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ELBOW

Modified anteromedial and anterolateral elbow arthroscopy portals show superiority to standard portals in guiding arthroscopic radial head screw fixation

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Abstract

Purpose Arthroscopic fixation of radial head radial head fractures is an appealing alternative to open reduction and internal fixation, which presents the advantage of minimal surgical trauma. The aim of this study was to evaluate if modifications to the standard anteromedial (AM) and anterolateral (AL) portals could allow screw placement for radial head fracture osteosynthesis closer to the plane of the radial head articular surface.

Methods Eight fresh-frozen specimens were prepared to mimic arthroscopic setting. Standard AL (ALst) and AM (AMst) and distal AL (ALdi) and AM (AMdi) portals were established. Eleven independent examiners were asked to indicate the optimal trajectory, when aiming to place a cannulated screw parallel to the radial head surface for radial head osteosynthesis. A three-dimensional digital protractor was used to measure the angle between the indicated position and a Kirschner wire placed parallel to the radial head articular surface (α). The Shapiro–Wilk normality test was used to evaluate the normal distribution of the samples. Means, standard deviations, and 95% confidence intervals (95% CI) were calculated for each portal. A coefficient of variation (CoV) was calculated to determine agreement among observers and intra-observer variability.

Results Mean α angles were $25.1 \pm 11.5°$ for AMst, $13.8 \pm 4.8°$ for AMdi, $17.1 \pm 13.4°$ for ALst, $-2.6 \pm 9.2°$ for ALdi. No overlapping in the 95% CI of ipsilateral standard and distal portals was observed, indicating that the difference between these means was statistically significant. The distal portals showed smaller inter-observer CoV as compared to the standard ones (AMst: 10.0%; AMdi: 4.6%; ALst: 12.5%; ALdi: 10.6%). Intra-observer CoV was similar for all portals (AMst: 5.5%; AMdi: 6.1%; ALst: 7.7%; ALdi: 7.1%).

Conclusions The use of distal AM and AL portals permits to obtain α angles closer to the radial head articular surface than standard AM and AL portals. This is expected to allow screw placement in a flatter trajectory, which should correlate with a superior biomechanical performance of fixation. Good reproducibility of Kirschner wire placement from distal portals was observer among different examiners. Modifications to the standard AM and AL elbow arthroscopy portals allow to place screws for radial head fracture osteosynthesis in a position which should guarantee superior biomechanical performance of fixation.

Keywords Elbow · Arthroscopy · Radial head · Fracture · Fixation · Anatomical study

Introduction

Arthroscopic fixation of radial head fractures is an alternative treatment option to open reduction and internal fixation (ORIF), in specific fracture types. Arthroscopy improves visualization of the articular surface of the radial head, which leads to a better understanding of the morphology of the fracture lines and fragments, and offers the possibility of distinctly testing joint stability [1–3]. Moreover, it permits

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to precisely assess and treat accompanying intra-articular pathology, like traumatic cartilage lesions, ligament injuries and lose bodies [4, 5]. Another advantage when compared with ORIF is the limited soft tissue dissection, which can improve healing by maintaining blood supply, may decrease the analgesic requirement and might shorten the hospital stay [6–8].

However, there is no evidence in the literature giving proof on an advantage of arthroscopic fracture fixation of the radial head, compared to open procedures. Although encouraging results have been reported by few authors, clinical data on arthroscopic fixation of radial head fractures is currently scarce, as are studies comparing open and arthroscopic fixation techniques [2, 3, 9]. Even more, arthroscopic radial head fixation is a technically demanding and potentially time-consuming procedure, with specific risks and complications [10].

One of the most challenging steps of this procedure is correct placement of Kirschner wires into the radial head, to facilitate temporary fixation of fracture fragments and to serve as a guide wire for cannulated screws for definitive fixation [2, 3]. In this process, selecting the appropriate portal for Kirschner wire introduction and directing the Kirschner wire correctly are relevant factors for a successful surgery: in facts, biomechanical principles indicate that a screw inserted perpendicular to the fracture line achieves a superior primary stability of an osteosynthesis [11]. Furthermore, to prevent iatrogenic irritation of articular structures, appropriate length and trajectory of the screws are critical, and malpositioning of the guiding Kirschner wire can lead to a descending course and result in excessively long screws.

