infection |
| 18 | Open | MSSA | 1 | Staged I&D |
| 19 | Open | MSSA | 3 | Infection Recurrence (x3) |

| Table 4. Demographic characteristics and functional outcomes of the study cohort. Scores collected at a mean duration of 3.2 years after initial presentation |
|---|---|---|---|---|
| Variable | n = | ASES | SANE | VR-12M | VR-12P |
| Total Cohort | 23 | 55.3 | 53.3 | 44.4 | 36.3 |
| Age (mean age = 62.7 years old) | | | | | |
| ≥ 65 years old | 9 (39.1%) | | | | |
| ≤ 65 years old | 14 (60.9%) | | | | |
| Sex | | | | | |
| Female | 10 (43.5%) | | | | |
| Male | 13 (56.5%) | | | | |
| Dominant Side | | | | | |
| 10 (43.5%) | | | | |
| 10 (43.5%) | | | | |
| Diabetes | 6 (26.1%) | | | | |
| CKD | 7 (30.4%) | | | | |
| Cancer History | 5 (21.7%) | | | | |
| Prior Joint Sepsis | 5 (21.7%) | | | | |
| Smoking | 13 (56.5%) | | | | |
| IV Drug Use | 4 (17.4%) | | | | |
| Index Procedure | | | | | |
| Open | 12 (52.2%) | | | | |
| Arthroscopic | 11 (47.8%) | | | | |
| Lifelong Antibiotics | 4 (17.4%) | | | | |
| Infection Recurrence | 5 (21.7%) | | | | |
| ≥ 1 Reoperation | 11 (47.8%) | | | | |
predict functional outcomes, though prior reports in the literature have established this connection (3). Our final cohort had an extensive comorbidity profile, including a substantial rate of IV drug abuse, smoking, and other immunocompromised states. Previously reported native infection study populations have demonstrated similar comorbidity profiles. Abdel et al. analyzed 50 native shoulder infections and found that patients were immunocompromised in 57% of cases, with a one year mortality rate of 17% (8). In a similar series of 21 patients, Klinger et al. found that 13 had an underlying medical disease, while Jeon et al. identified underlying disease in 13 of 19 patients (10, 13). Interestingly, joint aspiration WBC count, which is traditionally used to support a diagnosis when > 50,000 cells/µL, was not a reliable marker for infection in the present cohort (8, 14). This could also be suggestive of the underlying comorbidity profile, with immunocompromised patients potentially unable to mount an appropriate WBC response to infection. In terms of IV drug abuse, existing studies have likely underreported rates among affected patients secondary to a lack of follow-up and/or patient reporting. In a review of the literature, Lossos et al. reported five IV drug users in a cohort of 127 patients diagnosed with septic shoulder arthritis and they did not consider this a risk factor for native shoulder infection. The rate of IV drug abuse in our cohort was 17.4%, which is 6.7 times higher than the estimated rate of lifetime use among the United States population (14). In the present study, IV drug abuse carried an increased risk for below average ASES and VR-12P scores, and also predicted final ASES score, with a lower mean ASES score in IV drug users. Overall, the commonality of medical comorbidities and social risk factors associated with poor outcomes in patients with native shoulder infections necessitates aggressive treatment with attention to comorbid conditions and appropriately managed patient expectations (15). Furthermore, surgeons may consider the possibility of little to no patient follow-up when considering potential treatment strategies. Infections were successfully eradicated in the majority of patients despite over a third of the population requiring multiple I&Ds, which is consistent with the literature. Lifelong antibiotic suppression therapy was also not uncommon (8, 9). Mean ASES and SANE scores were highly variable, but overall fair. Functional outcomes after surgical treatment of native shoulder infection are presently underreported. In a retrospective study including 34 cases of septic arthritis treated with open or arthroscopic I&D and a mean follow-up of 32.4 months, Cho and Oh reported a mean final ASES score of 81.3, considerably higher than the 55.3 observed in our cohort (7). This could perhaps be attributed to differences in the comorbidity profiles of the two study populations. Jeon et al. also measured functional outcomes after arthroscopic I&D in 19 patients using the UCLA scoring system with an average score of 26 at a mean follow-up of 16.4 months, although 11 patients in their cohort had a concomitant rotator cuff tear. Both rotator cuff tear and degenerative arthritis are potential complications of native joint infection and treatment, and may eventually lead to conversion arthroplasty (13). Only one patient in our cohort required conversion arthroplasty, although a recent study examining shoulder arthroplasty as a sequela of native infection may suggest a higher incidence than we were able to identify (16).

There were no significant differences in our study between open and arthroscopic I&Ds in terms of infection eradication or functional outcomes. Open I&D was associated with a higher number of total infections required, but this is likely reflective of the underlying complexities favoring the use of an open approach in these cases, which is consistent with the literature. In their study, Cho and Oh directly compared arthroscopic (22 cases) and open (12 cases) I&D and found no significant differences in clinical outcomes between the two methods. Similar studies have also reported the equal efficacy of open and arthroscopic I&D, with arthroscopic I&D often favored in acute, less virulent infections (7). Future prospective studies could help to elucidate more precisely defined indications for open versus arthroscopic I&D (9, 14, 17).

Limitations
This study has several limitations, including its retrospective design and small population size. Potential inconsistencies in procedural and diagnosis codes allow for the possibility that patients meeting inclusion criteria were unintentionally excluded. The extensive comorbidity profile and mortality rate within this population lend insight into the complexity of these patients, but also substantially hinder the completion of necessary clinical follow-up required for inclusion within the study. Despite the fact that poor follow-up may have impacted our findings, it is an important variable to consider when treating this patient population. Our reported reinfection rate must be appreciated with the understanding that there is room for interpretation in delineating reinfection from persistent infection. As a number of reinfections in our cohort occurred shortly after the completion of antibiotics, some may instead classify these as persistent infections. Additionally, it is possible that potentially confounding variables were unaccounted for during statistical analysis. The retrospective nature of this study most importantly impacted the treatment courses, which lacked standardization. This led to only 14/23 patients with inflammatory marker results at the time of diagnosis, and variable postoperative courses that left us unable to fully assess the utility of specific protocols (i.e. radiographic assessment, repeat diagnostic testing, etc.). And finally, population size should be especially considered when interpreting statistical testing, particularly with multiple linear regression modeling.

In summary, infection clearance and fair functional outcomes following isolated shoulder joint sepsis can be achieved using surgical I&D followed by a course of antibiotics. There may be a high rate of concomitant morbidity and mortality among these patients. Continued investigation into this clinical scenario,
including the appropriate indications for open versus arthroscopic I&D and strategies to prevent long-term morbidity are warranted.

Acknowledgements
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References

Skin Tenting in Displaced Midshaft Clavicle Fractures

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Abstract

Background: The objectives of this study were to (1) identify factors associated with skin tenting in displaced midshaft clavicle fractures and (2) analyze individual surgeon variation in this diagnosis.

Methods: A retrospective cohort study was performed at two Level I trauma centers of 396 patients with displaced midshaft clavicle fractures treated by 47 surgeons with open reduction internal fixation from January 2010 to March 2019. Our main outcome measure was skin tenting, as diagnosed by the treating surgeon and used as an indication for surgical treatment.

Results: Skin tenting was diagnosed by the treating surgeon in 34 out of 396 patients (9%) with displaced midshaft clavicle fractures. Multivariable logistic regression analyses showed that lower BMI (P=0.002) and fracture shortening (P=0.03) were independently associated with skin tenting in displaced midshaft clavicle fractures. There was wide variation among surgeons in the rate of diagnosis of skin tenting, ranging from 0% to 41% prevalence of skin tenting depending on the treating surgeon (P<0.0001).

Conclusion: Although lower BMI and greater fracture shortening were associated with skin tenting, the diagnosis is subjective. We found wide variation in the diagnosis of skin tenting, even among surgeons within a single metropolitan area.

Level of evidence: III

Keywords: Body mass index, Displaced clavicle fracture, Midshaft clavicle fracture, Skin tenting, Surgeon variation

Introduction

The optimal treatment of displaced midshaft clavicle fractures is controversial. Multiple randomized clinical trials have shown similar functional outcomes after nonoperative and surgical treatment of displaced midshaft clavicle fractures. Surgical fixation yields higher rates of fracture union, but is associated with surgical risks and a higher rate of secondary surgery for hardware removal (1-5).

Skin tenting may occur in the setting of a displaced midshaft clavicle fracture when a fracture fragment threatens the integrity of the skin and overlying soft tissue envelope. Skin tenting is traditionally cited as an indication for expedient surgical treatment of displaced midshaft clavicle fractures to preempt an open fracture (6, 7). The diagnosis of skin tenting is subjective. The incidence and variation in the diagnosis of skin tenting are not well-described.

The primary objective of this study was to identify factors associated with skin tenting in displaced midshaft clavicle fractures. The secondary objective of this study was to analyze individual surgeon variation in the diagnosis of skin tenting. Our null hypothesis was that no identifiable risk factors exist for skin tenting in displaced midshaft clavicle fractures.

Materials and Methods

Study design

This study was performed with institutional review board approval. A retrospective chart review was conducted of all clavicle fractures surgically treated at two...
Level I Trauma centers and affiliated satellite hospitals in a single metropolitan area from January 2010 to March 2019. The hospital billing records database was queried using the Common Procedural Terminology (CPT) code 23515 (open treatment of clavicular fracture, includes internal fixation, when performed) for patients within the study period.

The medical records and available radiographs of 634 patients who underwent surgical treatment of a clavicle fracture were screened. One hundred eight patients were excluded for distal third clavicle fracture, 81 patients for age less than 18 years, 38 patients for delay from injury to presentation of more than 2 weeks, 9 patients for proximal third clavicle fracture, 7 patients for open fracture, 4 patients for revision surgery, and 2 patients for nondisplaced fracture in the setting of a floating shoulder injury pattern. Eleven patients met more than one exclusion criteria. One patient underwent bilateral clavicle surgeries under the same anesthesia, and only one side was included to maintain the assumption of independence. A final cohort of 396 patients who underwent surgical treatment of a displaced midshaft clavicle fracture were included in the study.

Outcome measurement and explanatory variables

Our primary outcome was skin tenting in the setting of a displaced midshaft clavicle fracture, as diagnosed by the treating surgeon and used as an indication for surgical treatment. A total of 396 displaced midshaft clavicle fractures treated by 47 surgeons comprised our cohort. The following explanatory variables were studied: age, body mass index (BMI), sex, dominant upper extremity injury, diabetes mellitus, smoking status, American Society of Anesthesiologists Physical Status Classification (ASA), fracture comminution, superior-inferior fracture displacement, and medial-lateral fracture shortening. BMI closest to date of surgery, within 1 year before or after treatment, was used for analysis. Medical comorbidities were assessed by a thorough review of the electronic medical record. Fracture comminution, displacement, and shortening were measured on the preoperative upright frontal clavicle plain radiographs showing the greatest displacement.

Statistical analysis

Descriptive statistics for explanatory variables were calculated for the study cohort. All explanatory variables had greater than 90% data completeness. All variables were analyzed using the data available and missing data were excluded [Table 1]. Bivariate analysis was used to screen for factors associated with skin tenting. Student’s t-test was used for continuous variables, Mann-Whitney U test was used for ordinal variables, and Fisher’s exact test was used for categorical variables. We included variables with \( P < 0.1 \) in our multivariable logistic regression model. Analysis of variance (ANOVA) was used for parametric data, and the Kruskal-Wallis test was used for nonparametric data in the analysis of surgeon variation in the diagnosis of skin tenting.

A convenience sample was used. The standard significance criterion of \( \alpha = 0.05 \) and standard power criterion of \( (1-\beta) = 0.80 \) was employed for all statistical tests. A priori power analysis showed that with a sample size of 393 had 80% power to detect a 5% difference in rates of skin tenting between groups assuming a 25% standard deviation.

Results

Descriptive results

This study included 396 patients who underwent surgical treatment of displaced midshaft clavicle fractures. Two hundred ninety-nine patients (76%) were of male sex. Mean age at time of surgery was 37 years. Mean BMI was 25. Median ASA classification was 1.5. Forty-three patients (11%) were smokers. One hundred seventy-nine patients (50%) had a clavicle fracture of the dominant upper extremity. Comminution was present in 75% of cases. Mean superior-inferior fracture displacement was 16 mm and mean medial-lateral fracture shortening was 15 mm [Table 1].

Factor associated with skin tenting

Skin tenting was diagnosed in 34 out of 396 patients (9%) with displaced midshaft clavicle fractures. In all cases, the presence of skin tenting served as sufficient indication for surgical treatment. Bivariate analyses showed that lower BMI \( (P = 0.001) \), fracture shortening \( (P = 0.01) \), and ASA classification \( (P = 0.04) \) were associated with skin tenting [Table 2].

Multivariable logistic regression analyses showed that lower BMI \( (P = 0.002) \) and fracture shortening \( (P = 0.03) \) were independently associated with skin tenting in displaced midshaft clavicle fractures [Table 3].
Surgeon variation in the diagnosis of skin tenting

Twelve surgeons treated 10 or more displaced midshaft clavicle fractures (range 10 to 47) in our cohort. Six sports medicine surgeons treated 128 fractures, four orthopaedic trauma surgeons treated 89 fractures, and two hand and upper extremity surgeons treated 64 fractures. Wide variation existed among these surgeons in the rate of diagnosis of skin tenting, ranging from 0% to 41% prevalence of skin tenting depending on the treating surgeon [Figure 1]. The differences among surgeons for the diagnosis of skin tenting was statistically significant (P < 0.0001).

There was no statistically significant difference in the diagnosis of skin tenting by subspecialty training among sports medicine, orthopaedic trauma, and hand and upper extremity surgeons. Post hoc Fisher's exact tests showed that surgeon #5 (P < 0.0001) and surgeon #12 (P = 0.007) varied from the mean of the other surgeons by a statistically significant amount. Fracture parameters (displacement and shortening) were not significantly greater for surgeon #5 and surgeon #12 compared with the remaining cohort.

No significant difference was seen among treating surgeons with regards to patient BMI, sex, diabetes mellitus, smoking status, ASA classification, fracture comminution, superior-inferior fracture displacement, or medial-lateral fracture shortening. Patient age significantly differed among treating surgeons (P = 0.03).

Discussion

Skin tenting is traditionally cited as a clear indication for surgical treatment of a displaced midshaft clavicle fracture (6). In theory, a clavicle fracture with skin tenting is an impending open fracture, and in fact, there have been case reports of initially closed clavicle fractures with skin tenting that have converted to open fractures when the overlying soft tissue envelopes necrosed (7).

The incidence of skin tenting in displaced midshaft clavicle fractures is not well-described in the literature. Kirmani et al. reported a 4% incidence of skin tenting in a retrospective case series comprising only five cases of skin tenting (8). Our present study showed a 9% incidence of skin tenting. A possible reason for the higher rate of skin tenting observed in our study may be that the patient populations at our two Level I trauma centers sustain higher energy injuries. Alternatively, it may be the case that the surgeons in our study more readily apply the diagnosis of skin tenting.

In this study, we have found medial-lateral fracture shortening and lower BMI to be independent risk factors.

<table>
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<tr>
<th>Table 2. Bivariate analyses of variables associated with skin tenting in displaced midshaft clavicle fractures (n=396)</th>
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<tr>
<td><strong>Comparison group (n=362)</strong></td>
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<tr>
<td><strong>Mean (Standard Deviation)</strong></td>
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<td>Age</td>
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<td>BMI</td>
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Number of non-missing values per variable indicated in Table 1. Bold indicates statistical significance.

<table>
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<th>Table 3. Multivariable logistic regression analysis for variables associated with skin tenting in displaced midshaft clavicle fractures (n=396)</th>
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<tr>
<td><strong>Multivariable logistic regression</strong></td>
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Number of non-missing values per variable indicated in Table 1. Bold indicates statistical significance.

† Reference groups for continuous and ordinal variables are minus 1 unit.
for skin tenting. Fracture comminution was not found to be a risk factor for skin tenting as previously posited (8). Similarly, superior-inferior fracture displacement was not associated with skin tenting, as superior-inferior displacement of midshaft clavicle fractures is primarily caused by the inferior displacement of the lateral fracture fragment along with the upper extremity. Shortening of the shoulder girdle, however, brings the medial fracture edge closer to the skin and predisposes to skin tenting. Lower BMI is likely associated with skin tenting due to a thinner soft tissue envelope overlying the fracture site. ASA was weakly but significantly correlated with BMI (Spearman’s $\rho = 0.19, P = 0.0002$) and fell out of significance in our multivariable logistic regression analysis, suggesting that it was a proxy for BMI.

The incidence of skin tenting diagnosed by individual surgeons ranged from 0% to 41% in our study. The wide variation in surgeon diagnosis of skin tenting reflects the challenging and subjective nature of the diagnosis and the lack of a reference standard. While part of the variation can likely be attributed to differing surgeon thresholds for what amounts to skin tenting, part of the variation may be due to differences in patient population and mechanism of injury seen by different surgeons. It may be the case that trauma surgeons, hand and upper extremity surgeons, and sports surgeons in our hospital system treat dissimilar patient populations with injuries of differing acuity and severity. However, risk factors for skin tenting, namely BMI and fracture shortening, were not significantly different among treating surgeons. Patient age was significantly different among treating surgeons, but this was not significantly associated with skin tenting.

The subjectivity in the diagnosis of skin tenting is compounded by a deficiency of the English language, as surgeons may refer to different physical examination findings when using the term “skin tenting.” Some surgeons may use skin tenting to mean an angular contour of the skin overlying the fracture, while other surgeons may imply that the fracture has pierced the fascia into the subcutaneous tissue. Still others may use skin tenting to mean blanching of the overlying skin, or even impending necrosis of the overlying skin. These scenarios occur with different frequencies and carry different implications for impending open fracture, and yet may all be called skin tenting by different, reasonable surgeons. More precise terminology regarding what is tented and what is threatened skin would be helpful for
communication and clinical management. There are limitations to our study. First, our study was retrospectively performed. Assessment of skin tenting was based on retrospective review of the medical record. However, we expect good documentation of skin tenting by the treating surgeon, especially when used as an indication for surgery. In a retrospective study on skin tenting, it can be difficult to differentiate between threatened skin and a sharp change in skin contour; however, in our cases of skin tenting, the skin tenting was notable such that the treating surgeons used it as part of their rationale for surgical treatment. Moreover, it is precisely this ambiguity and lack of a reference standard that is one of the central points of our study. Second, fracture parameters, such as displacement and shortening, were measured on plain radiographs. Dependent on the direction of the beam, these parameters may differ. In this study, we used the preoperative frontal plain radiographs that showed the greatest displacement for our measurements. Although we relied on an imperfect two-dimensional representation of a three-dimensional fracture, we believe this method is true to real-life surgeon practice. Third, we were unable to account for mechanism of injury and severity of trauma as a risk factor for skin tenting. Fourth, we were unable to comment on the timing and expediency of treatment after formal diagnosis. Finally, our study was performed at two Level I trauma centers in a major metropolitan area, which may limit the generalizability of our results to other settings.

