Introduction and literature review:

Orthopaedic implant removal is a common procedure with 10-15% of upper extremity fractures repaired requiring implant removal following plate osteosynthesis.[1-5] Frequent reasons for implant removal include pain, tendon irritation or rupture, infection, nonunion, and hardware prominence.[2,5] While patients who undergo implant removal often have improvement in their symptoms,[3, 6-7]the ease of specific implant removal can vary considerably. In fact, 85% of surgeons report that implant removal poses a significant burden on hospital resources.[8]

The perceived burden of implant removal is not without cause, as it represents a considerable cost to both the patient and healthcare system.[9] Implant removal surgeries are associated with a high frequency of complications, ranging from 12 to 41%[10-13], and can be associated with longer operative times and higher amounts of blood loss than initial procedures.[13] Potential complications including general operative risks such as infection, bleeding, and injury to important structures are compounded by risks specific to removal of the implant itself, such as broken and/or retained hardware, stripped screws, and re-fracture during, or after implant removal.[14,15] Pre-operative knowledge of the instruments needed to remove a given implant is critical to minimize potential risk to the patient. Ideally, the initial treating orthopaedic surgeon would also remove the implants, as is frequently the case. However, patients change providers, leave prior areas of care, or present to other institutions with peri-prosthetic fractures, infections, or other implant complications requiring urgent removal. It is therefore critical for the treating surgeon to know the compatibility of the screw removal system with the previously implanted hardware. Furthermore, despite acquisition of a

detailed prior operative report, there may still be ambiguity with respect to driver size and configuration as this may not be specifically enumerated in the operative report.

To assist surgeons removing unfamiliar instrumentation, several major orthopaedic implant companies have begun compiling universal extraction sets that take advantage of implant and driver compatibility amongst companies and simplify the extraction process.[16,17] While helpful, these removal sets do not include a compatibility reference and require direct visualization of the screw head to guide driver selection. These constraints make implant removal difficult, and necessitate intraoperative determination of implant and removal-set compatibility without the ability to plan instrument needs pre-operatively.

The purpose of this study is to facilitate removal of upper extremity specific orthopaedic implants by compiling a reference detailing the compatibility of screws produced by the most commonly used upper extremity orthopaedic implant companies[18] with regard to two commonly used implant removal sets and generally available driver configurations.

Material and Methods:

This study did not require Institutional Review Board (IRB) approval given criteria met for exempt status and no involvement of human or animal subjects. Orthopaedic implant manufacturer inclusion was determined by market share based upon industry-monitoring financial firms.[17] Publicly available surgical technique guides, typically in portable document format (PDF), were retrieved for each manufacturer of plate osteosynthesis implants for the phalanges, metacarpals, scaphoid, distal radius, forearm, olecranon, and humerus. Intramedullary or arthroplasty implant sets were excluded. Each technique guide was thoroughly reviewed for implant and screwdriver information and, in some cases, surgical

representatives were contacted to clarify the screw size and screw drive configuration, along with known removal set compatibility options. Screw and screwdriver compatibility were assessed and compared to two commonly utilized universal screw-removal sets as determined by the two highest grossing orthopaedic implant companies, Johnson & Johnson (J&J)/Depuy/Synthes (Raynham, MA) and Stryker (Kalamazoo, MI).[19] The data was compiled in table format with non-cannulated, locking, and cannulated screw offerings for each included company. Guide-wire size compatibility for cannulated offerings were also assessed and documented.

Results:

The top nine highest grossing upper extremity implant companies in 2017 according to market share were J&J/Depuy/Synthes with 31.5% of the market share, Zimmer/Biomet 23%, Wright Medical 10.5%, Stryker 8.4%, Smith & Nephew 4.2%, Exactech 4%, DJO 3.6%, Integra 0.8%, and Arthrex 0.2%.[18] DJO medical does not produce osteosynthesis implants and accordingly was excluded from this analysis. In total, eight upper extremity implant companies with commonly implanted upper extremity screws were included in this review.

The following tables are divided into company-specific, noncannulated, cannulated, and locking screws; they are further organized by screw diameter, screw type, guidewire diameter (if cannulated), driver type, the driver's catalog number, and the universal removal set where the required driver can be found. If the manufacturer of the implant is known, the surgeon can use **Table 1** to find the relevant removal information grouped by manufacturer. If the manufacturer is unknown, the surgeon can use a calibrated radiograph to identify and measure the screws and refer to **Table 2** (noncannulated, nonlocking screws), **Table 3** (cannulated

screws), or **Table 4** (locking screws). These tables are arranged by screw diameter and contain all associated extraction information for easy reference.

With proper preoperative planning, a surgeon can use these tables to determine which of the commonly available implant removal sets contains the necessary driver for a successful implant removal. While almost all the screws described in the tables can be removed by either the Synthes and/or the Stryker implant removal kits, there are a few screws that have non-traditional drive types. If the table indicates the necessary driver is not available in either removal set, then the catalog number of the driver produced by the manufacturer is provided. These catalog numbers are provided for all screws listed in the chart to allow surgeons to opt for a single driver if that option is available at their institution.

Discussion:

The proliferation of orthopaedic implant designs has allowed fixation to be tailored to specific injury patterns and greater options for orthopaedic surgeons. However, this diversity of implants is also problematic when implanted hardware requires removal especially when the operating surgeon did not perform the index procedure. Complications following implant removal for upper extremity fractures can be as high as 40%.[15] Selection of the appropriate driver is paramount to the success and expediency of an implant removal surgery. Indeed, it has been shown that a single slippage event can halve the maximal torque tolerated by a screw and hamper screw removal.[20]

The data reported in this study was prepared in an effort to facilitate appropriate driver selection for removal of upper extremity orthopaedic implants. One potential benefit of this data is reduced hospital cost. Operating room (OR) cost ranges from $22 to $133 per

minute,[21,22] not including surgeon and anesthesiologist time. Improved OR efficiency through appropriate driver selection pre-operatively and expeditious surgery can represent a significant time and cost savings. More accurate instrument selection and avoided instrument tray reprocessing could yield further savings, ranging from $75 to $330 per instrument set not used.[23]

Limitations of this study include the lack of inclusion of all upper extremity orthopaedic companies in the overall analysis. Though data from industry monitoring financial firms was used to compile a list representing 82% of the market share for upper extremity orthopaedic implants, companies with a smaller market share were omitted due to logistical necessity.[18]Additionally, although care was taken to ensure the accuracy of information collected for the reference, sample equipment was not available to perform physical verification with the implants themselves. Accordingly, the information presented in this manuscript is to serve as a guide and by no means a comprehensive or definitive source.

Future areas of study include the goal of identifying how readily this guide may be used to facilitate specific screw identification based upon a radiograph with magnification markers according to the proposed characteristics. It would further be beneficial to determine the distinct cost savings incurred through use of this guide with regard to both operative time and reprocessing costs.

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