To our knowledge, only one anatomical study investigated the technical aspects of this procedure. In their recent study on an arthroscopic radial head fracture fixation cadaveric model, Hodax and colleagues investigated the influence of the portals on the accessibility of the radial head in the axial plane; however, their study did not consider the sagittal and coronal planes [12].

Hence, the aim of the present study was to evaluate if modified anteromedial (AM) and anterolateral (AL) portals could assist in placing screws for radial head fracture osteosynthesis with an inclination closer to that of the radial head articular surface. The study hypothesis was that AM and AL portals placed 1 cm more distally would facilitate a flatter trajectory of the screws onto the radial head as compared to the standard AM and AL portals.

Materials and methods

For the present study, eight fresh-frozen cadaver specimens of upper extremities from human donors were available (females: 50%; right elbows: 37.5%; median age at death: 75.5 years). The specimens were obtained and prepared for a standard arthroscopic setting.

Before investigation, care was taken to evaluate the specimens for visible signs of previous trauma, gross instability or deformity. Radiographic images were taken to visualize integrity of the bony structures and joint congruency.

Prior to arthroscopy, under digital fluoroscopic control (Fluoroscan Insight-FD Mini, Hologic Medicor GmbH, Kerpen, Germany), a 1.6 mm Kirschner wire was drilled in the radial shaft, parallel to the radial head articular surface and 10 cm distal to the radiocapitellar joint (Fig. 1). This Kirschner wire (Kirschner wire-zero) was used as reference parallel to the radial head for subsequent measurements. The distal radioulnar joint was transfixed in neutral position of the forearm with another 1.6 mm Kirschner wire to prevent pronosupination of the forearm, as rotational movements would be associated with confounding of the measurements.

Arthroscopy was performed with the elbow positioned at 90° of flexion, mimicking patient positioning in lateral decubitus. Standard AM (AMst) and AL (ALst) and modified, distal AM (AMdi) and AL (ALdi) portals were established, strictly respecting osseous landmarks (Fig. 2). Table 1 reports the relative position of the study portals to elbow anatomical landmarks.

Diagnostic arthroscopy was performed. Subsequently, on one specimen, 11 independent examiners, all with experience in elbow arthroscopy and radial head fracture osteosynthesis (members of the ESSKA Elbow and Wrist committee 2016–2018), were asked to indicate with a 1.2 mm Kirschner wire the optimal trajectory, when aiming to place a cannulated screw parallel to the radial head surface for radial head osteosynthesis.

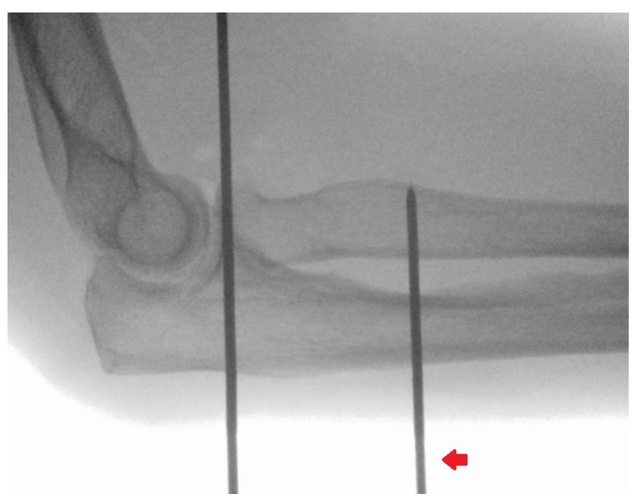

Fig. 1 Digital fluoroscopic control of the correct position of the reference Kirschner wire (Kirschner wire-zero, red arrow) with respect to the radiocapitellar joint

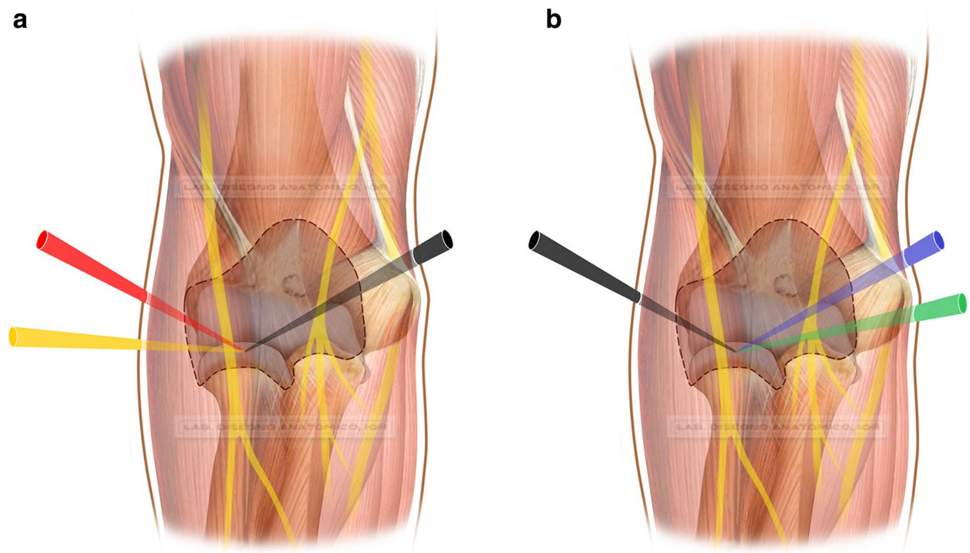

Fig. 2 Graphic illustration of the simulated arthroscopic setting, illustrating arthroscope and Kirschner wire positions to address the radial head from: **a** Standard (red) and distal (yellow) anterolateral (AL) portals; **b** Standard (blue) and distal (green) anteromedial (AM) portals. The arthroscope's position is represented in black: to work from the AM portals, the arthroscope was placed in the standard AL portal, whereas to work from the AL portals, the arthroscope was moved in the standard AM portal

Table 1 Relative position of the study portals to elbow anatomical landmarks

Portal	Antomical landmark	Position
AMst	Medial epicondyle	2 cm proximal and 1 cm anterior
AMdi	Medial epicondyle	1 cm proximal and 1 cm anterior
ALst	Lateral epicondyle	2 cm proximal and 1 cm anterior
ALdi	Lateral epicondyle	1 cm proximal and 1 cm anterior

AMst standard anteromedial portal; AMdi: distal anteromedial portal, *ALst* standard anterolateral portal; ALdi: distal anterolateral portal

The "screw inclination angle" (α) was defined as the angle between the plane parallel to the radial head (Kirschner wire-zero) and the trajectory of the Kirschner wire described above (Fig. 1). An external observer, not included among the examiners and not involved in the statistical evaluation of the collected data, measured the angle α with a three-dimensional digital protractor with one decimal digit accuracy (NixGame Developer, Penza, Russian Federation). The aforementioned task was repeated for each portal by 11 independent examiners on one specimen to assess inter-rater reproducibility, and by a single examiner (K.W.) on further seven specimens to assess intra-rater reproducibility.

Institutional approval of the study protocol was obtained by the Nicola's Foundation and ICLO Research Center (ID10603).

Statistical analysis

Statistical analysis (A.M.) was performed using GraphPad Prism v 6.0 software (GraphPad Software Inc.). The Shapiro–Wilk normality test was used to evaluate the normal distribution of the sample. Continuous variables were expressed as median and interquartile range [first quartile–third quartile] or as mean ± standard deviation, as appropriate. A coefficient of variation (CoV) was calculated to determine agreement among observers and intra-observer variability. Statistical evaluation of the differences among the groups was performed using one-way analysis of variance (ANOVA) with post hoc Sidak's multiple comparisons test. The significance level was set at p value lower than 0.05. The sample size was based on the methods of a previously published study on elbow arthroscopy portal placement [13].

Results

Measurements were obtained in the medial compartment (AMst and AMdi portals) for 11 examiners, whereas in the lateral for nine examiners for the ALst portal and eight for the ALdi portal. Mean α angles were 25.1 ± 11.5° (95% CI 17.4°–32.9°) for AMst, 13.8 ± 4.8° (95% CI 10.5°–17.0°) for AMdi, 17.1 ± 13.4° (95% CI 6.8°–27.4°) for ALst, − 2.6 ± 9.2° (95%CI − 10.3° to 5.2°) for ALdi. (Fig. 3).

No overlapping in the 95% CI of standard and modified portals was observed, indicating that the difference between these means was statistically significant; this was observed both for measurements repeated by different examiners on a single specimen (AMst vs. AMdi: $p = 0.049$; ALst vs. ALdi: $p = 0.001$) and for measurements repeated by a single examiner on different specimens (AMst vs. AMdi: $p = 0.009$; ALst vs. ALdi: $p = 0.001$). (Fig. 4).

The practical consequence of the results presented in Fig. 4 is that the modified portals permit to reach a Kirschner wire placement angle significantly closer to the radial head articular surface. The modified portals, in particular the AMdi, showed smaller inter-observer CoV as compared to

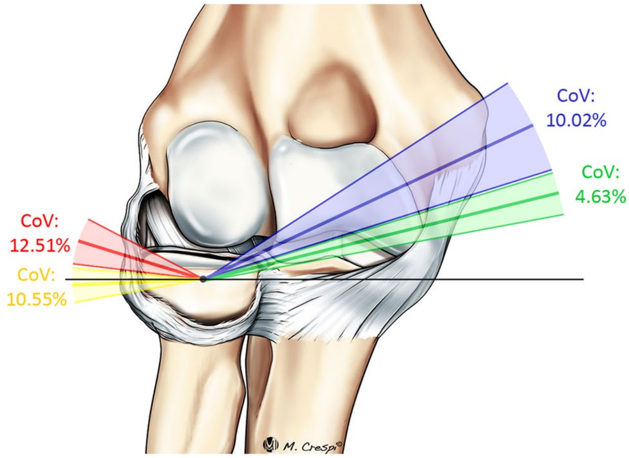

Fig. 3 Diagram of the radial head with superimposed mean α angles (thick solid lines) and their 95% CI (coloured area) for the AMst (blue), AMdi (green), ALst (red) and ALdi (yellow). The width of each coloured area is related to the coefficient of variation (CoV) among observers. *AMst* standard anteromedial portal, *AMdi* distal anteromedial portal, *ALst* standard anterolateral portal, *ALdi* distal anterolateral portal

the standard ones (AMst: 10.0%; AMdi: 4.6%; ALst: 12.5%; ALdi: 10.6%—Fig. 3).

When evaluating measurements repeated by a single examiner, the intra-observer CoV appeared similar for all portals (AMst: 5.5%; AMdi: 6.1%; ALst: 7.7%; ALdi: 7.1%).

Discussion

The main finding of this study is that modifications to the standard AL and AM elbow arthroscopy portals permit to place guide wires for cannulated screws in a flatter trajectory (α angle closer to the radial head articular surface). Thereby, placement of the screws parallel to the radial head articular surface should be facilitated and, according to present knowledge, this can affect the clinical practice, since a flatter trajectory should correlate with an enhanced biomechanical performance of fixation in fractures of the radial head and might facilitate the procedure [11, 14].

Moreover, this study showed good reproducibility of this operative technique, with a smaller inter-observer CoV for the modified portals as compared to the standard ones, indicating a more precise placement of the wires through the modified portals.

Fractures of the radial head occur commonly and delayed or inappropriate treatment may lead to limitation of forearm pronosupination with subsequent disability in everyday and working activities.

Radial head and neck fractures are divided into four groups according to the Mason classification [15], subsequently modified by Hotchkiss [16].

Optimal treatment should ensure anatomical reduction, stable fixation and avoid unnecessary soft tissue damage. Reduction and fixation is indicated in some type II and type III or IV fractures. Arthroscopic fixation can be considered for fractures with a maximum of two displaced fragments, still attached to the radial head. Fragments dislocated out of the radiocapitellar joint are usually not amenable to arthroscopic fixation [17].

Arthroscopy is an appealing alternative to ORIF for radial head fractures amenable to screw osteosynthesis, which presents the advantage of reduced surgical trauma [5, 8]. Furthermore, elbow arthroscopy allows to directly visualize the articular surface of the radial head, which leads to a better understanding of the morphology of the fracture lines and fragments [1–3] and permits to assess and treat other intra-articular pathology, for example performing a debridement of cartilage lesions or removing loose cartilage fragments [2, 4]. Eventually, arthroscopy can permit to combine procedures extremely demanding

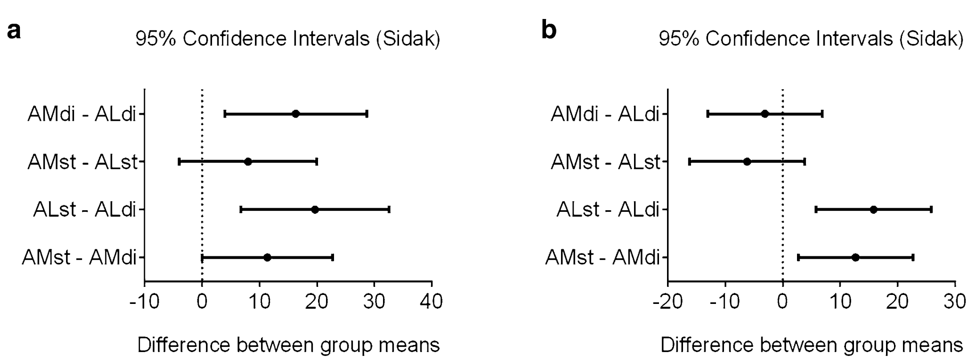

Fig. 4 Ordinary one-way ANOVA graph showing the 95% confidence intervals computed by Sidak's multiple comparisons test for the difference between the average α that can be contacted from one portal compared with the homolateral portal and the symmetric contralateral portal. **a** Multiple comparisons from 11 different examiners on one specimen. **b** Multiple comparisons from the same examiner on eight different specimens. *AMst* standard anteromedial portal, *ALst* standard anterolateral portal, *AMdi* distal anteromedial portal, *ALdi* distal anterolateral portal

with an open approach, like simultaneous radial head and coronoid osteosynthesis [18].

Reported results for arthroscopic fixation of radial head fractures are encouraging [2, 3, 6, 19–21]: Michels et al. [2] reported on 11 excellent and three good results out of 14 Mason type II radial head fractures treated by arthroscopically assisted reduction and percutaneous fixation, and Rolla et al. [3] showed satisfactory functional outcomes in six patients. More recently, Wang et al. [22] indicated arthroscopically assisted reduction and percutaneous fixation with Kirschner wires as reliable tool to achieve accurate reduction and rapid recovery on 18 patients with Mason type II and two with Mason type III radial head fractures [23]. Finally, Dawson and Inostroza [1] reported on the arthroscopic reduction and percutaneous fixation of a radial neck fracture in a child. Commonly, headless lag screws are used to perform radial head ARIF: to ensure an optimal arthroscopic treatment, proper placement of these fixation devices is fundamental.

Lag screws achieve highest primary stability on bone segments not subject to axial loads when placed perpendicularly oriented to the fracture surface [11]. Since most radial head fractures run perpendicular to the radial head articular surface, ideal screw inclination (α) would be at an angle of 0° to the radial head articular surface.

In contrast to ORIF, where the surgical approach permits to obtain this placement relatively easily, in ARIF α is restricted by portal placement. This is due to the fact, that only minimal trajectory deviations are allowed by soft tissue displacement and that numerous structures can interfere with the placement of the Kirschner wire in relation to the radial head surface, like the extensor muscles, the plica or the annular ligament, which lay in close proximity to the radial head [24]. Moreover, since thin screws are used for fixation of radial head fractures (e.g., 2.2–3.0 mm screws), also thin guide wires need to be placed, and the resistance of the annular ligament can be enough to sidetrack such wires. Finally, another issue that can influence proper screw placement is the fact that the arthroscopic view is 2-dimensional: malpositioning of the guide wires is then possible, since the radial head is a 3-dimensional structure and the surgeon usually only sees half of it through the arthroscope. Modifications of the standard portals have been described, especially in the lateral compartment [13, 25, 26], but the role of portals modification in assisting screw placement has not been discussed yet. Our investigation demonstrates for the first time that modifications in portal placement can significantly and favourably affect α. The average α that could be contacted from the ALdi portal was very close to the ideal target value of $\alpha = 0°$, with individual measurements reaching also theoretically undesired negative α values. This indicates that a certain degree of overcorrection can be expected from this portal, suggesting potential for a better intra-operative handling of fracture fragments.

Alternatively to anterior portals, screw fixation via a posterolateral portal can also be considered; however, the annular ligament is less mobile in its posterior part and this may significantly interfere with screw trajectory; moreover, since most fracture lines enter the posterolateral quadrant and exit the radial head through the anterior quadrants, posterior portals frequently don not allow direct fixation, thus making anterior portals a more versatile option [27].

Intra-operative complications of arthroscopically-assisted radial head fracture osteosynthesis include damage to neurovascular structures, ligaments and cartilage. Neurovascular damage is the most feared complication of elbow arthroscopy, in particular with anterior portals [28, 29].

The posterior interosseous nerve is separated from the joint capsule in its proximal course by the brachialis muscle, whereas distally, when passing at the level of the radial head, no muscle bellies divide this structure from the joint. Therefore, in arthroscopic radial head fracture fixation, injury to the posterior interosseous nerve may occur during portal placement and after accidental damage to the anterior joint capsule, which is separated from this nerve just by a thin layer of muscle and adipose tissue [10, 30–32].

On the anteromedial aspect of the elbow, the brachial artery and the median nerve lie superficial in a groove between the muscle bellies of the biceps brachii and the brachialis and follow the medial borer of the biceps brachii in anterolateral direction. Whereas in the anteromedial aspect of the elbow modifications of the standard AM portal can be conducted rather safely, with moderate risk of endangering the brachial artery and the median nerve [13], modifications to the AL portal may increase the risk of accidental damage to the posterior interosseous nerve, especially by excessively distalizing the AL portal towards the radiocapitellar joint line [10, 32, 33]. This implies that, to prevent neurovascular injuries, no portals can be created at an angle of $\alpha = 0°$ with respect to the radiocapitellar plane. Therefore, a compromise between safety and feasibility of the procedure and biomechanical efficiency of the fixation device is achieved by placing the screw with $\alpha \neq 0°$ (Fig. 5).

Limitations of this study include that it is an anatomical study on a limited number of specimens; this may amplify bias related to technical aspects of the procedure and does not allow differentiating between anatomical variants. Moreover, arthroscopic setting preparation and portal placement was performed by a single examiner; since experience-based variations on the standard portals are possible, other examiners with different habits might have been confounded by entering in a procedure initiated by a different surgeon. Furthermore, the study was designed to compare portals in terms of a mere geometric parameter (screw inclination angle), and not to investigate the

Fig. 5 Postoperative radiograph after arthroscopically assisted radial head fracture osteosynthesis using two cannulated screws, showing that different screw inclination angles with respect to the radial head articular surface can be obtained with the arthroscopic technique

potential complications or the possible technical difficulties related to these variations in the standard AL and AM portals. For example, the risk of an injury to the posterior interosseous nerve limits the distalization of the AL portal in a clinical setting [10, 32]. In this cadaveric setting, the main goal of the study was to obtain an angular measurement as precisely as possible. Transfixation of the distal radioulnar joint in neutral position was hence necessary to abolish the variations related to the rotational movements of the forearm. This, on the other hand, impedes to translate any finding related to the risk of posterior interosseous nerve injury to the clinical setting, as here maximal pronation of the forearm is mandatory whenever performing lateral extra-articular procedures, as portal placement [33]. Since forearm pronation was incompatible with a comparison between medial and lateral portals as desired the current study setting, a dissection of the lateral structures to seek for posterior interosseous nerve injuries has been avoided, because not effective in demonstrating portal safety. A dedicated study with specific focus on the lateral portals is expected to evaluate safety and reproducibility of the ALdi portal. