SHORT COMMUNICATION

Defining the Era of Shoulder Arthroscopy 2.0: A Perspective on Integrating Precision, Biology, and Smart Technology

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Abstract

Over the past four decades, shoulder arthroscopy has advanced from diagnostic exploration to sophisticated therapeutic procedures. However, current techniques remain limited in addressing complex pathologies. We propose the concept of the Era of Shoulder Arthroscopy 2.0 (ESA2.0)—defined by surgical precision, biological integration, and digital innovation. Technologies such as three-dimensional (3D) imaging, augmented reality, and robotics are being explored to enhance accuracy and reproducibility. Concurrently, biological strategies, including platelet-rich plasma, stem cells, and scaffold-based techniques, may improve healing. Smart systems, including AI-assisted diagnosis and wearable rehabilitation tools, support more personalized treatment and optimize outcomes. This paradigm may define a future standard in arthroscopic care, offering solutions to challenges previously deemed intractable.

Level of evidence: N/A

Keywords: Biological augmentation, Precision surgery, Shoulder arthroscopy, Smart technologies

Introduction

Over the past four decades, shoulder arthroscopy has evolved dramatically from a diagnostic tool into a key therapeutic technique. Initially adapted from knee arthroscopy in the 1980s, it was primarily used to manage instability and perform subacromial decompression.[1] Subsequent advances, including suture anchor technology, significantly broadened its clinical applications, establishing arthroscopy as the standard treatment for rotator cuff tears and shoulder instability (the 1.0 era).[1] Despite these successes, limitations persist, particularly in managing complex pathologies such as massive rotator cuff tears and substantial glenoid bone defects. Recognizing these shortcomings, we propose the concept of the era of shoulder arthroscopy 2.0 (ESA 2.0), framing these approaches as emerging, integrative strategies that emphasize advanced technologies and selective biological augmentations to overcome current challenges.

Main body

Definition of The ESA 2.0

The ESA 2.0 is proposed as a transformative shift toward greater precision, biological integration, and smart technology. Beyond merely refining existing techniques, this new era emphasizes individualized treatment approaches, leveraging advanced imaging, regenerative medicine, and artificial intelligence (AI) to potentially enhance clinical outcomes and address previously intractable shoulder conditions.

Precision Surgery

Precision surgery is a cornerstone of the ESA 2.0 concept, characterized by highly individualized preoperative planning and advanced intraoperative navigation. The integration of three-dimensional (3D) imaging, augmented reality (AR), and early-stage robotic assistance allows surgeons to achieve unprecedented accuracy in complex

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procedures. For example, AR navigation systems provide real-time visual guidance, significantly improving the accuracy of anatomical structure placement and reducing the risk of complications associated with improper positioning.[2] By contrast, truly robotic assistance in soft-tissue shoulder arthroscopy remains at an early, largely investigational stage: cadaveric feasibility work has shown that robotic platforms can technically perform diagnostic and simple arthroscopic maneuvers but face instrumentation and workflow limitations, indicating that clinical deployment is not yet established.[3] Recent overviews of robotic-assisted arthroscopy similarly frame current systems as promising for precision (stability, tremor filtration, reproducible trajectories) yet emphasize the need for dedicated shoulder-specific tools, validation, and workflow integration before routine clinical adoption.[4] Moreover, the use of AI-driven image analysis and computer-assisted guidance is emerging to support preoperative diagnosis and tailored surgical planning, potentially enabling better prediction of clinical outcomes and more individualized care. Taken together, these technologies are best regarded as emerging adjuncts that may advance precision in shoulder arthroscopy pending further shoulder-specific evidence and clinical validation.

Biological Augmentation

Advancements in arthroscopic shoulder surgery are increasingly investigating biological adjuncts to enhance tendon healing and repair durability. Platelet-rich plasma (PRP) is a prominent example, delivering concentrated growth factors to injury sites. Despite mixed results in early trials, PRP—especially leukocyte-poor preparations applied at the tendon–bone interface— has been reported in selected studies to reduce rotator cuff retear rates and improve short-term functional scores.[5] Mesenchymal stem cell (MSC) therapies represent another frontier in biologic augmentation. Augmenting rotator cuff repair with bone marrow–derived MSCs has shown higher healing signals in observational and early clinical series.[6] Similarly, adipose-derived regenerative cells injected into partial-thickness tears have demonstrated safety and, in some reports, superior clinical improvement compared to steroid treatment.[7] Scaffold-based techniques are also being explored to biologically reinforce repairs. Bioinductive patches and grafts (e.g., collagen scaffolds or dermal allografts) can be arthroscopically overlaid on repairs to serve as a healing matrix. Certain studies indicate that patch augmentation can lower retear rates and improve tendon integrity.[8] However, clinicians must remain vigilant for issues such as immune responses or infection and consider cost-effectiveness, as these biologically enhanced strategies are not yet uniformly adopted and continue to evolve.

Smart Surgical and Rehabilitation Technologies

Artificial intelligence and machine learning are increasingly under study for perioperative decision-making. AI-driven image analysis can achieve high experimental accuracy in detecting rotator cuff tears on magnetic resonance imaging (MRI) and even automating anatomic measurements for surgical planning. Moreover, predictive algorithms are being investigated to forecast patient-specific outcomes, such as the likelihood of repair failure or suboptimal recovery, enabling more personalized surgical strategies.[9] Although current AI applications in shoulder arthroscopy are largely experimental, early results underscore the future potential for more data-informed, precision surgery in the near future.[9]

On the postoperative front, wearable sensors and digital health platforms are increasingly evaluated for rehabilitation. Inertial measurement unit (IMU) sensors integrated into braces or wearables can enable continuous monitoring of shoulder kinematics during daily activities. Coupled with machine-learning analytics, such systems may accurately classify and track rehabilitation exercises, facilitating remote coaching and timely feedback.[10] A digital home exercise program (with virtual feedback) has been reported to achieve functional gains equivalent to or superior to those of standard physiotherapy, while requiring fewer clinical resources.[11] Innovative approaches, such as augmented reality-based therapy, have likewise demonstrated enhanced recovery outcomes: patients performing AR-guided shoulder exercises post-rotator cuff repair report significantly greater improvements in shoulder function than those on conventional programs.

Conclusion

The ESA 2.0 is best understood as an emerging framework that integrates precision technology, minimally invasive methods, personalized 3D surgical planning, and biological augmentation technology. This collective approach aims to improve functional outcomes, accelerate recovery, minimize pain, and reduce complication risks in shoulder arthroscopy, pending broader validation and clinical adoption.

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