Skin tenting in displaced midshaft clavicle fractures is uncommon. BMI and fracture shortening are significant, independent risk factors for skin tenting. The nature of the diagnosis of skin tenting is subjective, and the diagnosis is made more variable by inherent imprecision in our terminology. There is significant practice variation in the diagnosis of skin tenting, even among surgeons within a single metropolitan area. Further study is warranted to understand the cause of this practice variation.

Disclosure: The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

References

The Value of the Distal Radioulnar Joint Effusion in Diagnosing Triangular Fibrocartilage Complex Tears on Magnetic Resonance Imaging

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Research performed at Hooper Hand Unit, St John’s Hospital, UK

Abstract

Background: A retrospective study was conducted to evaluate the role of distal radioulnar joint (DRUJ) effusion in aiding the diagnostic accuracy of central triangular fibrocartilage complex (TFCC) tears on non-contrast MRI.

Methods: 89 consecutive patients who had undergone wrist arthroscopy for ulna sided wrist pain in our unit were identified and their preoperative imaging reviewed. Two consultant musculoskeletal Radiologists independently reported the presence or absence of a DRUJ effusion and or a TFCC tear. The inter-observer variability was calculated using weighted Kappa tests. Two by two tables were constructed to calculate the sensitivity and specificity of reported TFCC tear or DRUJ effusion on MRI in correctly diagnosing central TFCC tears identified at arthroscopy.

Results: Sensitivity of MRI to report a TFCC tear was 0.56 and specificity was 0.79. Sensitivity increased to 0.89 if either a DRUJ effusion or TFCC tear were seen on MRI. When observed together, the presence of both a DRUJ effusion and a TFCC tear seen on the imaging lead to a sensitivity of 0.74 and PPV of 82% when compared to findings at arthroscopy. In the absence of both DRUJ effusion and TFCC tear, the specificity of MRI increased to 0.92. Agreement by the radiologists on the presence of DRUJ effusion was substantial (k value 0.67) and TFCC tear was moderate (k value 0.58).

Conclusion: The presence of DRUJ effusion on MRI can further improve sensitivity of MRI in diagnosing central TFCC tears. The sensitivity of detecting a central TFCC tear on MRI scan when both a DRUJ effusion and a TFCC tear were seen (0.74) is comparable to rates demonstrated on MRA meta-analysis results (0.78). Furthermore, considering the absence of both a DRUJ effusion and TFCC tear seen on MRI is useful in excluding the presence of a TFCC tear at arthroscopy.

Level of evidence: III

Keywords: Arthroscopy, Triangular fibrocartilage complex, Wrist injuries

Introduction

To diagnose the aetiology of ulna sided wrist pain, investigation with Magnetic Resonance Imaging (MRI) is often utilised. A common cause of ulna sided wrist pain is a central tear in the triangular fibrocartilage complex (TFCC) with seventy percent of symptomatic patients in the age group 50–69 years being found to have a TFCC injury (1-2). In 2012 a meta-analysis demonstrated that (Magnetic
resonance arthrogram) MRA was superior to MRI in detecting TFCC tears, sensitivity 0.84 versus 0.75; specificity 0.95 versus 0.81 respectively (3). The largest meta-analysis to date to examine the role of MRI and MRA for the diagnosis of TFCC injuries was published in 2018. This has shown that MRA remains a superior mode of diagnostic imaging for TFCC tear (sensitivity 0.78; and specificity 0.85). However, whilst the diagnostic accuracy of MRI has remained almost constant (sensitivity 0.76; and specificity 0.82), the advantage of MRA over MRI was less than in previous studies (4). In addition, MRA is invasive, can be painful and has the potential risks of allergic reaction, irritation and swelling due to chemical synovitis from contrast. Infection, in addition, is a very rare but serious potential complication (5).

The hypothesis for this study was that the observation of an effusion within the distal radial ulnar joint (DRUJ) on a non-contrast MRI can improve the diagnostic accuracy of central TFCC tears.

Materials and Methods
A retrospective review of all consecutive patients who underwent wrist arthroscopies for treatment of ulna sided wrist pain, with suspected TFCC pathology in our unit was conducted. Patients with peripheral TFCC tears, inflammatory arthropathies or synovitis were excluded; as were patients who had previously undergone wrist arthroscopy on the same side, or where the MRI scan had movement artefact.

Two consultant musculoskeletal specialist radiologists reviewed the MRI imaging independently, provided only with the clinical history as recorded on the imaging request form and blinded to the result of arthroscopy. The scans had been performed at multiple centres, on 1.5 Tesla machines and the field of view was of the wrist, distal forearm to distal metacarpals. The standard sequences included T1, T2 and PDFS in coronal, sagittal and axial views, although there was some minor variation between centres. The radiologists reported the presence or absence of a central TFCC tear on plain MRI scan for each patient. On a literature review we found no established criteria to define a DRUJ effusion on MRI. Therefore, an effusion was defined as the presence of excessive fluid within the distal radial ulna joint, seen on the PDFS coronal or sagittal views and reported independently by the musculoskeletal radiologist. Following these criteria, the radiologists noted the presence or absence of a DRUJ effusion, focusing on the proton density fat suppression (PDFS) coronal images [Figure 1; 2]. Each radiologist was blinded to the others report. To measure inter observer agreement between the radiologists Cohen’s Kappa coefficient (k) was calculated for the reported presence or absence of DRUJ effusion and central TFCC tear respectively on MRI. The operation notes were reviewed to ascertain whether there was a central TFCC tear identified intra-operatively. At operation, TFCC tears were confirmed or refuted using the standard practice of radiocarpal joint arthroscopic observation and probing of the fibrocartilage disc.
or DRUJ effusion and comparison made to findings at arthroscopy. This was used to calculate the sensitivity and specificity, and positive and negative predictive values. Parallel testing was used to calculate the sensitivity and specificity of the two findings (tear and effusion) on MRI. P values were calculated using chi-square test, with $P < 0.05$ being considered significant. Confidence intervals were calculated using the Clopper-Pearson test.

**Results**

The unit performed a total of 89 consecutive wrist arthroscopies for patients with ulnar sided wrist pain during the time period studied. After exclusions (including one patient with movement artefact on imaging), 81 patients were included. Two further patients were excluded as a consensus could not be reached between radiologists on the presence or absence of an effusion, leaving a final cohort of 79 patients.

The sensitivity of MRI in detecting TFCC tear was 0.56 (95% CI, 0.41-0.71), and DRUJ effusion was 0.76 (0.61-0.91) independently. The specificity of detecting TFCC tear was 0.79 (0.61-0.91) and DRUJ effusion 0.61 (0.42-0.77), [Tables 1-3]. When the findings of either a central TFCC tear or a DRUJ effusion were identified on MRI, sensitivity increased further to 0.89, on parallel testing. The specificity of MRI to exclude a TFCC tear increased to 0.92 if the TFCC was reported as intact and there was no DRUJ effusion present. Inter-observer variability was calculated using Cohen’s Kappa coefficient ($k$). Where the $k$-value can fall between 0 and 1, with one being perfect agreement (6). Agreement on reported presence of DRUJ effusion was substantial ($K$ value 0.67) and agreement on reported presence of TFCC tear was moderate ($K$ value 0.58).

### Table 1. Two by two table demonstrating patient numbers with TFCC status as seen on a non-contrast MRI against wrist arthroscopy findings of a TFCC tear

<table>
<thead>
<tr>
<th>MRI</th>
<th>Wrist arthroscopy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TFCC tear</td>
</tr>
<tr>
<td>TFCC tear</td>
<td>26</td>
</tr>
<tr>
<td>TFCC intact</td>
<td>20</td>
</tr>
</tbody>
</table>

### Table 2. Two by two table demonstrating patient numbers with the presence of absence of a DRUJ effusion against wrist arthroscopy findings of a TFCC tear

<table>
<thead>
<tr>
<th>MRI</th>
<th>Wrist arthroscopy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TFCC tear</td>
</tr>
<tr>
<td>DRUJ effusion present</td>
<td>35</td>
</tr>
<tr>
<td>DRUJ effusion absent</td>
<td>11</td>
</tr>
</tbody>
</table>

### Table 3. Correlation of MRI findings with TFCC tears found on arthroscopy

<table>
<thead>
<tr>
<th>MRI findings</th>
<th>Sensitivity (95% CI)</th>
<th>Specificity (95% CI)</th>
<th>PPV (%)</th>
<th>NPV (%)</th>
<th>$P$ value ($X^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TFCC</td>
<td>0.56 (0.41-0.71)</td>
<td>0.79 (0.61-0.91)</td>
<td>78.79 (64.74-88.26)</td>
<td>56.52 (47.21-65.39)</td>
<td>.002</td>
</tr>
<tr>
<td>DRUJ effusion</td>
<td>0.76 (0.61-0.88)</td>
<td>0.61 (0.42-0.77)</td>
<td>72.92 (63.13-80.90)</td>
<td>64.52 (50.34-76.53)</td>
<td>.001</td>
</tr>
<tr>
<td>TFCC tear OR DRUJ effusion</td>
<td>0.89</td>
<td>0.48</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No TFCC tear AND no DRUJ effusion</td>
<td>0.43</td>
<td>0.92</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Discussion**

In our unit the sensitivity and specificity of MRI in identifying a central TFCC tear based on its radiological appearance is lower than that quoted previously in the literature. This highlights the complexity of identifying TFCC pathology on plain MRI, as despite our reporting radiologists being specialists in the field of musculoskeletal imaging, their inter-observer agreement on the presence of a TFCC tear was only moderate ($K$ value 0.58). Familiarity with the anatomy of the TFCC is a prerequisite for identification of TFCC tears and accessibility to specialist musculoskeletal radiologists may limit provision locally in smaller units.

However, there was substantial agreement between the independent radiologists when reporting a DRUJ effusion ($K$ value 0.67), which indicates that this finding is more easily evaluated than TFCC anatomy on plain MRI. For the purpose of diagnosing central TFCC tears, a DRUJ effusion observed in isolation has lower positive predictive value as an indicator for a central TFCC tear at arthroscopy than the observation of a TFCC tear on scan. It is likely that this is as DRUJ joint effusions may be caused by other pathologies such as joint damage or degeneration. However, when the observation of A DRUJ effusion is used with the observation of a TFCC tear on MRI, it is shown to aid the diagnosis of a TFCC tear.

Our study has also shown that non-contrast MRI scan can be useful to exclude the presence of a TFCC tear as the specificity of MRI to exclude a TFCC tear was high (0.92) if the TFCC was reported as intact and there was no DRUJ effusion seen.

Although MRA is superior in diagnosing full-thickness central TFCC tears, non-contrast MRI remains a useful tool for investigating ulnar-sided wrist pain due to its non-invasive nature and being a quicker, cheaper procedure. We show that the presence or absence of a
DRUJ effusion on an MRI scan can be a useful additional indicator of underlying TFCC pathology, in the absence of an MRA scan.

Disclosure: The authors report no conflict of interest concerning materials or methods used in this study or the findings specified in this paper.

References

Deep Infection after Distal Radius Open-reduction Internal Fixation: A Case Series

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Research performed at Rothman Orthopaedic Institute, Thomas Jefferson University, Philadelphia, PA, USA

Abstract

Background: Given its low incidence, the management of deep infection following distal radius open-reduction internal fixation (ORIF) has not been well reported. In an effort to expand our current understanding, the purpose of this case series is to present the treatment strategies and functional outcomes associated with deep infection after distal radius ORIF.

Methods: All patients with deep infections after distal radius ORIF over a ten-year period were identified and their treatment courses assessed.

Results: The cohort consisted of three women and one man with an average age of 55.5 ± 17.6 years. Mean time from infection presentation to irrigation and debridement (I&D) with removal of hardware (ROH) was 16 days (Range: 3 – 44 days). The identified bacterial species in all cases was Staphylococcus aureus (MRSA = 2, MSSA = 2). Three patients were treated with intravenous antibiotics, while one patient was treated with oral antibiotics. Mean time from infection presentation to final clinical follow-up was 11 months (Range: 3 – 20 months). Two patients required repeat I&D. A clinical determination of successful infection eradication was made in all cases.

Conclusion: The reported rate of deep infection after distal radius ORIF is less than 1%. There is no well-defined treatment algorithm for patients with deep infection after distal radius ORIF. However, removal of hardware and post-operative oral or intravenous antibiotic therapy appears effective, and is consistent with the standard practices of treating infection after other orthopaedic surgeries.

Level of evidence: IV

Keywords: Distal radius, Infection, Open-reduction internal fixation, Treatment

Introduction

Distal radius fractures are among the most commonly encountered orthopaedic injuries. When surgical management is required, open-reduction internal fixation (ORIF) strategies are often utilized with reliable outcomes (1,2). While various post-operative complications can occur, the reported rate of deep infection is less than 1% (3,4). Due to its rarity, there is a paucity of information regarding the management of deep infection after ORIF. Similarly, the impact of deep infection on overall outcomes after distal radius ORIF is underreported.

In an effort to expand the current understanding, the purpose of this case series is to present the treatment courses and outcomes of patients with surgically-managed deep infections after distal radius fracture ORIF.

Materials and Methods

A database search was conducted to first identify all patients within a single orthopaedic group between 2009–2019 who underwent ORIF of a distal radius fracture
(CPT codes: 25607, 25608, 25609). This produced a cohort of 5,673 patients. We further stratified this group by selecting patients with an associated irrigation and debridement (I&D) code within 18 months of their initial ORIF, which produced 155 patients. The electronic medical records of the remaining patients were reviewed to identify those who underwent re-operation for an isolated deep infection after ORIF. Exclusion criteria included initial open fracture (91), loss to follow-up (1), and radiocarpal fracture/dislocation (1). A total of four patients with clinical follow-up through completion of antibiotic therapy were included.

Electronic medical records were further reviewed to collect demographic variables including age, sex, injury laterality, and comorbidities, diagnostic and treatment variables, and available outcome data including range of motion (ROM), Disabilities of the Arm, Shoulder, and Hand (DASH and Quick-DASH) scores, and radiographic measures at final follow-up. All data was collected, and descriptive statistics reported.

Results
Summary
Descriptive characteristics of the patients within this series are summarized in Table 1. Final radiographs after hardware removal were available for three patients, and measurements are reported in Table 2. The determination of infection resolution was made clinically in all cases. There were no further complications, infection recurrence, or unplanned reoperations within the cohort.

Case One
This was a 72-year-old female with a history of rheumatoid arthritis on Methotrexate and Prednisone. The patient sustained an AO Type C distal radius fracture, which was treated with volar plating and allograft bone grafting. Nineteen days after surgery, the patient presented to the office with cellulitis and ulcerations surrounding the incision site. The patient was started on oral Clindamycin and topical Mupirocin. Initially, the presumed superficial infection improved, but 1 month later, it acutely worsened. At that time, radiographs demonstrated a healing fracture with incorporating bone graft [Figure 1]. However, due to concern for deep infection, the patient underwent I&D with ROH 63 days after the index surgery. High-viscosity bone cement mixed with 500 milligrams of vancomycin powder was placed within the open screw holes and around a metaphyseal void to avoid the need for supplemental fixation. A deep drain was placed. Intra-operative cultures grew Methicillin-sensitive Staphylococcus aureus (MSSA), and the patient received a six-week course of intravenous (IV) cefazolin. Two months after surgery, range of motion was near symmetric to the contralateral side with only a minor deficit in supination. Radiographs taken seven months post-operatively demonstrated satisfactory position of the spacer with surrounding bone consolidation [Figure 1]. Therefore, the spacer was left in place indefinitely. Quick-DASH score recorded nine months after hardware removal was 34. The patient died one year after I&D from an unrelated cause.

Table 1. Descriptive characteristics of the study cohort

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>36 – 74 years old</td>
</tr>
<tr>
<td>Body Mass Index</td>
<td>26 – 36</td>
</tr>
<tr>
<td>Time from ORIF to Infection Presentation</td>
<td>5 days – 5 months</td>
</tr>
<tr>
<td>Time from Infection Presentation to I&amp;D</td>
<td>3 – 44 days</td>
</tr>
<tr>
<td>Duration of Post-operative Antibiotics</td>
<td>4 – 8 weeks</td>
</tr>
<tr>
<td>Current Tobacco Users</td>
<td>1</td>
</tr>
<tr>
<td>Dominant-sided Fractures</td>
<td>2</td>
</tr>
<tr>
<td>Presenting Symptom</td>
<td></td>
</tr>
<tr>
<td>Skin changes</td>
<td>3</td>
</tr>
<tr>
<td>Altered Mental Status</td>
<td>1</td>
</tr>
<tr>
<td>ESR Obtained at Infection Presentation</td>
<td>2 (Both WNL)</td>
</tr>
<tr>
<td>Radiographic Changes at Infection</td>
<td>1 (Screw Displacement)</td>
</tr>
<tr>
<td>Presentation</td>
<td></td>
</tr>
<tr>
<td>Bacterial Species</td>
<td></td>
</tr>
<tr>
<td>MSSA</td>
<td>2</td>
</tr>
<tr>
<td>MRSA</td>
<td>2</td>
</tr>
<tr>
<td>Route of Post-operative Antibiotics</td>
<td></td>
</tr>
<tr>
<td>Intravenous</td>
<td>3</td>
</tr>
<tr>
<td>Oral</td>
<td>1</td>
</tr>
<tr>
<td>Type of Postoperative Antibiotics</td>
<td></td>
</tr>
<tr>
<td>Vancomycin</td>
<td>2</td>
</tr>
<tr>
<td>Cefazolin</td>
<td>1</td>
</tr>
<tr>
<td>Cephalexin</td>
<td>1</td>
</tr>
<tr>
<td>Repeat I&amp;D Required</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 2. Radiographic measurements at final follow-up after hardware removal for deep infection after distal radius ORIF

<table>
<thead>
<tr>
<th>Case</th>
<th>Radial Tilt</th>
<th>Volar Tilt</th>
<th>Radial Height</th>
<th>Ulnar Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>One</td>
<td>17°</td>
<td>14°</td>
<td>7 mm</td>
<td>- 1 mm</td>
</tr>
<tr>
<td>Three</td>
<td>20°</td>
<td>- 6°</td>
<td>10 mm</td>
<td>- 1 mm</td>
</tr>
<tr>
<td>Four</td>
<td>26°</td>
<td>19°</td>
<td>13 mm</td>
<td>- 2 mm</td>
</tr>
</tbody>
</table>

ESR = Erythrocyte sedimentation rate, WNL = Within normal limits, MSSA = Methicillin-sensitive Staphylococcus aureus, MRSA = Methicillin-resistant Staphylococcus aureus.
illness, without infection recurrence.

**Case Two**

This was a 36-year-old male without any medical co-morbidities who sustained an AO Type B fracture that was treated with volar plating. At 2 months post-operatively, the fracture was healed, and ROM was improving with physical therapy. However, 3 months after surgery, the patient presented with serosanguinous drainage from the incision. Radiographs demonstrated a healed fracture with a single displaced locking screw [Figure 2]. The patient was started on Cephalexin and subsequently underwent I&D with ROH ten days later (112 days after index ORIF). Intra-operative cultures grew MSSA, and the patient was maintained on Cephalexin for one month after surgery. Post-operatively, active ROM at 3 weeks was 24° of flexion, 18° of extension, 10° of ulnar deviation, and 8° of radial deviation. The patient failed to follow-up after two months, by which point there were no signs of residual infection.

**Case Three**

A 74-year-old female with a history of hypertension and diabetes mellitus underwent ORIF with a volar plate and a temporary spanning plate after suffering an AO Type C fracture. Five days after surgery, the patient presented to the emergency department with fever, tachycardia, altered mental status, blood glucose level greater than 600, purulent drainage from the volar wrist incision and a suspected urinary tract infection. The patient was started on empiric IV antibiotics. Once stabilized, eight days after the index ORIF, the patient underwent I&D, which revealed gross purulence. The volar plate was removed, but the dorsal spanning plate was maintained. A repeat I&D was performed three days after the first. Deep and superficial drains were placed within the volar-sided wound. Intra-operative cultures grew Methicillin-resistant Staphylococcus aureus (MRSA), and the patient received an eight-week course of IV vancomycin. The spanning plate was removed five months after the index ORIF without complication. Eight weeks after spanning plate removal the patient demonstrated excellent ROM with a DASH score of 36. Nineteen months after I&D, the patient remained free of infection.

**Case Four**

This was a 40-year-old female smoker with no significant past medical history, who underwent ORIF with volar plating for an AO Type C fracture. The immediate post-operative course was unremarkable. Approximately three months after ORIF, the patient underwent breast...
surgery and developed an abscess at that surgical site post-operatively that was treated with bedside drainage and oral antibiotics. Two months later (5 months status post index wrist surgery), the patient presented to the clinic with a two-centimeter soft tissue mass over the dorsum of the wrist. Radiographs demonstrated a fully healed fracture. Given that the patient was experiencing tenderness over the volar aspect of the wrist as well, the decision was made to schedule ROH with I&D and mass exploration. Until the surgery, the patient was placed on oral Cephalexin. During the I&D, the dorsal mass was found to be a purulent collection that was communicating with the volar hardware. Two days later, the patient returned to the operating room for repeat I&D, which included debridement of devitalized bone surrounding many of the previous screw locations. Intra-operative cultures grew MRSA, and the patient was successfully treated with six weeks of IV vancomycin. No further surgery was required. At 20 months after surgery, clinical progress notes documented full passive ROM without pain and stable active ROM with some deficits compared to the contralateral side. Wrist rotation and digital ROM were full. The final DASH score was 35 and there was no recurrence of infection.

Discussion

Deep infection requiring surgery after distal radius fracture ORIF is a rare occurrence for which there is little data on treatment strategies and outcomes. In our series, the incidence of deep infection over a 10-year period was approximately 0.1% – slightly below the aforementioned rate of 0.6% reported in the literature (4). Our treatment involved surgical debridement and ROH, with post-operative antibiotics. Although this did result in eradication of the infections in all patients, functional deficits did persist, as reflected by final DASH scores. Given its rarity, there is no well-defined treatment algorithm for patients with deep infection after distal radius ORIF. However, ROH and post-operative antibiotic therapy is consistent with the standard practices of treating infection after other orthopaedic surgeries. Hardware removal and IV antibiotics have long been mainstays in the treatment of infection after joint arthroplasty (5). Similar strategies have also been reported for infections after lower extremity fracture ORIF (6). In comparison to joint arthroplasty, a complicating variable in determining optimal hardware management after fracture is whether or not the injury has healed (7). Two of our four patients had complete radiographic union at the time of infection presentation, and in these cases, the implant was removed without complication or re-injury. In one patient who underwent ROH prior to complete healing, antibiotic cement was used to fill in remaining bony voids to augment fracture stabilization after hardware removal. This may be a useful strategy in acute infections with still healing fractures to allow for ROH without the need for adjunct fixation. This patient was immobilized within a thermoplastic splint for three weeks after hardware removal before resuming light ROM and eventually recovered near symmetric ROM at the affected wrist compared to the contralateral side.

Intravenous antibiotics were used in three patients. However, recent reports have questioned the necessity of IV antibiotics for such infections. In a randomized controlled trial of 1,054 participants with bone and joint infections, Li et al. demonstrated that six weeks of oral antibiotics were not inferior to IV antibiotics when assessing the rates of treatment failure at one year (8). Ninety-three percent of their population were also treated with surgical intervention and, consistent with our series, Staphylococcus aureus species were the most commonly identified causative organisms (8). Though only one patient was treated with oral antibiotics within our cohort, which limits the conclusions to be drawn from this regimen, oral antibiotics may be an alternative when combined with hardware removal.

As a retrospective case series, our study has inherent limitations. First, deep infection requiring surgery after distal radius ORIF is quite rare, which limits the size of our study and the scope of our findings. Second, while our incidence of deep infection is low, it is possible that patients with deep infection presented elsewhere for treatment and were not represented here. Similarly, although we assessed for infection up to 18 months after surgery, it is possible that deep infection could occur beyond this time frame and would not have been represented in our study. Our series of patients and reported incidence is perhaps most accurately representative of acute infection after surgery, as the initial search parameters did not capture sub-acute or chronic infections presenting after 18 months post-operatively. We suspect the frequency of this occurring would remain quite low. Finally, there may be particular injury characteristics or patient comorbidities that lead to an increased risk of deep infection, but we were not able to identify these in the present study.

In conclusion, deep infection after distal radius ORIF appears to be quite rare. Treatment includes operative debridement and a post-operative antibiotic regimen. Provided that the fracture has healed, hardware can be removed without need for supplemental support. In instances of more acute infection prior to fracture healing, additional stabilization of the fracture is warranted either through spanning fixation or antibiotic impregnated cement when feasible. These infections can be successfully eradicated with such treatment, but functional deficits can remain. Although it is uncommon, surgeons should maintain a high level of vigilance for deep infection in patients who present with wound drainage after surgery or with new-onset swelling and pain.

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References


The Accuracy of 3D Printed Carpal Bones Generated from Cadaveric Specimens

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Abstract

Background: Computer assisted three-dimensional (3D) printing of anatomic models using advanced imaging has wide applications within orthopaedics. The purpose of this study is to evaluate the 3D printing accuracy of carpal bones.

Methods: Seven cadaveric wrists underwent CT scanning, after which select carpal bones (scaphoid, capitate, lunate, and trapezium) were dissected in toto. Dimensions including length, circumference, and volume were measured directly from the cadaver bones. The CT images were converted into 3D printable stereolithography (STL) files. The STL files were converted into solid prints using a commercially available 3D printer. The 3D printed models’ dimensions were measured and compared to those of the cadaver bones. A paired t-test was performed to determine if a statistically significant difference existed between the mean measurements of the cadavers and 3D printed models. The intraclass correlation coefficients (ICC) between the two groups were calculated to measure the degree of agreement.

Results: On average, the length and circumference of the 3D printed models were within 2.3 mm and 2.2 mm, respectively, of the cadaveric bones. There was a larger discrepancy in the volume measured, which on average was within 0.65 cc (15.9%) of the cadaveric bones. These differences were not statistically significant (P > 0.05). There was strong agreement between all measurements except the capitate’s length and lunate’s volume.

Conclusion: 3D printing can add value to patient care and improve outcomes. This study demonstrates that 3D printing can both accurately and reproducibly fabricate boney models that closely resemble the corresponding cadaveric anatomy.

Level of evidence: V

Keywords: Cadaver, Carpal bones, Computed tomography (CT), Three-dimensional (3D)

Introduction

Three-dimensional (3D) printing is a process which involves fabricating an object based on a computerized model, a concept which was first introduced in the 1980s and since has become one of the most efficient methods for fabricating custom-designed products for various uses. These models can be generated de novo using computerized aided design (CAD) software. More recently, data sources from advanced medical imaging techniques such as computed tomography (CT) and magnetic resonance imaging (MRI), have gained popularity. The radiological scan, which is most often generated in a Digital Imaging and Communications in Medicine (DICOM) file format, can be processed and converted into a Standard Tessellation Language (STL) file which is recognized by 3D printers (1).

Computer assisted 3D printing of anatomical models using advanced imaging has wide applications in the medical field and specifically within orthopaedics (2). These anatomical models can be printed on-demand
based on a medical image, thus becoming increasingly popular for their use in medical education, pre-surgical planning and surgical training, and the creation of patient-specific guides, implants, and prosthetics. An anatomical 3D printed model can aid in pre-surgical planning by allowing the surgeon to visualize tissue anatomy, simulate the surgical process, select and manipulate surgical equipment, and demonstrate these techniques to patients preoperatively affording them a better understanding of their pathology (3).

George et al describe the inaccuracies that occur during each step of the 3D printing process: imaging, segmentation, STL generation, STL post-processing, 3D printing, and cleaning/preparation of the anatomic model (4). A major contributor to this inaccuracy is the difference in attenuation thresholds of the imaged bone and adjacent soft tissue structures during segmentation, which leads to imprecise bone dimensions (4). An inaccurate 3D printed model of a patient’s anatomy can potentially result in an inappropriate treatment plan leading to negative consequences for the patient and clinician (4). Previous work by Ogden et al and Wu et al has sought to determine the dimensional accuracy of these 3D printed anatomical models compared to that of the cadaveric bones.

The purpose of this study is to investigate how accurate 3D printed anatomical models of select carpal bones are to their corresponding cadaveric specimens. We hypothesize that the 3D printed models will be very accurate and show no statistically significant differences in measured length, circumference, and volume compared to that of the cadaveric bones.

Materials and Methods
A basic science, cadaveric study was performed. Eight adult cadaveric wrists from Science Care were scanned on a 16-slice multi-detector CT unit (Siemens Somatom Emotion, Siemens Medical) using a bone algorithm consisting of: 130 kVp, 200 mAs, and 1 mm slice thickness with no gap or overlap. These source data were used to generate 0.75 mm axial reconstructions at 0.4 mm increments (i.e. 0.35 mm overlap) and 1 mm sagittal and coronal reconstructions, with no overlap or gap, in both bone and soft tissue windows. The imaging protocol described above is consistent with that used in standard clinical practice (7). Cadavers with evidence of bony injury or previous surgical intervention were excluded, leaving seven cadaveric wrists as the basis for this study. After the scans were obtained, each cadaver was dissected and the scaphoid, capitate, lunate, and trapezium were removed, yielding 28 bony specimens for evaluation. Dissection was carefully done to remove as much of the soft tissue as possible on each of the bones, while maintaining the native cartilage. Two authors (JM and CL) performed the dissections. A cadaveric scaphoid after dissection is shown in Figure 1.

Each bone was measured for volume (cc), length (mm), and circumference (mm) by one of three authors (JM, CL, and PB), yielding a total of 84 cadaveric measurements as follows: (a) The volume of each bone was measured using a volume displacement technique. This was done by measuring the displaced water with a 1.00 cc tuberculin syringe after the carpal bone was placed in a glass that was filled with the maximum amount of water, leaving a meniscus at the top. The measurements of water displacement were performed immediately, not allowing the bone to absorb water and affect the volume measurement; (b) The length of each bone was considered its longest dimension and was measured using a digital caliper. The length of the scaphoid bone was considered the distance from the tip of the proximal pole to the tip of the distal pole. The length of the capitate was considered its length from the 3rd metacarpal articulation to the lunate articulation (distal pole to proximal pole). The length of the lunate was considered the distance spanning the capitate articulation in the sagittal plane. The length of the trapezium was considered its length from the 2nd metacarpal articulation to the tip of the ridge adjacent to the groove for the flexor carpi radialis tendon; (c) The circumference of each bone was measured by wrapping a silk suture around specific portions of each carpal bone. The circumference of the scaphoid was measured around the midportion of its waist. The circumference of the capitate was measured around the midportion of its body in the axial plane. The circumference of the lunate was measured around its capitate articulation and its radius articulation. The circumference of the trapezium was measured around its trapezoid articulation and its 1st metacarpal articulation. Figure 2 is an illustration of each carpal bone and a representation of where the length (points A to B) and circumference (continuous X’s) were measured.
The process of converting CT images into 3D printed anatomical models is described as follows. The DICOM data from each CT scan was processed and manually converted into a STL file with segmentation, threshold editing, island isolation, and smoothing. 3D Slicer (www.slicer.org), a medical informatics, open source software platform was used for the processing of the DICOM data. The resulting STL file for each carpal bone was then edited and prepared for 3D printing using Meshmixer (www.meshmixer.com) and Netfabb (www.autodesk.com/netfabb), open source modeling software. No modification (e.g. smoothing) was performed as this would have altered the dimensions. The 3D modeled individual carpal bones were then printed using a commercially available, fused deposition modeling (FDM) 3D printer (www.ultimaker.com) with a layer resolution of 20-200 microns and an XYZ accuracy of 12.5/12.5/2.5 microns. The 3D printer uses a 3.0 mm diameter, 0.75 kg weight spool of polylactic acid (PLA) filament. The filament cost approximately $0.10-0.20 per 3D print. The CT data acquisition, the reconstruction software, and the 3D printer were all either used commonly in clinical practice, free ware, or commercially available, therefore, our methodology can be replicated in any clinical setting. Figure 3 displays a cadaveric scaphoid compared to its 3D printed anatomical model. Each of the 28 3D printed models were measured for length, circumference, and volume in the same fashion as the cadaver bones [Figure 2].

In total, 56 specimens (28 cadavers and 28 3D printed models) were evaluated with 3 measurements each, yielding a total of 168 measurements. The dimensions of the cadaver bones were compared to those of their corresponding 3D printed models in order to evaluate the accuracy of the conversion and printing process. The absolute difference in measurements was calculated and a percent error (% error) between these measurements was calculated using the formula: % error = [(|cadaver-3D|)/3D]x100. A paired t-test was performed to determine if a statistically significant difference existed between the mean measurements of the cadavers and 3D printed models. A p-value of less than 0.05 was considered statistically significant. The intraclass correlation coefficients (ICC) between the two groups were calculated to measure the degree of agreement. A power analysis was performed and in order to reach power of 80%, a total of 160 cadaveric wrists (80 per group) would be required.

Results

Table 1 displays the cadaver bones’ and 3D printed models’ mean measurements, standard deviations, absolute differences, and percent error. The absolute difference between the cadavers’ and 3D printed models’ measurement was calculated. This value was then divided by the 3D printed model’s measurement and multiplied by 100 to determine the percent error between the cadaver’s and 3D printed model’s measurement. The percent error is one way to quantify the discrepancy between measurements. On average, the cadaver capitates were 0.50 cc larger in volume than their corresponding 3D printed models, and the cadaver trapeziums were 2.5 mm longer than their corresponding 3D printed models. Otherwise, all 3D printed models’ measurements on average were larger than their corresponding cadaver measurements. The average length and circumference of the 3D printed bones were within 2.3 mm and 2.2 mm, respectively, of the cadaveric bone dimensions. The average volume of the 3D printed bones was within 0.65 cc of the cadaveric bones, which was a larger discrepancy compared to length and circumference, corresponding to an error of
The accuracy of 3D printed carpal bones generated from cadaveric specimens

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15.9%. The P-value displayed in Table 1 is the result of the paired t-test performed to determine if a statistically significant difference existed between the means of cadaver and 3D printed model measurements. None of these mean values were significantly different (P>0.05). All measurements except for the capitate’s length and lunate’s volume demonstrate strong agreement between the two groups represented by high ICC values shown in Table 2.

Discussion
Currently in the field of orthopaedics, the use of 3D printing technology is gaining much popularity; however, the knowledge is limited, the learning curve is steep, and the cost is high, all of which have prevented its multitude of applications from becoming commonplace.
in clinical practice (8). Operative complications in the majority of complex orthopaedic cases are due to prolonged operative and anesthesia time, excessive intraoperative bleeding, and the administration of high dose medications, some of which can be attributed to inadequate and imprecise pre-operative planning (9). Increasing evidence has shown that the use of 3D printed models for surgical planning has led to an increase surgical success rate, decreased operative time, and enhanced physician-patient communication (10,11). 3D printing could add tremendous value to patient care and improve outcomes. For this reason, 3D printing should be accurate, reproducible, and efficient; therefore, studies are needed to confirm the reliability of 3D printing in order to justify its everyday use in clinical practice.

In the present study, we compared dimensions (length, circumference, and volume) of select cadaver carpal bones (scaphoid, capitate, lunate, and trapezius) to their corresponding 3D printed models that were based on CT scans of the cadaveric wrists. Our results indicate that there is no statistically significant difference between measurements of the cadaver bones and those of their paired 3D printed models, suggesting that 3D printing based on STL files generated from CT scans is accurate. It was unanticipated that nearly all the 3D printed models' measurements were larger on average than their corresponding carpal bones’ measurements. Soft tissue and cartilage are poorly visualized and differentiated from one another on CT imaging. In contrast, CT is highly effective in delineating boney structures. Therefore, since the models were printed based on CT scans, one can imagine that a 3D printed model is itself a purely boney representation of the cadaver bone stripped of its surrounding connective tissue such as cartilage, ligament, and tendon. If this were true, measurements of length, circumference, and volume on average would likely be smaller in the 3D printed models given that the cadaver specimens had remaining soft tissue attachments despite the authors’ best effort to skeletonize the bone during cadaveric dissection in toto.

There are only a few articles on biomedical 3D printing that describe the accuracy and/or reproducibility, which are key elements that must be addressed by both the researchers and practicing radiologists who play a large role in producing 3D printed models for patient care. There is the potential for error in each step of the 3D printing process, which includes imaging, segmentation, STL generation, STL postprocessing, 3D printing, and cleaning/preparation of the anatomic model (4). Huotilainen et al aimed to demonstrate the imprecision of the DICOM to STL conversion step (12). In their study, three different institutions converted an identical DICOM data set of a single patient’s skull into an STL file using their preferred software, none of which were the same. Using the same 3D printer, these STL files were subsequently used to fabricate 3 individual medical skull models. The three fabricated skulls were scanned and differences in the model geometries were evaluated utilizing CAD inspection software. The authors concluded that medical models of the same individual can vary greatly depending on the DICOM to STL conversion software and technical parameters used. The cumulative errors that occur during each step of the workflow protocol are often overlooked due to an overreliance on the underlying technologies. As the use of 3D printing becomes more widespread, radiologists will need to validate their techniques by using standardized accuracy and reproducibility metrics, and all those involved in clinical 3D printing will have to abide by reporting guidelines.

Specific to hand surgery, Schweizer et al evaluated the accuracy of reductions of surgically reconstructed scaphoid nonunions or fractures using patient-specific 3D printed reduction guides compared to a freehand technique (13). Preoperatively, 3D surface models of the injured and uninjured scaphoid were generated from CT scans. The uninjured scaphoid served as a reconstruction template and ‘mirror-model’. Postoperatively, a 3D surface model of the healed scaphoid was generated from a CT scan obtained at fracture union. Translational differences in the flexion-extension, ulnar-radial, and pronation-supination planes between the superimposed ‘mirror-model’ and postoperative healed 3D surface model were recorded. When comparing the average residual displacement between scaphoids in the reduction guide group and the freehand group, there was a statistically significant difference of 7° versus 26°, respectively. The authors concluded that although the scaphoid is small, custom 3D printed reduction guides lead to a significantly more anatomic reconstruction compared to that resulting from a freehand technique (13).

There were several limitations to our study. First, two authors performed the cadaveric wrist dissection, which was operator dependent without an exact technique followed. Because of this, varying amounts of soft tissue remained on the cadaver bones with the potential to skew measurements. In contrast, the 3D printed models represented a purely boney structure without soft tissue or cartilage given the different signal densities of these tissues on CT scan. Second, the aforementioned protocol used to measure length and circumference is imperfect due to the normal anatomical variation that existed amongst the seven cadaveric wrists. The measurement of each cadaver bone and model was performed in an operator dependent fashion by multiple authors. Previous work by Heinzelmann et al established morphometric data for the scaphoid by defining its length and width measured from the proximal pole to the distal articular surface and around the waist, respectively (14). Similarly, Vaezi et al evaluated normal radiographic indexes of the wrist including capitate length, which was defined as the distance from its distal pole to proximal pole on an AP x-ray of the wrist (15). These established anatomic dimensions of the scaphoid and capitate correspond to those utilized in our study; however, there remains a paucity of data on the accepted length and circumference of the trapezium and lunate to guide our determination of these dimensions. It is questionable...
if the length and circumference were measured in the exact location for both the cadaver bone and 3D printed model. Markers on the carpal bones to indicate locations for measuring circumference and length were deemed unnecessary as these placed by one observer would have biased the second observer. Only one set of data points for each measurement exists, and therefore, actual kappa coefficients cannot be calculated. Our methodology utilizing multiple authors to repeatedly measure the same specimen serves as a proxy to inter- and intra-rater reliability. Third, though not statistically significant, the 15.9% difference in average volume between cadaver and 3D printed models is likely clinically significant, especially when creating custom implants for carpal bone fixation using 3D printed models as a template. The difference in average volume can be attributed to the inconsistency of the measuring technique and our study’s limited sample size (n=7). The volume displacement technique utilized allows for a great deal of inconsistency, specifically in the amount of fluid that is drawn up with the tuberculin syringe. It is very likely that not all of the displaced fluid was measured with some being left at the glass-bowl interface. Future studies should work to increase the sample size, which in theory would decrease the standard deviation and lessen the effects of human error on the difference in measurements between cadaver bones and 3D printed models. Lastly, 3D Slicer was used because it is ubiquitous and free, but this technology has not been validated.

Within the field of Orthopaedics, 3D printing gives way patient-specific instrumentation, which is not only useful, but also cost effective (16). Despite this, inaccurate 3D printed models can potentially result in inappropriate preoperative planning, ultimately leading to complications for the patient and clinician (4). This study demonstrates that the process of 3D printing can both accurately and reproducibly fabricate boney models that closely resemble the corresponding cadaveric anatomy.

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Convenience is Key for Patient Engagement with Remote Video Visits in a Musculoskeletal Practice

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Abstract

Background: Remote video visits (aka telemedicine, virtual care) have the potential to increase access to orthopaedic specialty evaluation while decreasing the overall cost of care. Clinical implementation of remote video visits may benefit from an understanding of potential barriers to participation.

Methods: We enrolled one hundred and thirty participants from a university-based musculoskeletal clinic with a large uninsured population. We asked participants to complete a survey, including demographics and scaled perception questions about remote video visits. Data from these surveys were analyzed with multivariable logistic regression to determine factors associated with willingness to participate in video visits, as well as the situations in which patients would consider a video visit.

Results: Willingness to participate in video visits was associated with the perception of video visits being more convenient (OR 3.0) and a decreased perceived importance of physical exam (OR 0.36) but not age, technology comfort, or travel distance to the clinic. Additionally, those with prior video visit experience were more comfortable with technology, perceived video visits to be more convenient, and were more willing to have another video visit. Fifteen percent were willing to have a video visit for their first visit, while 78% would participate for a routine non-surgical follow-up.

Conclusion: Musculoskeletal telemedicine programs can become established by focusing on people that prioritize convenience, place less importance on a hands-on exam, and are established patients.

Level of evidence: II

Keywords: Musculoskeletal care, Telemedicine, Virtual, Willingness

Introduction

Rural patients and those living in low-income parts of the city may face long or taxing (e.g., several busses) travel to get to a specialist. For rural patients, merely finding a specialist is challenging, as of 2010, there were 263 specialists per 100,000 population in urban counties while only 30 specialists per 100,000 in the most rural counties (1). Nevertheless, this increased density of specialists does not guarantee access for urban residents. Low-income patients face challenges such as unavailable or unaffordable childcare, difficult public transportation, inconvenient clinic hours, and work insecurity, which often lead to inappropriate use of the emergency departments for care that could otherwise be performed in an office setting (2). Remote video visits leverage the power of our telecommunication technologies to provide synchronous care to patients while simultaneously removing many of the barriers to in-person visits. Aware of these advantages, companies like Amazon (Seattle, WA, USA) and Walmart (Bentonville, AR, USA) have begun to offer video visits to their employees as an...
additional benefit (3, 4). Policymakers and payers alike have also created initiatives to increase the use of video visits. With outbreak of COVID 19, changes in federal law have made video visits more accessible for Medicare patients through the removal of requirements that an in-person visit must occur before a virtual encounter and the removal of stipulations that patients must be located in a rural area. Commercial payers have followed suit by offering zero-dollar copays for telehealth visits.

Though these regulatory changes are in response to an unprecedented public health emergency, it is feasible that many will continue after the crisis.

In 2015, a group in Rochester, New York, expanded access to primary care through the use of remote video visits. Based on post-visit surveys of this pilot program, 93% of patients reported that the video visit was an alternative to an after-hours clinic, and 86% reported that it was an alternative to the emergency room (5). The survey reported time savings of six or more hours, and reduced time off work by three to four hours. Respondents reported that a video visit was more convenient, decreased their travel time, and provided a quick assessment of their concerns.

In addition to increased access, studies have demonstrated video visits to be comparable to in-person encounters for the provider’s ability to determine the correct diagnosis and make decisions regarding imaging studies or lab tests (6-8). In 2014, a cohort study used a video conferencing system to evaluate 34 patients after total joint arthroplasty in addition to their routine in-person visits and compared their experience to a group of 44 patients who only participated in routine in-person visits. Results showed fewer unscheduled visits, fewer phone calls, and better satisfaction in the video call group than in those that only had in-person visits (9). Nevertheless, there is little utilization of this technology amongst surgical specialists and their patients. Though 96% of orthopaedists’ believe that video visits can aid in care, only 11% endorse using any virtual care modality (10, 11). Challenges in scheduling, concerns over reimbursement and apprehension over patient engagement, top the list of barriers to using video visits.

One concern that may limit the adoption of remote video visits for musculoskeletal care is that patients and clinicians might expect that an adequate physical examination must be done in person. In a prior qualitative study, patients who had participated in a video visit for primary care preferred an in-person encounter if they thought a physical exam might affect decision making (12). Traditional “hands-on” specialists, such as orthopaedic surgeons, may fear that patients will doubt the validity of medical advice given without an in-person exam. Orthopaedic surgeons surveyed about obstacles to remote video visits listed a lack of physical contact with patients and unsatisfactory patient relationships as the most significant limitations (13). This study aimed to address such concerns through a direct patient survey. We characterized patient perceptions of the use of video visits in the setting of a musculoskeletal clinic to yield insights into the willingness of patients to participate. Finally, we identified the characteristics of patients who are more likely to utilize a video visit platform.

The present study poses three questions: 1. what is the impact of a patient’s perception of remote video visits on willingness to participate in video visits? 2. What demographic characteristics (i.e. age, gender, race, distance from clinic, difficulty with travel, device ownership, prior knowledge, and prior experience with remote video visits) are associated with willingness to participate in video visits? 3. For what encounter types are patients willing to use remote video visits?

Materials and Methods

Study Design

Participants were recruited for this prospective cross-sectional survey from new and return patients visiting a university-based musculoskeletal specialty clinic, including an Arthroplasty, Orthopaedic Sports Medicine, and a back and neck pain clinic. All English-speaking individuals 18 years and older were eligible for inclusion in the study from October to December 2019. We invited patients meeting the inclusion criteria to participate. Patients who had previously been enrolled were excluded. The Institutional Review Board approved this project.

Participants were first provided with a description of remote video visits and then given a survey with questions about demographics (age, race, gender, home zip code), ownership of a device capable of making a video call, prior experience with video visits, and difficulty with travel to the clinic. The survey also contained six statements about video visits asking them to state their level of agreement/disagreement using the Likert scale (strongly agree, agree, neutral, disagree, strongly disagree). Neutral participants and those who agreed or strongly agreed with the statement “I would be willing to receive some of my musculoskeletal care through video visits” were then allowed to select which situations they would be willing to utilize video visits. Surveys were delivered on an iPad or administered orally if the participant preferred. All survey questions required an answer, so there was no missing data.

Study Population

The 130 subjects included 73 (56%) women and 57 (44%) men with a median age of 49 with an interquartile range [IQR] 38-59 years [Table 1]. Ninety percent of our survey population endorsed having a device capable of making a video call. Sixty-three percent had prior knowledge of video visits, and 14% had participated in one before. 75% of our study population would be willing to have a virtual visit, while 25% would not. Our study population was slightly older than the US population and similar in its racial diversity with 62% identifying as Non-Hispanic Caucasian (vs. 60% in the US population), 21% identify as Hispanic (18%), and 11% as black (12%), and lived a median distance of 7.6 miles away from the clinic (14).

Statistical analysis

An a priori power calculation determined that a sample size of 130 patients was needed to answer our primary study question with 80% statistical power (with alpha =
## Results

**Impact of perception on willingness to participate in video visits**

The multivariable analysis demonstrated that participants who thought of video visits as more convenient than in-person visits were more likely to participate in video visits (odds ratio [OR] 3.0, 95% confidence interval [CI] 1.4-6.6). Those that thought a hands-on exam was important were less likely to participate in remote video visits (OR 0.36, 95% CI 0.13-1.0) [Table 2]. Although 46% of people in our study strongly agreed with the statement, "I feel comfortable with using technology," only 27% strongly agreed that a video visit is more convenient than an in-person visit. Additionally, Age and distance from the clinic were not significant predictors of willingness to participate in video visits.

**Association between prior experience and perceptions of video visits**

There were notable differences between those with previous video visit experience and those without on bivariate analysis [Figure 1]. Those with prior experience were more comfortable with technology, perceived video visits to be more convenient and were more willing to have another video visit (p=0.030, 0.011, and 0.044 respectively) [Figure 1].

**Encounter type and willingness to use remote video visits**

Seventy-eight percent of participants were neutral or agreed with the statement, "I would be willing to receive some of my musculoskeletal care through video visits" and were allowed to select the situations in which they would be willing to utilize video visits. These results showed that participants had specific preferences for

### Table 1. Patient characteristics

<table>
<thead>
<tr>
<th>Variables</th>
<th>N = 130</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age in years</td>
<td>49 (38-59)</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
</tr>
<tr>
<td>Men</td>
<td>57 (44)</td>
</tr>
<tr>
<td>Women</td>
<td>73 (56)</td>
</tr>
<tr>
<td>Race/Ethnicity</td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>81 (62)</td>
</tr>
<tr>
<td>Non-White</td>
<td>49 (38)</td>
</tr>
<tr>
<td>Distance from Clinic in miles</td>
<td>7.6 (3.7-13)</td>
</tr>
<tr>
<td>Device Ownership</td>
<td>117 (90)</td>
</tr>
<tr>
<td>Prior Knowledge</td>
<td>82 (63)</td>
</tr>
<tr>
<td>Prior Experience</td>
<td>19 (14)</td>
</tr>
<tr>
<td>Willingness to Participate in Video Visits</td>
<td>98 (75)</td>
</tr>
</tbody>
</table>

Continuous variables as median (interquartile range); discrete variables as number (percentage).

### Table 2. Multivariable Logistic Regression Model of factors associated with willingness to participate in a virtual visit

<table>
<thead>
<tr>
<th>Variables</th>
<th>Odds Ratio</th>
<th>95% Confidence Interval</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior Knowledge</td>
<td>1.6</td>
<td>0.45-6.0</td>
<td>0.45</td>
</tr>
<tr>
<td>Prior Experience</td>
<td>3.1</td>
<td>0.23-42</td>
<td>0.40</td>
</tr>
<tr>
<td>Race (White)</td>
<td>2.6</td>
<td>0.70-9.4</td>
<td>0.152</td>
</tr>
<tr>
<td>Ownership of device capable of making a video call</td>
<td>2.2</td>
<td>0.28-16</td>
<td>0.46</td>
</tr>
<tr>
<td>Difficulty with Travel</td>
<td>1.8</td>
<td>0.90-3.6</td>
<td>0.10</td>
</tr>
<tr>
<td>Comfort with Technology</td>
<td>1.9</td>
<td>0.80-4.3</td>
<td>0.14</td>
</tr>
<tr>
<td>Provider understanding in virtual visit</td>
<td>1.7</td>
<td>0.79-3.8</td>
<td>0.17</td>
</tr>
<tr>
<td>Quality of care in virtual visit</td>
<td>2.1</td>
<td>0.98-4.72</td>
<td>0.056</td>
</tr>
<tr>
<td>Importance of physical exam</td>
<td>0.36</td>
<td>0.13-1.0</td>
<td>0.049</td>
</tr>
<tr>
<td>Convenience of a virtual visit</td>
<td>3.0</td>
<td>1.4-6.6</td>
<td>0.005</td>
</tr>
</tbody>
</table>

Bold indicates statistically significant difference.
the types of encounters they would be willing to have via video visit [Table 3]. Seventy-eight percent indicated their willingness to participate for routine, non-surgical follow-ups, while 15% indicated that they would be willing to have their first visit with a clinician done over a video call. We also found that patients have specific preferences on how to schedule video visits. We presented survey participants with the options of a traditional appointment time in which they would be given a specific time to be called (i.e., 8 am) and a time window where they would receive a call during a four-hour time window (i.e., 8 am-12 pm). Seventy-eight percent of participants indicated that they would participate if their video visits were scheduled with traditional appointment times, compared to 41% if the appointment for time window appointments.

Discussion

While many published studies are showing that the utilization of remote video visits reduces the overall cost of orthopaedic and specialty care, few have explored the perceptions of patients and possible barriers to use (15-17). We gathered data to inform efforts to increase the utilization of remote video visits in musculoskeletal care.

This study has limitations. First, as a cross-sectional study of hypothetical willingness to participate in video visits, our conclusions may not reflect real-world choices. Secondly, to avoid survey fatigue, some potentially relevant demographic factors were omitted, such as education, insurance status, and income level. Additionally, a Spanish version of the survey was not created leading to a potential under sampling of our Hispanic population, however 21% of survey participants identified as Hispanic potentially limiting the effect of this limitation. We think these factors had a limited influence on the findings given the diversity of the sample population. Our results apply best to an urban university-based office setting with about 60% uninsured or underinsured patients, which may have distinct biases and more significant social barriers compared to other demographics. Additionally, this study was conducted before rapid changes related to COVID 19 pulled telehealth to the forefront of care in the U.S. It is unknown whether acceptance of video encounters may have shifted in response to a greater reliance on telecommunications platforms for other areas of daily life.

The observation that willingness to try a remote video visit was associated with perceived convenience of video
visits, and a decreased perceived importance of the physical exam points to characteristics of early adopter patients than can help a musculoskeletal telemedicine program become established. These findings are what one might expect, although the lack of association between willingness to try a video visit and age and distance of travel suggests the "convenience" of a video encounter cannot be anticipated with these factors. Furthermore, the lack of an association between interest in remote video visits and technology comfort demonstrates the value of measuring the most influential factors. The low percentage of people willing to have their initial visit via video suggests a general mistrust of the diagnostic capability of video visits and the ability to build the physician/patient relationship over a virtual platform which does not seem warranted based on several studies showing comparable quality (6-8).

The finding that previous experience with video visits increased engagement with future remote video visits likely reflects that the misconceptions and hesitations patients may have about remote video visits are often alleviated after participating in a video visit. This experience was also identified in video visit studies in family medicine and rheumatology (12, 18). During the COVID 19 pandemic, the medical field has rapidly expanded video visit capabilities and society as a whole has had to adapt to a greater reliance on telecommunications technologies in our daily lives. Knowing this, orthopaedic surgeons now have the opportunity to demonstrate the convenience of video visits to their patients and normalize the practice for routine musculoskeletal care moving forward.

The implementation of video visits into a musculoskeletal practice may be more successful among people for whom an in-person appointment is difficult, however traditionally held barriers such as age, travel distance and technology comfort do not correspond with perceived convenience. Openness to remote video visits seems more related to trust that a specialist can give good advice without being in the same room and without a hands-on examination. Offering video visits for return patients may help jump start a telemedicine program and increase patient comfort with video visits, leading to increased utilization for other visit types in the future. Further work is needed to demonstrate the quality of physical exams performed during video encounters and to validate new maneuvers to facilitate those performed remotely. Moving forward, with the increased utilization of telemedicine and virtual care in response to COVID 19, patients are more likely to have been previously exposed to virtual care and therefore may be more willing to participate in these encounters. It behooves our profession to further develop skills and better platforms to facilitate this change on behalf of our patients.

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Development of Porous Photopolymer Resin-SWCNT Produced by Digital Light Processing Technology Using for Bone Femur Application

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Abstract

Background: Although bone tissue has the unique characteristic of self-repair in fractures, bone grafting is needed in some situations. The synthetic substances that are used in such situations should bond to the porous bones, be biocompatible and biodegradable, and do not stimulate the immune responses. Biomaterial engineering is the science of finding and designing novel products. In principle, the most suitable biodegradable matrix should have adequate compressive strength of more than two megapascals. At this degradation rate, the matrix can eventually be replaced by the newly formed bone, and the osteoprogenitor cells migrate into the scaffold. This study aimed to evaluate the fabrication of a scaffold made of polymer-ceramic nanomaterials with controlled porosity resembling that of spongy bone tissue.

Methods: A compound of resin polymer, single-walled carbon nanotube (SWCNT) as reinforcement, and hydroxyapatite (HA) were dissolved using an ultrasonic and magnetic stirrer. A bio-nano-composite scaffold model was designed in the SolidWorks software and built using the digital light processing (DLP) method. Polymer-HA scaffolds with the solvent system were prepared with similar porosity to that of human bones.

Results: HA-polymer scaffolds had a random irregular microstructure with homogenizing porous architecture. The SWCNT improved the mechanical properties of the sample from 25 MPa to 36 MPa besides having a proper porosity value near 55%, which can enhance the transformation and absorption of protein in human bone.

Conclusion: The combined bio-nanocomposite had a suitable porous structure with acceptable strength that allowed it to be used as a bone substitute in orthopedic surgery.

Level of evidence: Therapeutic study

Keywords: 3-D Printing, Biocompatible materials, Carbon nanotubes, Hydroxyapatite, Tissue engineering

Introduction

Bone defects due to fractures, congenital anomalies, osteoporosis, and cancers are major challenges in orthopedic surgeries. With the increasing number of old population and the increased life expectancy, patients and orthopedic surgeons encounter an increased demand for artificial biomaterials to repair the large bone defects during the surgery (1-2). The biodegradable materials fabricated with engineering techniques are made of natural polymers and ceramics, which can be a bone substitute in bone defects and act as a suitable artificial tissue (3-4). Bone and tissue engineering aim to investigate methods of fabricating new products, reduce side effects, and increase the efficacy of the fabricated products (4-6). In recent years, bioengineers are preparing and determining the best artificial composition with proper mechanical and biological characteristics for orthopedic surgeries in large bone defects (1-6). The polymeric-ceramic bionanocomposite is one of these new synthetic tissues with similar architecture to that of the real spongy bones (5-6). The application of different porous scaffolds with biocompatible and biodegradable materials that can accelerate the repairing process in
the bone without any side effects to the adjacent tissues is still a matter of debate among bioengineers (3-4). Hydroxyapatite (HA) is the most important ingredient in bone tissue and a calcium phosphates (CaPs) biochemical agent with low mechanical performance including low fracture toughness and compressive strength. Varieties of research have been done on this material investigating the repairing process of bones using this substance (5-8). The HA powders are easy to transfer from implanted places; however, molding of HA is troublesome due to its hardness and brittleness. Therefore, scientists are trying to compensate and improve the poor mechanical properties of HA using new composites made of organic polymers (8-12).

Research has shown that single-walled carbon nanotube (SWCNT) can have an inductive effect on osteoblasts in the fracture site as a part of bioceramic composites other than its biodegradation capacity (13-16). These nanotubes have high thermal, electrical, and strength properties, which make them a promising candidate for increasing the mechanical properties of HA (12). Three-dimensional (3D) printers, space holders, freeze-drying, and hot and cold isostatic press method are different ways to make scaffold-shaped polymer nanocomposites (17-19). 3D printers can create complex porous specimens with high porosity to be used in spongy bone fractures (11). However, the feasibility and mechanical properties of 3D-printed porous-ceramic nanocomposites based on photopolymer resins for orthopedic applications have not been investigated up to date. This study investigated the mechanical strength of 3D-printed HA and the SWCNT bio-nanocomposite scaffold.

**Materials and Methods**

**Fabrication of a hydroxyapatite-carbon nanotube bio-nanocomposite**

Initially, 20 milliliters (ml) of ethanol was mixed with 20 ml of the dental photopolymer resin (Dental resin, DITAX Company with 360-410 nanometer (nm) wavelength and ultraviolet (UV) curing) to make a porous scaffold which was then placed on the magnetic stirrer for 45 minutes (min). Afterward, 0.5 gram (g) of nano-HA powder (Merck, Germany, 40-80 nm, 98% purity) was added to the composite solution and placed on a magnetic stirrer for 60 min with an ultrasonic bath at a temperature of 135°C. The combination of the composite solution and HA with dental resin was prepared. Subsequently, 0 weight-percentage (wt%), 1 wt%, and 2 wt% of SWCNT was added to the HA-photopolymer solution and mixed with the magnetic stirrer at room temperature for 2 hours at 250 revolutions per minute (rpm) and a temperature of 135°C. Subsequently, 0.2 ml triethanolamine (TEA) was added to the mixed solution to create more surface tension, disperse the composite nanoparticles on the solution, and prevent agglomeration. The prepared nanocomposite containing 0 wt%, 1 wt%, and 2 wt% SWCNT solutions were inserted in the digital light processing (DLP) machine to print the porous architecture [Figure1]. The inter-structural distances in a scaffold model were set at 0.5 square millimeters (mm²). The models were designed with a cylindrical shape to mimic the real human bone. The above design was done by SolidWorks software and saved as an STL file to be sent into the DLP printer software (creation Workshop) as shown in Figure 1. The drying time was 10 seconds per layer using UV light in which the height of each layer was set at 0.02 mm.

**Characterization of the bio-nano composite scaffold**

The phase analysis and chemical element analysis were performed on the three samples using x-ray diffraction (XRD) and X-ray fluorescence (XRF), respectively. The XRD device is mainly used to estimate the size of crystals in crystalline structures, along with its many other applications. The XRF is used to decompose superficial layers of the porous scaffold. This technique can be used to perform elemental analysis in qualitative and semi-quantitative formulas, especially in the case of mineral samples. The porous scaffold morphology was investigated using XL30 and Scanning Electron Microscope (SEM) tools in Amirkabir University of Technology, Tehran, Iran. Different magnification was applied to investigate the morphology of porous bone architecture. To prepare the nanocomposite scaffolds for cell culture assay, the HA combined with SWCNT and dental resin were sterilized and washed using 70% ethanol. Afterward, the samples dried in a clean room with ambient temperature. The fibroblast (HuGu) cells were cultured from human gums in a culture medium containing DMEM and cow serum within six polystyrene cavities. The adherent cells were washed away using PBS solution after seven days. The cells were grown and cultured under controlled conditions (95% air, 5% carbon dioxide) at 37°C and the culture medium was changed once every two days. In the next step, 10,000 cells were cultured from human gums in a culture medium containing DMEM and cow serum within six polystyrene cavities. The adherent cells were washed away using PBS solution after seven days. The cells were grown and cultured under controlled conditions (95% air, 5% carbon dioxide) at 37°C and the culture medium was changed once every two days. In the next step, 10,000 cells were cultured in the plate. The porous scaffold made in DMEM solution containing 15% FBS was incubated for seven days. A positive response to cellular toxicity indicated a
lack of biocompatibility, while a negative response (non-toxicity) does not necessarily represent a biocompatible property.

**Mechanical investigation of the 3D-printed scaffold**

The compressive strength (CS) test was used for the porous HA-SWCNT composite samples using SANTAM-STM50 with a load cell of 10-20 kilonewtons (KN) following ASTM-D5024-95a standard. The dimensions of each specimen were 10×10×10 cubic millimeters (mm³) with a speed of 0.5 meters per min. The elastic modulus was calculated from the slope of the stress-strain curve, which was considered as the amount of compressive strength under the compression test. Samples were tested three times to ensure the accuracy and precision of the obtained data. All the fabrications were done based on try and error and five times repetition. The porosity of the scaffolds was measured following Archimedes’ principle using Image-J software. Porosity measurements provide information on the size and distribution of pores, permeability, and the presence of structural imperfections in spherical ceramic structures. In this method, due to the hydrophobic nature of the polymer, ethanol was used to penetrate easily into fine porosities. The amount and the volume (Vₚ) of ethanol in the cylinder were measured respectively. The sample was then put in ethanol for five minutes to be completely saturated. The volume measured after saturation is shown by Vₑ. The difference between the two volumes (Vₑ - Vₚ) represents the size of the scaffold. The ethanol-impregnated scaffold was removed from the cylinder and the residual volume is shown by Vᵣ. The amount of Vₑ - Vᵣ is known as the volume of ethanol absorbed by the scaffold. Therefore, the final volume of the scaffold is calculated based on Equation 1 below:

\[ V = [(Vₑ - Vᵣ) + (Vₑ - Vₚ)] / (Vₑ - Vₚ) \]  

(1)

**Micromechanical model of the porous bony scaffold**

According to the mechanical results, several conventional models were developed on the porous scaffolds to repair damaged bone with new hard composite tissue made of the DLP technique. However, the acquisition of mechanical properties of such porous scaffolds using laboratory methods is very time-consuming and costly. Many researchers have focused their studies on mathematical methods, such as elastic modulus and porosity ratio to predict the mechanical properties and most of the previous models were based on the finite element method (FEM). In this paper, various micromechanical methods have been introduced to obtain the effect of porosity on the elastic modulus of bone scaffolds. Single-scale ceramic scaffold modeling and multi-scale composite scaffold modeling were performed using Abaqus software. The mechanical properties of HA in different porosities were presented in the current study due to the widespread use of HA in bone scaffolds. The conventional micromechanical model was used to evaluate the elastic modulus of porous (Ep) and elastic modulus of solid (Es) versus porosity of the bone using Dewey models, as indicated by Equation 2 and 3.

\[ E_p = 1 - \xi \phi \]  

(2)

\[ \xi = \frac{(1 - \nu_s)(27 + 15\nu_s)}{(2(7 - 5\nu_s))} \]  

(3)

**Results**

Figure 2 demonstrates the XRD spectra of HA, SWCNT, and the composition of HA-SWCNT from 20° to 80°. Based on the observations, the obtained porous scaffold was made of a single-phase HA, and no additional sustained phase was detected. The main peaks of XRD for HA powder on plane “211”, “112”, “300”, and “202” were similar to the natural bone, indicating its medical usefulness. The agglomeration of SWCNT in the photopolymer resin matrix leads to a different mechanical performance proven by micromechanical modeling. The XRD pattern showed that the HA powder had a purity of 96% and its mineral impurities included Na₂O (1 wt%) and MgO (1 wt%). Some researchers have evaluated the mechanical features of a similar composite from 20 to 60 MPa (19-33). The XRD pattern showed that the intensity of composite powder was between the intensity of the single-crystal HA and the SWCNT powders. The HA-SWCNT was synthesized at 30-40° with an intensity of 300-400 rpm.

The SEM images of the fabricated scaffolds are shown in Figure-3 (a-c). The status of a porous scaffold plays an important role in cell functions. Based on the obtained results, the porosities of these scaffolds are in the range of 100-300 micrometers that could improve cell proliferation and extracellular matrix (ECM) by stem cells of bone marrow (BMSCs). Figure 3 (d) indicates the properties of cultured cells in the samples that contained 0 wt%, 1 wt%, and 2 wt% SWCNT in the bio-resin-HA matrix after seven days. The obtained results suggested...
that the 1wt% SWCNT sample had good biocompatible behavior compared to other samples.

As indicated by Figure 4, the CS evaluation revealed that adding 1 wt% SWCNT increased the CS by more than 30%. The CS diagram increased slowly by nearly 36 MPa after adding 2 wt% SWCNT. The CS analysis indicated that the elastic modulus of the SWCNT is higher than that of HA bioceramic which affects the mechanical properties of the matrix. The obtained CS was measured at 25, 33, and 36 MPa for a sample containing 0, 1, and 2 wt% SWCNT, respectively. In this study, the porosity did not change extensively regarding the accuracy of the DLP technique, which was near 100-150 micron for the cell growth and improvement of growth factors. The porosity of the sample increased from 55 to 61% after SWCNT was increased up to 2 wt%, as shown in Figure 4(b).

Figure 5 (a-b) compares the rate of elastic modulus of the solid form to the elastic modulus of the porous form (Es/Ep) with the porosity value for bio-nanocomposite containing various amounts of SWCNT. The micromechanical model performed well and the scaffold was tailored to the size of the lesion using the rapid prototyping technique [Figure 5]. Considering the elastic modulus, the obtained porosity rate indicated that a good porous bone was produced and would be bonded with surrounding tissues when its fracture strength reaches 85% of the normal bone. The microhardness might be influenced by the amount of porosity of the pore size and strut size. The results of the XRF analysis on the sample of HA powder are presented in Table 1. These XRF results confirmed the presence of the HA with the SWCNT phase with high purity. It was found that calcium and phosphorus are the main elements of the HA powder. Moreover, impurities in the HA structure included sodium and magnesium ions.

**Discussions**

HA composites can be employed to repair bone defects in bone tissue engineering sciences. The microstructure of this ceramic has weak mechanical properties and low chemical stability that needs to be reinforced and strengthened using such compounds as carbon nanotube, titanium, and zirconium nanoparticles (15-18). It is not possible to make a nanocomposite containing 0, 1, and 2 wt% SWCNT, respectively. In this study, the porosity did not change extensively regarding the accuracy of the DLP technique, which was near 100-150 micron for the cell growth and improvement of growth factors. The porosity of the sample increased from 55 to 61% after SWCNT was increased up to 2 wt%, as shown in Figure 4(b).
containing HA and SWCNT without dispersant since the base and reinforcement nanoparticles deposit rapidly to overcome the bioceramic weight. The use of dispersant prevents this event and leads to proper homogeneity. The addition of different quantities of SWCNT nanoparticles can enhance the basic structure of artificial bone designed by the DLP technique. The addition of SWCNT increases the CS of the specimen by more than two times. Generally, the porosity of the samples in this method was between 55% and 61%, which was notable. The addition of 1 to 2 wt% SWCNT results in optimal porosity and compressive strength. The results of a study conducted by Saber-Samandari et al. showed that bone scaffold had significant mechanical and biological properties (17). They synthesized a porous bone tissue composite with intrusive phases of collagen (polymer) and HA (biochemical). The scaffold fabricated by the DLP technique presented proper mechanical, biocompatibility, and bioactivity properties and showed remodeling capabilities. The HA nanoparticles improved the properties of the scaffold in several ways due to high specific surface area and apatite formation (29-33). In terms of tissue engineering, the reinforced nanocomposite with these bioactive nanoparticles had an increased mechanical performance. In addition, reduction of the particle size to the nanoscale can increase the structural property of these scaffolds given the known biological properties of HA in terms of bone conductivity and bone growth. The results of micromechanical model simulation showed that the designed models had the same average load-bearing in terms of power distribution, which can transfer function uniformly (31-32). However, a porous structure scaffold exhibited greater endurance against the same load in terms of the stresses entailed in the scaffold model, which is a significant positive factor. There are two main reasons for the implementation of this scaffold in the body. One is the higher load tolerance that makes it more efficient and safe. Therefore, the probability of failure is less even with the application of excessive force. Moreover, due to higher porosity and spacing between the scaffold columns, collagen and HA are more scalable in this model than other

<table>
<thead>
<tr>
<th>Elements</th>
<th>(%w/w)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaO</td>
<td>55.2</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>37.5</td>
</tr>
<tr>
<td>Na₂O</td>
<td>1.7</td>
</tr>
<tr>
<td>SO₂</td>
<td>1.6</td>
</tr>
<tr>
<td>MgO</td>
<td>1.4</td>
</tr>
<tr>
<td>SiO₂</td>
<td>1.2</td>
</tr>
<tr>
<td>Cl</td>
<td>0.89</td>
</tr>
<tr>
<td>H₂O</td>
<td>0.83</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>0.65</td>
</tr>
<tr>
<td>SrO</td>
<td>0.60</td>
</tr>
<tr>
<td>K₂O</td>
<td>0.55</td>
</tr>
<tr>
<td>C</td>
<td>0.42-0.8</td>
</tr>
<tr>
<td>CuO</td>
<td>0.40</td>
</tr>
</tbody>
</table>
micromechanical models. Therefore, it is expected that this model can accelerate the bone repair process. The attached cells derived from MSC can be differentiated into the osteoblast embryonic stem cells (OESCs). It should be noted that the internal evaluation of these scaffolds is ongoing in an animal study. The CS diagram indicates that the strength of the polymer composite increases with an increased portion of SWCNT. With the increase of SWCNT, elastic modulus (E) and ultimate tensile strength (UTS) are incremented as a result. In other words, the composites with a higher concentration of SWCNT are more rigid and become less deformed. The fracture models indicate more ductile performance through the stress and strain curves. The CS of ceramic scaffolds depends on the size and geometric shape of the porosity. In the same line, Karbasi et al. added different amounts of CNT to poly-3-hydroxybutyrate (PHB) (19). They obtained proper structural properties for soft and hard tissue applications. Vatankhah et al. produced novel composite scaffolds based on Tecophilic (TP) that proliferated the rate of the smooth muscle cells (SMCs) (20). They accomplished using this tissue for vascular grafts with adequate cell growth. In another study, researchers enhanced the weak mechanical properties of architecture using natural urinary bladder ECM with polycaprolactone (PCL) polymer. The manufacture of geometrically complex nanocomposites containing magnetic nanoparticles (MNPs), which can be used as thermal therapy or hyperthermia against cancerous cells, is one of the prominent features of the DLP method compared to other techniques for the preparation of scaffolds (24-31). This study aimed to demonstrate the capacity of a 3D printing technique, DLP, in the production of HA scaffolds (28-32).

Given the capabilities of the DLP-3D printing technique in the manufacturing of complex bone components, materials such as photopolymer resins, HA, and SWCNT can be used to create models of bone scaffolds. These bony scaffolds with sufficient porosity can accelerate the bone repairing process. The fabricated scaffold can be adopted as a suitable porous structure in orthopedic surgeries. The scaffold presented in this study can repair the small bone defects following orthopedic surgery. In addition, the obtained results indicated that the sample containing 1 wt% SWCNT presents proper mechanical and chemical features compared to other samples.

**Ethics approval:** The scientific and ethical approval of this study was done by the Iran University of Medical Sciences that registered inquiry and funding under the registered number “IR.IUMS.REC.REC.1398.122”.

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12th. Iranian Congress of Medical Physics):328–
The Impact of COVID-19 on Neck of Femur Fracture Care: A Major Trauma Centre Experience, United Kingdom

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Abstract

Background: The aim of this study was to investigate the impact of the COVID-19 pandemic on the management and outcome of patients with neck of femur fractures.

Methods: Data was collected for 96 patients with neck of femur fractures who presented to the emergency department between March 1, 2020 and May 15, 2020. This data set included information about their COVID-19 status. Parameters including inpatient complications, hospital quality measures, mortality rates, and training opportunities were compared between the COVID-19 positive and COVID-19 negative groups. Furthermore, our current cohort of patients were compared against a historical control group of 95 patients who presented with neck of femur fractures before the COVID-19 pandemic.

Results: Seven (7.3%) patients were confirmed COVID positive by RT-PCR testing. The COVID positive cohort, when compared to the COVID negative cohort, had higher rates of postoperative complications (71.4% vs 25.9%), increased length of stay (30.3 days vs 12 days) and quicker time to surgery (0.7 days vs 1.3 days). The 2020 cohort compared to the 2019 cohort, had an increased 30-day mortality rate (13.5% vs 4.2%), increased number of delayed cases (25% vs 11.8%) as well as reduced training opportunities for Orthopaedic trainees to perform the surgery (51.6% vs 22.8%).

Conclusion: COVID-19 has had a profound impact on the care and outcome of neck of femur fracture patients during the pandemic with an increase in 30-day mortality rate. There were profound adverse effects on patient management pathways and outcomes while also affecting training opportunities.

Level of evidence: VI

Keywords: Coronavirus, COVID-19, Hip fracture, Neck of femur fracture, SARS-CoV-2

Introduction

Neck of femur fractures account for 50% of all hip fractures, with the majority of these fractures occurring in elderly patients with underlying osteoporosis (1, 2). With an ageing population, this is a significant concern for health care systems worldwide as hip fractures cause a huge economic and social burden (3). The general principles for neck of femur fracture care include a holistic assessment, prompt medical optimisation and early surgery to provide patients with the best chance of recovery while minimizing the incidence of postoperative complications and mortality (4). The emergence of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2/2019-nCoV disease (COVID-19)) in China at the end of 2019 has caused a large global pandemic, endangering the health and well-being of everyone, especially the elderly (5). At the time of writing, a total of 216 countries and territories have reported cases, with 26.9 million confirmed diagnosis and greater than 880,000 deaths worldwide.
the world have been redeployed to manage the crisis, with human and physical resources diverted to meet the rising critical care demands. Many of the resources usually used to provide orthopaedic care were repurposed, thus limiting the capacity to continue providing urgent orthopaedic care. Despite this reallocation of resources, patients with neck of femur fractures have continued to present to Emergency Departments (ED) and require urgent medical care (8, 9).

Our hospital has restructured its medical operations to tackle the large number of COVID-19 patients that presented in the spring of 2020. Despite this fact, the department’s orthopaedic trauma service has continued to provide care to all patients presenting with the diagnosis of a neck of femur fracture. The purpose of this report is to analyse the perioperative complication rate, mortality rate, impact on training as well as in patient hospitalisation issues associated with neck of femur fracture patients who presented during the global COVID-19 pandemic.

Materials and Methods
A single-centre cross-sectional study was performed where two different time periods were analysed. We analysed a consecutive series of neck of femur fracture patients who presented to our Hospital’s ED between March 1, 2020 to May 15, 2020 (COVID-19 pandemic time) as well as the same time period in 2019 (pre-COVID-19). Inclusion criteria were patients who presented with either an OTA/AO 31A or OTA/AO 31B fracture, whilst patients who had OTA/AO 31C or peri-prosthetic fractures of the femur were excluded. Fracture of the femoral neck was confirmed on physical exam and with standard radiographs of the affected hip. The surgical treatment was decided by the attending orthopaedic surgeon and followed the general standard of care for neck of femur fracture. Patients were identified as COVID positive if they had a positive COVID-19 RT-PCR test prior to, during or after hospitalisation for their neck of femur fracture. In order to assess the COVID-19 pandemic era cohort, we compared them to a second group of 95 neck of femur fracture patients who presented to the same ED before the pandemic in 2019. In terms of patient’s demographics between the two groups, the only significant difference was the higher incidence of pre-existing renal disease in the 2020 cohort compared to the 2019 cohort (22.9% vs 8.4%, P = 0.009). There were also no significant differences in terms of fracture location between the 2 cohorts.

When comparing surgical information and hospital quality measures between the two groups, the 2020 cohort had more cases of delayed surgery (25.0% vs 11.8%, P = 0.023) and a higher 30-day mortality rate (13.5% vs 4.2%, P = 0.039) while having fewer admissions into an orthopaedic specific ward as there was no orthopaedic specific wards due to re-allocation of wards (54.1% vs 100%, P < 0.001). Furthermore, the indirect impact of COVID-19 on training could be seen as there was a reduction in number of operations performed by ST3-ST8 orthopaedic registrars in the 2020 group (22.8% vs 51.6%, P < 0.001), whilst the number of geriatrician assessments performed by specialist registrars increased in the 2020 group (35.4% vs 0.0%, P < 0.001) [Table 1].

COVID-19 positive cohort vs COVID-19 negative cohort
Among the 2020 cohort patients, seven (7.3%) were confirmed COVID positive by testing. Five patients were diagnosed post-operatively after a patient on their
Table 1. 2019 cohort (Pre-pandemic) vs 2020 cohort (COVID-19 pandemic)

<table>
<thead>
<tr>
<th>Patient Demographics</th>
<th>2019 Cohort (n = 95)</th>
<th>2020 Cohort (n = 96)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years) (mean ± SD)</td>
<td>83.6 ± 9.0</td>
<td>84.9 ± 8.3</td>
<td>0.286</td>
</tr>
<tr>
<td>Sex, n (%)</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>25 (26.3%)</td>
<td>26 (27.1%)</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>70 (73.7%)</td>
<td>70 (72.9%)</td>
<td></td>
</tr>
<tr>
<td>Home Status</td>
<td></td>
<td></td>
<td>0.143</td>
</tr>
<tr>
<td>Own Home</td>
<td>81 (85.3%)</td>
<td>73 (76.0%)</td>
<td></td>
</tr>
<tr>
<td>Nursing Home</td>
<td>14 (14.7%)</td>
<td>23 (24.0%)</td>
<td></td>
</tr>
<tr>
<td>Pre-operative AMTS* (mean ± SD)</td>
<td>7.7 ± 3.3</td>
<td>6.6 ± 3.9</td>
<td>0.052</td>
</tr>
<tr>
<td>ASA¹, n (%)</td>
<td>0.375</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>0 (0%)</td>
<td>3 (3.1%)</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>17 (17.9%)</td>
<td>17 (17.7%)</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>60 (63.2%)</td>
<td>60 (62.5%)</td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>18 (18.9%)</td>
<td>16 (16.7%)</td>
<td></td>
</tr>
<tr>
<td>Nerve Block at A&amp;E, n (%)</td>
<td></td>
<td></td>
<td>0.280</td>
</tr>
<tr>
<td>68 (71.6%)</td>
<td>61 (63.5%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bone Protection Pre-fracture, n (%)</td>
<td>14 (14.7%)</td>
<td>10 (10.4%)</td>
<td>0.391</td>
</tr>
<tr>
<td>Bone Protection Post-fracture, n (%)</td>
<td>44 (46.3%)</td>
<td>40 (41.7%)</td>
<td>0.561</td>
</tr>
<tr>
<td>Delirium Assessment (mean ± SD)</td>
<td>1.5 ± 2.7</td>
<td>2.3 ± 3.0</td>
<td>0.084</td>
</tr>
<tr>
<td>Pre-existing Lung Disease, n (%)</td>
<td>0.052</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asthma</td>
<td>11 (11.6%)</td>
<td>6 (6.3%)</td>
<td></td>
</tr>
<tr>
<td>COPD</td>
<td>11 (11.6%)</td>
<td>6 (6.3%)</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>4 (4.2%)</td>
<td>13 (13.5%)</td>
<td></td>
</tr>
<tr>
<td>Pre-existing Cardiovascular Disease, n (%)</td>
<td></td>
<td></td>
<td>0.451</td>
</tr>
<tr>
<td>64 (67.4%)</td>
<td>59 (61.5%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>History of Malignancy, n (%)</td>
<td>0.271</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25 (26.3%)</td>
<td>33 (34.4%)</td>
<td></td>
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<tr>
<td>Pre-existing Diabetes, n (%)</td>
<td>0.540</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 (12.6%)</td>
<td>16 (16.7%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-existing Renal Disease, n (%)</td>
<td>0.009*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 (8.4%)</td>
<td>22 (22.9%)</td>
<td></td>
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<tr>
<td>Pre-existing Dementia, n (%)</td>
<td>0.489</td>
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<tr>
<td>23 (24.2%)</td>
<td>19 (19.8%)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Injury Information**

<table>
<thead>
<tr>
<th>Fracture Type</th>
<th>2019 Cohort (n = 95)</th>
<th>2020 Cohort (n = 96)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intra-capsular</td>
<td>67 (70.5%)</td>
<td>59 (61.5%)</td>
<td>0.344</td>
</tr>
<tr>
<td>Intratrochanteric</td>
<td>23 (24.2%)</td>
<td>28 (29.2%)</td>
<td></td>
</tr>
<tr>
<td>Subtrochanteric</td>
<td>5 (5.3%)</td>
<td>9 (9.4%)</td>
<td></td>
</tr>
<tr>
<td>Additional Trauma, n (%)</td>
<td>2 (2.1%)</td>
<td>8 (8.3%)</td>
<td>0.100</td>
</tr>
</tbody>
</table>

**Surgical Information**

<table>
<thead>
<tr>
<th>2019 Cohort (n = 93)</th>
<th>2020 Cohort (n = 92)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-operative Cases, n (%)</td>
<td>2 (2.1%)</td>
<td>4 (4.2%)</td>
</tr>
<tr>
<td>Time from presentation to surgery (days) (mean ± SD)</td>
<td>1.2 ± 0.9</td>
<td>1.2 ± 0.7</td>
</tr>
<tr>
<td>Implant, n (%)</td>
<td>0.207</td>
<td></td>
</tr>
</tbody>
</table>
recovery ward tested positive, whilst two were diagnosed pre-operatively. Two (28.6%) of the seven COVID positive patients passed away; one dying due to bacterial pneumonia secondary to COVID infection in hospital, whilst another patient died two months after discharge in the community. 27 (28.1%) patients were not tested in primary hospitalization. When comparing demographic and injury characteristics, there were no differences between the COVID positive and COVID negative groups.

In terms of surgical information, the COVID positive group had a faster time to surgery (0.7± 0.5 days vs 1.3 ± 0.7 days, \(P = 0.028\)) as well as a higher post-operative complication rate (71.4% vs 25.9%, \(P = 0.021\)). In terms of hospital quality measures, the COVID positive group had a longer length of stay (30.3 ± 16.8 days vs 12.0 ± 7.3 days, \(P < 0.001\)) and had a greater admission rate into orthopaedic specific wards (100% vs 50.6%, \(P = 0.014\)) [Table 2].

<table>
<thead>
<tr>
<th>Table 1. Continued</th>
<th>47 (51.5%)</th>
<th>37 (40.2%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sliding Hip Screw</td>
<td>22 (23.7%)</td>
<td>34 (37.0%)</td>
</tr>
<tr>
<td>Total Hip Replacement</td>
<td>6 (6.5%)</td>
<td>11 (12.0%)</td>
</tr>
<tr>
<td>Long Intramedullary Nail</td>
<td>3 (3.2%)</td>
<td>6 (6.5%)</td>
</tr>
<tr>
<td>Cannulated Screws</td>
<td>5 (5.4%)</td>
<td>4 (4.3%)</td>
</tr>
</tbody>
</table>

\(P = 0.708\)

<table>
<thead>
<tr>
<th>Anaesthesia Type, n (%)</th>
<th>General</th>
<th>77 (82.8%)</th>
<th>74 (80.4%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spinal</td>
<td>16 (17.2%)</td>
<td>18 (19.6%)</td>
<td></td>
</tr>
</tbody>
</table>

\(P = 0.558\)

<table>
<thead>
<tr>
<th>Length of procedure (minutes) (mean ± SD)</th>
<th>79.3 ± 26.9</th>
<th>82.2 ± 39.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay &gt;36 Hours to Surgery, n (%)</td>
<td>11 (11.8%)</td>
<td>23 (25.0%)</td>
</tr>
<tr>
<td>Post-operative Complication Rate, n (%)</td>
<td>29 (31.2%)</td>
<td>27 (29.3%)</td>
</tr>
</tbody>
</table>

\(P = 0.023^*\)

Inpatient Mortality, n (%)  
2019 Cohort (n = 95)  
Inpatient Mortality, n (%)  
2020 Cohort (n = 96)  
\(P = 0.567\)

\(P = 0.039^*\)

<table>
<thead>
<tr>
<th>Length of Stay (days) (mean ± SD)</th>
<th>14.1 ± 8.4</th>
<th>13.4 ± 9.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Admission to Orthopaedic Ward, n (%)</td>
<td>95 (100%)</td>
<td>52 (54.1%)</td>
</tr>
<tr>
<td>Time to Geriatrician Assessment (days) (mean ± SD)</td>
<td>1.1 ± 0.9</td>
<td>1.2 ± 1.1</td>
</tr>
</tbody>
</table>

\(P = 0.292\)

<table>
<thead>
<tr>
<th>Hospital Quality Measures</th>
<th>2019 Cohort (n = 95)</th>
<th>2020 Cohort (n = 96)</th>
<th>(P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inpatient Mortality, n (%)</td>
<td>5 (5.3%)</td>
<td>8 (8.3%)</td>
<td>0.567</td>
</tr>
<tr>
<td>30-Day Mortality, n (%)</td>
<td>4 (4.2%)</td>
<td>13 (13.5%)</td>
<td>0.039*</td>
</tr>
<tr>
<td>Length of Stay (days) (mean ± SD)</td>
<td>14.1 ± 8.4</td>
<td>13.4 ± 9.5</td>
<td>0.581</td>
</tr>
<tr>
<td>Admission to Orthopaedic Ward, n (%)</td>
<td>95 (100%)</td>
<td>52 (54.1%)</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Time to Geriatrician Assessment (days) (mean ± SD)</td>
<td>1.1 ± 0.9</td>
<td>1.2 ± 1.1</td>
<td>0.292</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Registrar Training Information</th>
<th>2019 Cohort (n = 93)</th>
<th>2020 Cohort (n = 92)</th>
<th>(P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surgeon Grade, n (%)</td>
<td>Consult</td>
<td>45 (48.4%)</td>
<td>71 (77.2%)</td>
</tr>
<tr>
<td>ST3+</td>
<td>48 (51.6%)</td>
<td>21 (22.8%)</td>
<td></td>
</tr>
<tr>
<td>Anaesthetist Grade, n (%)</td>
<td>Consult</td>
<td>51 (54.8%)</td>
<td>55 (59.8%)</td>
</tr>
<tr>
<td>ST3+</td>
<td>42 (45.2%)</td>
<td>37 (40.2%)</td>
<td></td>
</tr>
<tr>
<td>Geriatrician Grade, n (%)</td>
<td>Consult</td>
<td>95 (100%)</td>
<td>54 (56.3%)</td>
</tr>
<tr>
<td>ST3+</td>
<td>0 (0%)</td>
<td>34 (35.4%)</td>
<td></td>
</tr>
</tbody>
</table>

\(^*\)AMTS = Abbreviated Mental Test Score, \(^1\)ASA = American Society of Anaesthesiologist Classification, \(^*\)\(P < 0.05\)
Table 2. COVID-19 positive cohort vs COVID-19 negative cohort

<table>
<thead>
<tr>
<th>Patient Demographics</th>
<th>COVID-19 Positive (n = 7)</th>
<th>COVID-19 Negative (n = 89)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years) (mean ± SD)</td>
<td>88.4 ± 4.4</td>
<td>84.6 ± 8.5</td>
<td>0.241</td>
</tr>
<tr>
<td>Sex, n (%)</td>
<td></td>
<td></td>
<td>0.670</td>
</tr>
<tr>
<td>Male</td>
<td>1 (14.3%)</td>
<td>25 (28.1%)</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>6 (85.7%)</td>
<td>64 (71.9%)</td>
<td></td>
</tr>
<tr>
<td>Home Status</td>
<td></td>
<td></td>
<td>0.353</td>
</tr>
<tr>
<td>Own Home</td>
<td>4 (57.1%)</td>
<td>69 (77.5%)</td>
<td></td>
</tr>
<tr>
<td>Nursing Home</td>
<td>3 (42.9%)</td>
<td>20 (22.5%)</td>
<td></td>
</tr>
<tr>
<td>Pre-operative AMTS* (mean ± SD)</td>
<td>3.9 ± 4.4</td>
<td>6.9 ± 3.8</td>
<td>0.051</td>
</tr>
<tr>
<td>ASA*, n (%)</td>
<td></td>
<td></td>
<td>0.522</td>
</tr>
<tr>
<td>I</td>
<td>0 (0%)</td>
<td>3 (3.4%)</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>0 (0%)</td>
<td>17 (19.1%)</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>6 (85.7%)</td>
<td>54 (60.7%)</td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>1 (14.3%)</td>
<td>15 (16.9%)</td>
<td></td>
</tr>
<tr>
<td>Nerve Block at A&amp;E, n (%)</td>
<td>4 (57.1%)</td>
<td>57 (64.0%)</td>
<td>0.703</td>
</tr>
<tr>
<td>Bone Protection Pre-fracture, n (%)</td>
<td>1 (14.3%)</td>
<td>9 (10.1%)</td>
<td>0.549</td>
</tr>
<tr>
<td>Bone Protection Post-fracture, n (%)</td>
<td>2 (28.6%)</td>
<td>38 (42.7%)</td>
<td>0.696</td>
</tr>
<tr>
<td>Delirium Assessment (mean ± SD)</td>
<td>2.4 ± 1.5</td>
<td>2.2 ± 3.1</td>
<td>0.866</td>
</tr>
<tr>
<td>Pre-existing Lung Disease, n (%)</td>
<td></td>
<td></td>
<td>0.738</td>
</tr>
<tr>
<td>Asthma</td>
<td>1 (14.3)</td>
<td>5 (5.6%)</td>
<td></td>
</tr>
<tr>
<td>COPD</td>
<td>0 (0%)</td>
<td>6 (6.7%)</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>1 (14.3%)</td>
<td>12 (13.5%)</td>
<td></td>
</tr>
<tr>
<td>Pre-existing Cardiovascular Disease, n (%)</td>
<td>5 (71.4%)</td>
<td>54 (60.7%)</td>
<td>0.703</td>
</tr>
<tr>
<td>History of Malignancy, n (%)</td>
<td>3 (42.9%)</td>
<td>30 (33.7%)</td>
<td>0.689</td>
</tr>
<tr>
<td>Pre-existing Diabetes, n (%)</td>
<td>2 (28.6%)</td>
<td>14 (15.7%)</td>
<td>0.330</td>
</tr>
<tr>
<td>Pre-existing Renal Disease, n (%)</td>
<td>3 (42.9%)</td>
<td>19 (21.3%)</td>
<td>0.195</td>
</tr>
<tr>
<td>Pre-existing Dementia, n (%)</td>
<td>3 (42.9%)</td>
<td>16 (18.0%)</td>
<td>0.137</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Injury Information</th>
<th>COVID-19 Positive (n = 7)</th>
<th>COVID-19 Negative (n = 89)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fracture Type</td>
<td></td>
<td></td>
<td>0.183</td>
</tr>
<tr>
<td>Intra-capsular</td>
<td>3 (42.9%)</td>
<td>56 (62.9%)</td>
<td></td>
</tr>
<tr>
<td>Intratrochanter</td>
<td>2 (28.6%)</td>
<td>26 (29.2%)</td>
<td></td>
</tr>
<tr>
<td>Subtrochanter</td>
<td>2 (28.6%)</td>
<td>7 (7.9%)</td>
<td></td>
</tr>
<tr>
<td>Additional Trauma, n (%)</td>
<td>0 (0%)</td>
<td>8 (9.0%)</td>
<td>1.000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Surgical Information</th>
<th>COVID-19 Positive (n = 7)</th>
<th>COVID-19 Negative (n = 85)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-operative Cases, n (%)</td>
<td>0 (0%)</td>
<td>4 (4.5%)</td>
<td>1.000</td>
</tr>
<tr>
<td>Time from presentation to surgery (days) (mean ± SD)</td>
<td>0.7 ± 0.5</td>
<td>1.3 ± 0.7</td>
<td>0.028*</td>
</tr>
<tr>
<td>Implant, n (%)</td>
<td></td>
<td></td>
<td>0.170</td>
</tr>
</tbody>
</table>
### Table 2. Continued

<table>
<thead>
<tr>
<th></th>
<th>COVID-19 Positive (n = 7)</th>
<th>COVID-19 Negative (n = 89)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anaesthesia Type</td>
<td></td>
<td></td>
<td>0.619</td>
</tr>
<tr>
<td>General</td>
<td>5 (71.4%)</td>
<td>69 (81.2%)</td>
<td></td>
</tr>
<tr>
<td>Spinal</td>
<td>2 (28.6%)</td>
<td>16 (18.8%)</td>
<td></td>
</tr>
<tr>
<td>Length of procedure (minutes) (mean ± SD)</td>
<td>103.0 ± 55.4</td>
<td>80.5 ± 38.1</td>
<td>0.152</td>
</tr>
<tr>
<td>COVID Lab Test Before Surgery, n (%)</td>
<td>2 (28.6%)</td>
<td>35 (41.1%)</td>
<td>0.698</td>
</tr>
<tr>
<td>Delay &gt;36 Hours to Surgery, n (%)</td>
<td>0 (0%)</td>
<td>23 (27.1%)</td>
<td>0.186</td>
</tr>
<tr>
<td>Post-operative Complication Rate, n (%)</td>
<td>5 (71.4%)</td>
<td>22 (25.9%)</td>
<td>0.021*</td>
</tr>
</tbody>
</table>

#### Hospital Quality Measures

<table>
<thead>
<tr>
<th></th>
<th>COVID-19 Positive (n = 7)</th>
<th>COVID-19 Negative (n = 89)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inpatient Mortality, n (%)</td>
<td>1 (14.3%)</td>
<td>7 (7.9%)</td>
<td>0.467</td>
</tr>
<tr>
<td>30- Day Mortality, n (%)</td>
<td>1 (14.3%)</td>
<td>12 (13.5%)</td>
<td>1.000</td>
</tr>
<tr>
<td>Length of Stay (days) (mean ± SD)</td>
<td>30.3 ± 16.8</td>
<td>12.0 ± 7.3</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Admission to Orthopaedic Ward, n (%)</td>
<td>7 (100%)</td>
<td>45 (50.6%)</td>
<td>0.014*</td>
</tr>
<tr>
<td>Time to Geriatrician Assessment (days) (mean ± SD)</td>
<td>1.1 ± 0.9</td>
<td>1.2 ± 1.1</td>
<td>0.876</td>
</tr>
</tbody>
</table>

#### Registrar Training Information

<table>
<thead>
<tr>
<th></th>
<th>COVID-19 Positive (n = 7)</th>
<th>COVID-19 Negative (n = 85)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surgeon Grade</td>
<td></td>
<td></td>
<td>1.000</td>
</tr>
<tr>
<td>Consultant</td>
<td>6 (85.7%)</td>
<td>65 (76.5%)</td>
<td></td>
</tr>
<tr>
<td>ST3+</td>
<td>1 (14.3%)</td>
<td>20 (23.5%)</td>
<td></td>
</tr>
<tr>
<td>Anaesthetist Grade</td>
<td></td>
<td></td>
<td>1.000</td>
</tr>
<tr>
<td>Consultant</td>
<td>4 (57.1%)</td>
<td>51 (60.0%)</td>
<td></td>
</tr>
<tr>
<td>ST3+</td>
<td>3 (42.9%)</td>
<td>34 (40.0%)</td>
<td></td>
</tr>
<tr>
<td>Geriatrician Grade</td>
<td></td>
<td></td>
<td>0.702</td>
</tr>
<tr>
<td>Consultant</td>
<td>5 (71.4%)</td>
<td>49 (55.7%)</td>
<td></td>
</tr>
<tr>
<td>ST3+</td>
<td>2 (28.6%)</td>
<td>32 (36.4%)</td>
<td></td>
</tr>
</tbody>
</table>

*AMTS = Abbreviated Mental Test Score, ASA = American Society of Anaesthesiologist Classification, * P < 0.05

**Discussion**

The COVID-19 pandemic has led to a global surge in critically ill patients, forcing hospitals to reallocate resources, potentially resulting in reduced health care access for patients requiring essential care (11). The prognosis of COVID-19 is relatively poor for elderly patients, especially those who have multiple co-morbidities (12). Neck of femur patients treated at our hospital were optimized, and the great majority were treated expeditiously when possible as we tried to treat these patients as we would have before the pandemic.

In our present cohort of patients, COVID positive patients experienced a greater complication rate compared to COVID negative patients, which included complications such as hospital acquired pneumonia, urinary tract infection, acute kidney injury, myocardial infarction, atrial fibrillation and sepsis. The increased frequency and types of perioperative complications observed in this cohort mirrors reports from other specialties (13, 14). Damage caused by COVID-19 infection is a dysfunctional immune response accompanied by pulmonary and
systemic inflammation (15, 16). This, compounded with the secondary insult of anaesthetic use and operative intervention may have primed these patients for the pulmonary and cardiac complications observed in this cohort. It is also interesting to note that the COVID positive cohort compared to the COVID negative cohort had a lower pre-operative AMTS (3.9 ± 4.4 vs 6.9 ± 3.8, \( P = 0.051 \)), which was borderline significant, mirroring the findings by Kuo et al that pre-existing dementia is a major risk factor for developing COVID-19 in the elderly (17).

According to COVID-19-BOAST guidelines, patients were allowed to fully weight bear immediately to allow faster rehabilitation with the aim of reducing inpatient stay and exposure to COVID-19 (18). It is important that patients were encouraged to mobilise as bed bound patients are prone to develop hypostatic pneumonia, which exhibits similar symptoms to COVID-19 as well deep vein thrombosis of the lower extremities and bed sores (19). When comparing the 2020 cohort to the 2019 cohort, there was no significant difference in the length of stay in hospital, but when comparing the COVID positive to COVID negative patients, the COVID positive patients had a significantly longer length of stay. The reason for this was that our hospital’s guidelines required all COVID positive patients to be isolated for 14 days and no longer test positive before being discharged.

The British Geriatric Society issued guidelines for the management of hip fractures during the COVID-19 pandemic with the aim of promoting prompt (<24h) consultant-delivered surgical and anaesthetic care where possible (20). The average time to surgery from presentation for the 2020 cohort was 1.2 days and 23 (25%) patients had a greater than 36-hour delay before their surgery. 20 of the 23 patients had a delay as they were waiting for space on the theatre list, whilst the other 3 patients were delayed due to reversal of anti-coagulation medication.

Hip fractures should be treated as soon as possible regardless of their COVID status as 30-day mortality rates after surgery decreases from 6.55 to 5.8% when the wait time for surgery is less than 24h (21). Recent studies from Spain and New York conducted by Muñoz Vives et al and Egol et al respectively both found a significant higher mortality rate in elderly patients with a hip fracture and an associated positive test for COVID-19 (22, 23). However, no significant difference in mortality rates between the COVID positive and COVID negative patients were found in our study. On the other hand, there was a significantly higher 30-day mortality rate in the 2020 cohort compared to the 2019 cohort, which was also reported by Egol et al (23). Among the 13 patients in the 2020 cohort who passed away, 6 were found to have delayed surgery (>36 hours) due to a long theatre waiting list and this could potentially explain the higher 30-day mortality rate in the 2020 cohort as the risk of mortality increases by 1.8% for every hour of delay past 24 hours (24).

Apart from the direct impact of COVID-19 on the quality of patient care, there were indirect impacts on surgical training as well due to despecialisation and redeployment of orthopaedic registrars. The Royal College of Surgeons of England published guidance of emergency care during the pandemic and it is thought that the burden of trauma care provision will be undertaken by consultants, whilst orthopaedic registrars will be providing general medical services to other patients around the hospital (25). This was true in our study as the number of surgeries carried out by orthopaedic registrars decreased in the 2020 cohort compared to the 2019 cohort, whilst there was an increase in number of registrars performing geriatric assessments in the 2020 cohort, which was solely done by consultant geriatricians in the 2019 cohort.

Limitations of our study include its retrospective design as well as a lack of long-term outcomes. We also limited our analysis to patients who tested positive for COVID-19 in hospital. There was a chance that there were potential missed cases in individuals with clinical or radiological evidence of COVID-19 due to the limited sensitivity of the RT-PCR test. Given the high likelihood of asymptomatic COVID-19, it was possible that some patients in our cohort had asymptomatic COVID-19 and were not tested or potentially developed COVID-19 after a negative test and were therefore missed. It should also be noted that the number of COVID positive patients in our study sample were fairly low (7.3%).

In conclusion, the COVID-19 pandemic has had a drastic impact on the care of elderly patients presenting with neck of femur fractures. Our study found that patients with neck of femur fractures treated during the pandemic had an increased 30-day mortality rate potentially due to longer waiting times for surgery, whilst there was also a reduction in admission to orthopaedic specific wards during the pandemic, which was associated with less specialist nursing care and lower consultant orthogeriatric reviews. Furthermore, the COVID-19 positive cohort were found to have a longer length of stay in hospital as well as higher post-operative complication rates.

**Patient Consent:** Being a retrospective study without patient interventions, consent for participation was not required.

**Conflicts of Interest:** The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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References


CASE REPORT

The Charcot Knee Arthropaty: The Diagnostic and Surgical Challenge. A Case of Syphilis Arthropaty and a Review of Literature

Carlo Cardile, MD; Carlo Cazzaniga, MD; Beatrice Marzini, MD; Marco Bongiovanni, MD; Roberto Marasco, MD; Paolo Ragni, MD

Research performed at Asst-Rhodense “Salvini Hospital”, Garbagnate Milanese - Milano, Italy

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Abstract

The Charcot knee is a progressive, degenerative disease of the joint that may represent a diagnostic challenge; at the moment, poorly controlled diabetes mellitus is the main cause of this condition. We describe here a case of a man presenting with an end stage joint arthropathy who was diagnosed with neurosyphilis. Tabetic arthropathy is currently a very rare disease, but in the past represented the main cause of joint arthropathy. Finally, we discussed the different surgical options of Charcot arthropathy, our choice of megaprosthesis implant and the failure of such procedure mainly due to patient’s unreliability to care leading to infective complications and peri-prosthesis fracture.

Level of evidence: IV

Keywords: Arthroplasty, Charcot, Knee, Syphilis, Tabetic arthropaty

Introduction

Neuropathic arthropathy is a progressive and degenerative process that leads to destruction and collapse of the weight-bearing surface of joints, of the sub-chondral bone and to the development of large effusions that stretch and damage supporting soft-tissue structures (1,2). In the past, tabetic arthropathy, described by Jean Martin Charcot in 1868, was the most common cause of neuropathic arthropathy; currently, it is an unusual finding because of the early diagnosis and treatment of syphilis, and the most common cause of Charcot arthropathy is represented by poorly controlled diabetes mellitus an early detection of Charcot arthropathy is mandatory for these patients to prevent cartilage injuries and avoid disease progression with deformity and joints destruction (3-5).

The surgical treatment of Charcot knee remains controversial; in the past, it was considered an absolute contraindication for implant of total knee arthroplasty TKA due to the less favorable outcome secondary to unstable neurologic status, development of ataxia, severe joints destruction, bone defects, and deformities (6-9). However, this reports had usually a short follow-up, did not included homogeneous patients, and used different type of prostheses. Nevertheless, despite the technical challenges of the procedure and the high rate of complications reported including peri-prosthetic joint infection, tibiofemoral dislocation and periprosthetic fractures, other authors reported satisfactory results with the use of increased constraint, stems, augments, and revision-type TKA components (10-12).

We report here a case of a patients presenting with a severe Charcot arthropathy who was finally diagnosed with an end stage neurosyphilis; the patient was initially treated with a knee’s megaprosthesis but developed major complications during follow-up leading to amputation.
Case Report
A 67-years old man attended to the Emergency Department for progressive swelling of the right knee with edema and worsening pain of the entire right leg [Figure 1]. A color Doppler ultrasound excluded deep venous thrombosis. X-ray and CT scan of the knee showed deformity of the femoral-tibial joint with erosion of the medial femoral condyle and significant intra-articular swelling, with local contrast-enhancement; MRN confirmed severe joint erosion, diffused calcifications and inhomogeneous contrast enhancement of the bone at the femoral condyle and at tibial plateau, compatible with osteomyelitis [Figure 2-5]. Arthrocentesis was negative for septic arthritis findings; finally, scintigraphy with marked leucocytes confirmed an uneven hyper-captation of the right knee. Autoimmunity pattern and blood tests were normal, including C-reactive protein and procalcitonin; blood and urine cultures were negative for bacteria and fungi. A bone biopsy showed aspecific lymphoplasmacellular infiltrate. Charcot arthropathy was suspected but the patient had persistently normal glucose levels and glycated hemoglobin levels of 36 mmol/mol (normal value < 42 mmol/mol). Finally, syphilis was suspected and rapid plasma reagin (RPR) and TPHA were done, resulting positive at significant titers in both plasma and cerebrospinal fluid. Intravenous ceftriaxon (2 grams/daily) was then administered (patient had a past history of allergy to penicillin) for 14 days before surgery.

Due to the rapid joint and bone destruction occurred in three months from admission, an implant of knee megaprosthesis was planned; two weeks after surgery, the patient had an accidental trauma with damage of the knee extensor system and lateral dislocation of the patella [Figure 6-12]. In the next few days, a delayed healing of the surgical wound was observed and meticillin-resistant Staphylococcus aureus was isolated from culture. Daptomycin was then started associated with local VAC therapy leading to a progressive improvement of the surgical wound. After 4 weeks of intravenous daptomycin, antibiotic treatment was shifted, according to antibiogram, to trimethoprim/sulfamethoxazole and doxycycline and the patient was finally discharged from the hospital. Two weeks later, the patient had an accidental fall that resulted in a peri-prosthetic, open fracture b3 type Vancouver [Figure 13; 14]. Further, the patients revealed that he had taken antibiotic therapy only occasionally and rejected to continue the treatment. Meticillin-resistant Staphylococcus aureus was isolated again from surgical wound. As a consequence, considering the severity of the fracture, the persistence of meticillin-resistant Staphylococcus aureus and the patient's unreliability to care, we decided to amputate the leg [Figure 15; 16].

Discussion
Currently, the main cause of Charcot knees is diabetes mellitus; destructive tabetic arthropathy has become rare in the course of tertiary syphilis because of early diagnosis and treatment. Tabetic arthropathy occurs in the late stages of the disease, usually 20 to 30 years when primary syphilis is not properly treated. This condition results in loss of perception of pain combined with repeated subclinical micro-trauma leading to significant fragmentation, destruction and collapse of joints that...
is typical of Charcot arthropathy. Syphilis peripheral neuropathy is not always present, therefore joint changes can precede neurological deficit. In advanced stages, bone destruction with soft tissue changes leads to deformities. Patients usually have very mild symptoms compared to radiological findings that include subchondral sclerosis, osteophytosis, subluxation and soft tissue swelling. Long-standing neuro-arthropaty is characterized by a subversion of joints. It’s really hard to come up to diagnosis during the evolution of the disease; in fact, our patient was not aware of having a tertiary syphilis because he never had symptoms compatible with primary or secondary syphilis. During the diagnostic phase, the patient underwent to rapid and progressive joint destruction with loss of functionality, therefore no chance of conservative treatment was possible. At the early stage of disease, differential diagnosis with osteomyelitis, osteonecrosis, calcium pyrophosphate dihydrate crystal deposition disease, psoriac arthritis and osteoarthritis was difficult because swelling and little pain prevailed on the deformity pattern.

Once eradication treatment for tertiary syphilis was
completed, the surgical approach was considered. In the early stages of joint involvement, the Charcot’s knee treatment includes local treatment such as joint lavage, local steroid, or synoviorthesis. Palliative reduction of instability by immobilization and weight control are important to reduce micro-traumas that
can deteriorate the joints. Arthrodesis of the knee has been performed since the early 1900s to treat pain and instability associated with advanced osteoarthritis, post-traumatic arthritis, Charcot arthropathy, infectious arthritis, poliomyelitis, and reconstruction following tumor resection. Massive bone loss may substantially reduce the success rate of arthrodesis (6). Nevertheless, many patients with Charcot arthropathy are choosing to preserve motion with a total knee arthroplasty, considering arthrodesis only in case of failure of this procedure. Arthrodesis is a possible surgical treatment option, but it usually results in poor limb function; on the contrary, total knee arthroplasty could guarantee a better functional outcome (13-15). Some authors suggest that there are distinct stages of neuro-arthropathy based on clinical and imaging patterns. This should be consider when planning surgery because poor outcomes after TKA for Charcot knees are often obtained from unnecessarily early surgery; as a consequence surgical intervention should be considered only in the reconstruction or coalescence stages. Sometimes fragmentation, destruction and coalescence coexisted in the same knee and is not simple choose the perfect timing for surgery. The choice of the type of constraint in Charcot’s knee is still debated. Although most authors consider unconstrained or highly constrained components inappropriate for Charcot knees, others demonstrated that condylar constrained implants are the optimal choice and that hinged components are inappropriate because of the high risk of periprosthetic fractures and aseptic loosening. Strong constraint is likely to increase the stress on the implant–bone interface, leading to a high risk of failure. However constrained condylar and rotating hinge prostheses are used for Charcot joints with bone deficiency and soft tissue imbalance. Further, even if Charcot arthropathy is not an absolute contraindication to total knee arthroplasty, the use of this procedure is associated with a high risk of serious complications. Finally, megaprostheses play a decisive role in rescuing joints that present severe bone loss, when it is necessary to preserve a joint function or when the loss of substance does not allow arthrodesis without significant shortening (16).

In our patient, the metaphyseal involvement of both femur and tibia led us to choose the constrained megaprostheses, to bridge the bone loss. The choice of megaprostheses could provide a better functional outcome while preserving the limb but with the awareness of possible systemic and local complications associated with the prosthetic implant. The management of the extensor mechanism was technically performed by the anterior transposition of the tendons of the medial and lateral twins and thanks to the quadriceps tenodesis obtained with non-absorbable high resistance points.

At our knowledge, this is the first case of Charcot knee treated with a modular megaprostheses implant. Amputation, as an additional surgical option, should be considered only in case of implant failure mainly due to infective complications and periimplant fractures related to a low pain perception as occurred in our patient.

The timing and surgery technique and the prosthesis choice should be carefully considering before arthroplasty and these choices should be done according to patient’s clinical condition. Amputation represents a possible alternative in case of implant failure; modern leg prostheses may guarantee an acceptable quality of life in this specific conditions.

References


CASE REPORT

Cubitus Varus Corrective Osteotomy and Graft Fashioning Using Computer Simulated Bone Reconstruction and 3D Printed Custom-Made Cutting Guides

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Abstract

Preoperative planning is of paramount importance in saving time as well as helping achieve a more precise correction of the deformities. Along with preoperative measurements, customized cutting guides can facilitate intraoperative correction of the deformity with higher confidence. In this report, we are presenting the application of preoperative planning and 3D printed customized cutting guides for correcting cubitus varus alignment of the elbow in an 18 year old male with satisfactory intraoperative and postoperative results.

Level of evidence: IV
Keywords: 3D-printing, Computer-aided-design, Cubitus varus, Elbow, Osteotomy, Pre-operative planning

Introduction

3D-printing technology is an emerging field in the healthcare industry. In this process, extruded material is printed layer over layer to make the 3D model. The 3D model is designed and converts to G-code which translates into the 3D-printing machine. This technology has wide application in orthopedic clinical use as orthoses, patient-specific osteotomy instrument, orthopedic implant, and tissue engineering (1).

With the help of computer simulation, design tools, computational algorithms, and imaging techniques as Computed Tomography (CT) scans, 3D models of various tissues can be simulated, reconstructed, and 3D printed. This technology has also different applications in dental surgery, maxillofacial reconstruction, cranioplasty, and vascular surgery (2, 3).

Preoperative planning is one of the significant method in managing orthopedic surgery. In this report, we used both virtual preoperative planning and 3D-printing technology in understanding the osteotomy and planning out a strategy. This technique can be helpful both in increasing the efficiency and reducing the surgical morbidity.

Case presentation

An 18-year-old man was referred with left elbow cubitus varus following a supracondylar fracture in childhood [Figure 1]. He also had mild lateral elbow pain but no sign or symptom of ulnar nerve palsy was present. The visual analogue score of pain at rest was 0 and with activity was 3 out of 10 which was mostly fatigue rather than pain. Clinical carrying angle was 35 degree of varus. Elbow range of motion was 0-135 degrees and comparable to the other side. In order to be precise in varus correction, we decided to use the preoperative planning using the computer-based software. We applied the computed tomographic (CT) cuts of both normal and the affected
elbow to reconstruct the elbow joint.

Materials and Methods

In this case, the 3D model of the bone is generated by the CT scan raw data. This toolkit which is used by an open-source software (Fiji) helped orthopedic surgeons to make a 3D model of the scan data within the required Hounsfield unit. This threshold separates the compact and spongy bone in the CT-scan data. In this study, which is implemented by 3D point cloud registration algorithm; we aimed to correct the deformed humerus patient bone. 3D models of both humerus bones in the left and right upper extremities is post-processed in order to drive smooth and solid objects for the further measurement and processing. The following steps are done to produce the cutting guides with the use of 3D printing. DICOM images were imported in the Mimics TM (Materialise, Belgium) software. The desired 3D model was segmented and edited with the “edit mask” command. The segmented 3D model was exported as STL file and imported into the 3-maticsTM (Materialise, Belgium) software to design the jigs. Both deformed and healthy upper extremity STL files aligned together in the proximal part [Figure 2a].

Based on this modeling, 40 degrees of angulation was measured and a wedge of the same degrees was designed to be cut and move. Given that, we designed a cutting jig to guide for the wedge to be cut [Figure 3a-b]. This has been performed with designing a base on the cutting surface. During surgery, the wedge was cut (Pink Part in Figure 3a) and placed over the lateral border of the distal humerus fragment to create the distal segment [Figure 4]. In order to locate the wedge precisely, the pink part was rotated in two planes. The center of rotation was the point between two legs of the cutting triangle [Figure 3a]. By rotating the bone wedge, the grey part was slipped along the wedge as the lower edge meets the yellow distal bone to maintain a solid bone with corrected angle [Figure 4]. By reducing the distal segment to the proximal humerus, the 40 degrees deformity was corrected and alignment was achieved precisely [Figure 5 a-d]. Because there was a negligible deformity in the sagittal plane, we made cuts perpendicular to the shaft. The goal after rotating the wedge was complete contact of bone surfaces. Range of motion was tested after provisional fixation to make sure the reduction is in appropriate position. There was no appreciable anterior tilt of the distal fragment at surgery, however, due to the difference in bone diameters in the new set-up of the fragments, there is a seemingly anterior tilt of the distal fragment in the sagittal plane. Moreover, the surface area of the wedge is triangular with the posterior base and
anterior angle which contributes to the appearance of anterior tilting of the distal fragment after 180 rotation of the wedge to be aligned with the anterior cortex of the distal fragment.

**Results**

Patient was followed up for 4 months. A complete bone healing was evident at the last visit on the final radiographs [Figure 6 a-b]. Range of motion was 0-135
degrees of extension to flexion, 85 degrees of pronation and 80 degrees of supination which was comparable to preoperative motion and the contralateral side [Figure 7 a-d]. Force of flexion and extension was 5 out of 5 eliciting no pain with resisted motion. Visual analogue scale (VAS) with activity was 2 and at rest was 0 out of 10. Clinical carrying angle was 5 degrees of valgus. He did not develop any sign or symptoms of injury or entrapment of ulnar, radial or median nerve. The patient was completely satisfied with the outcome of surgery.

**Discussion**

Preoperative planning is one of the significant methods in managing orthopedic surgeries. In this report, we used both virtual preoperative planning and 3D-printing technology in lieu of planning the cuts prior to the actual surgery. There are some reports using custom-made cutting guides to correct a cubitus varus with different surgical techniques. Murase et al. used this technique to make custom-made guides for close wedge osteotomy of a cubitus varus deformity in 6 steps. This included creating computer bone models from CT data, evaluating the

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**Figure 5** c,d. Elbow anteroposterior (5c) and lateral (5d) view showing corrected ulnohumeral angle

**Figure 6** a,b. Follow-up anteroposterior (6a) and lateral (6b) radiographic views four months after corrective osteotomy showing progressive healing with maintained alignment.

**Figure 7** a, b. Follow-up after four months shows full range of motion almost equal to the healthy side in extension (7a), flexion (7b).
CUBITUS VARUS CORRECTION USING CUSTOM CUTTING GUIDES

3-D deformity, planning the 3-D corrective osteotomy, operative set up, performing the 3-D osteotomy using the custom-made surgical guides, and postoperative care (4).

In another study, 13 children with cubitus varus underwent preoperative planning using computer simulation. Out of 13, 10 had excellent, 2 had good and 1 had fair results with a mean carrying angle of 11 degrees at the final follow-up (5).

The application of 3D print is extending into orthopedic surgery. 3D printed casts and splints is a brand new method of immobilization that provides more comforts to the patient (6). Besides the application of preoperative planning with 3D printed cutting guides, specific customized implants are currently designed and implanted with successful outcomes. Although the drawback of this new technology is the ‘time’, this technology is becoming more popular as the advances are emerging.

It seems that bone reconstruction and computer simulation is a reliable method to make custom-made cutting guides for precise correction of deformities. It helps shorten the surgery time and increases the accuracy of deformity correction.

References

LETTER TO THE EDITOR

Effectiveness of the Guidelines for the Non-Operative Management of Knee Osteoarthritis

Dear Editor,

Despite being the commonest musculoskeletal disorder, knee Osteoarthritis (OA) has no consensual treatment guideline for its management. The variety of treatment guidelines creates confusion in the management of patients. Therefore, a consensus treatment guideline is necessary to manage these patients with evidence-based treatment modalities.

We have analyzed six existing guidelines on the non-operative management of knee OA [Table 1]. They included recommendations from the American Academy of Orthopaedic Surgeons (AAOS), National Institute of Health and Care Excellence, European Society for Clinical and Economic Aspects of Osteoporosis, Osteoarthritis and Musculoskeletal Disease, Osteoarthritis Research Society International (OARSI), The Royal Australian College of General Practitioners (RACGP), and the Cochrane review (1-5). A consensus was found on the efficacy of self-management programs, land-based exercise, and weight loss. These guidelines do not recommend the use of acupuncture in OA and there was a mixed opinion for the use of physiotherapy modalities and orthotics. The non-steroidal anti-inflammatory drugs are recommended for pain relief, but along with their topical forms, their long-term use is not advisable. The effects of paracetamol on the early stages of the disease and opioids on the later stages of the disease are debatable. Furthermore, it should be noted that the use of glucosamine and chondroitin has been discouraged by most of these guidelines. Use of intra-articular steroids for acute pain and inflammation is recommended by the majority of guidelines, but not for

Table 1. Findings of various studies and their recommendations

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<td>1. Self-management program</td>
<td>Strong</td>
<td>Strong</td>
<td>Recommended</td>
<td>No recommendation</td>
<td>Conditional recommendation</td>
<td>No or small benefit</td>
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<td>2. Land-based exercise</td>
<td>Strong</td>
<td>Strong</td>
<td>Recommended</td>
<td>Recommended</td>
<td>Strong</td>
<td>Recommended</td>
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<td>3. Weight management</td>
<td>Moderate</td>
<td>Strong</td>
<td>Recommended</td>
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<td>Strong</td>
<td>Strong</td>
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<td>4. Use of physical agents</td>
<td>Inconclusive</td>
<td>Recommended</td>
<td>Recommended</td>
<td>Conditionally recommended (transcutaneous electrical nerve stimulation)</td>
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<td>Unclear</td>
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<td>5. Manual Therapy</td>
<td>Inconclusive</td>
<td>Recommended</td>
<td>Recommended</td>
<td>Recommended</td>
<td>N/A</td>
<td>N/A</td>
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<td>6. Off Loading knee braces (for medial osteoarthritis)</td>
<td>Inconclusive</td>
<td>Recommended</td>
<td>Recommended</td>
<td>Not recommended</td>
<td>N/A</td>
<td>Unclear</td>
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<td>7. Lateral wedge insoles</td>
<td>Not recommended</td>
<td>Recommended</td>
<td>Recommended</td>
<td>Not recommended</td>
<td>N/A</td>
<td>Unclear</td>
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<td>8. Acupuncture</td>
<td>Not recommended</td>
<td>N/A</td>
<td>Not recommended</td>
<td>Not recommended</td>
<td>N/A</td>
<td>Benefits are small</td>
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Email: drabhishekvaish@gmail.com

Table 1. Continued

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<td>1. Glucosamine and chondroitin</td>
<td>Not recommended</td>
<td>Strong recommendation</td>
<td>Not recommended</td>
<td>N/A</td>
<td>Inconclusive (chondroitin)</td>
<td>No benefit (glucosamine)</td>
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<td>2. Oral Opioid</td>
<td>Strong</td>
<td>Weak recommendation</td>
<td>Recommended</td>
<td>No significant benefit</td>
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<td>3. Topical non-steroidal anti-inflammatory drugs</td>
<td>Strong</td>
<td>Strong recommendation</td>
<td>Recommended</td>
<td>Strongly recommended</td>
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<td>4. Oral non-steroidal anti-inflammatory drugs</td>
<td>Strong</td>
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<td>Recommended</td>
<td>Conditional recommendation</td>
<td>N/A</td>
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<td>5. Paracetamol</td>
<td>Inconclusive</td>
<td>Not recommended</td>
<td>Recommended</td>
<td>N/A</td>
<td>Minimal improvements</td>
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<td>6. Opioid/pain patches</td>
<td>Inconclusive</td>
<td>Weak recommendation (end-stage arthritis)</td>
<td>N/A</td>
<td>Not recommended</td>
<td>N/A</td>
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<td>7. Duloxetine</td>
<td>N/A</td>
<td>Weak recommendation</td>
<td>N/A</td>
<td>Recommended</td>
<td>Conditional recommendation</td>
<td>N/A</td>
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<td>Intra-articular injections</td>
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<td>1. Corticosteroids</td>
<td>Inconclusive</td>
<td>Weak recommendation</td>
<td>Recommended</td>
<td>Conditional recommendation</td>
<td>Unclear</td>
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<td>2. Hyaluronic acid</td>
<td>Not recommended</td>
<td>Weak recommendation</td>
<td>Not recommended</td>
<td>Conditional recommendation</td>
<td>Support the use</td>
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<td>3. Platelet-rich plasma and Stem cell therapy</td>
<td>Inconclusive</td>
<td>N/A</td>
<td>Special arrangement</td>
<td>No recommendation (platelet-rich plasma)</td>
<td>N/A</td>
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Stem cells and Platelet Rich Plasma therapy. Moreover, the use of Hyaluronic Acid is still debatable [Figure 1]. We noticed several discrepancies in these recommendations which can be explained by the fact that these varied groups represent different geographical areas, patient cohorts, as well as various existing and prevalent practice methods in their specialties and their particular geographical area. For example, the studied recommendations were from both surgical association (e.g., AAOS) and physician associations (e.g., RACGP, OARSI). The bias of the treating physician towards a particular treatment modality is based on their training. We believe that the acceptability of the patient is based on cost factors, ease of access to a particular treatment modality, social conditioning towards pain perception, and whether the treatment modality is covered by insurance or their healthcare provider or it is from out of pocket expenses. There could also be an organizational bias due to their commitment to a particular section of care providers like the government, general practitioners, surgeons, rheumatologists, or physical therapists.

We are aware that the standardization of recommendations is a difficult and challenging task due to various factors, like heterogeneity of patient
population, method of study, evaluation of the results, different stages of disease presentation, various lifestyles and activity demands, access to healthcare, co-morbidities, and demographic diversities. Although these recommendations are useful at large for the guidance of healthcare providers, they cannot be entirely applied to the clinical practice of every physician and surgeon. Much more work and white papers are required which are derived from the studies of large population groups from various parts of the world with the consideration of various individuals and demographic factors.

References


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The manuscript should include the following sections:

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   (a) Title of the paper which should be short and succinct
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   (c) The institution where the work was done
   (d) The authors’ appointments
   (e) The name and address of the corresponding author where reprints should be sent
   (f) A short running head of no more than 40 characters

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   (a) It should not be more than 150 words for unstructured abstract (in review articles and case reports) and no more than 250 words for structured abstract with sections like background, materials and methods, results, conclusion (in original articles)
   (b) It should be factual and succinct
   (c) For basic science papers the last sentence of the abstract should describe the clinical relevance of the study.

3. Key words
   At the end of the abstract, authors should provide 3-5 key words for information retrieval. Key words should be taken from Medical Subject Headings (MeSH) from Index Medicus.

4. Main text
   The main text should be written in clear and simple English and divided into sections. In general the sequence should be as follows:
   (a) Introduction
   (b) Material and methods
   (c) Results
   (d) Discussion (it should avoid repeating preceding information)
   (e) Acknowledgements (if any)
   (f) Declaration of interests
   (g) References (refer to below for details)
   (h) Legends for figures and tables
   (i) Tables
   (j) Figures

   Number of figures should not be more than 16. Each photograph must be numbered and correctly oriented to show the topside. Avoid heavy pencil marks. Histological slides should mention the magnification and the stain. Lettering in
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Introduction
The introduction should be concise. The importance of the research topic should be stated. A short review of the established knowledge should lead on to what is known and unknown. The hypothesis of the research project (research question) should be explained.

Patients and methods
This can be written in continuous prose with generous use of paragraphs or sub-headings. The following issues should be covered:
- Demographics of the patients or subjects
- Inclusion and exclusion criteria
- Study design
- Interventions, treatment
- Methods of measurement
- Statistics
- Ethics and clinical trial registration where relevant

Results
It is important to avoid including methods or discussion in the results section. The reader should be helped to see exactly what has happened, using a combination of text, tables, and figures. The expert advice of a statistician should be used. Good visual presentation is often the best way of making the data clear. Figures should look good and the legend should explain the figure without reference to the text. Often journals allow for supplementary data to be published online only—this is a useful way to publish large tables and additional figures.

Discussion
The hypothesis raised in the introduction should be considered in relation to the results obtained in the study. The discussion should explain why the results support the hypothesis and why they do not. It is important not to present actual results in the discussion. The results should be considered in relation to other published articles. It is important to identify the limitations of the study and to suggest directions for future research.

Acknowledgements
The precise role of all authors should be listed and any additional contributors to the study should be listed.

Declaration of interests
Sources of funding for the study and any personal funding received from relevant pharmaceutical industries by authors should be declared.

References
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Examples of the most common reference types are provided below. (Please pay particular attention to the formatting, word capitalization, spacing and style.)

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2-Book chapter in book with editor and edition
Instruction for Authors

3-Electronic publications

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The legends should be listed separately from the tables and figures. These should be clear and concise. It is important to have the correct number for the appropriate table or figure.

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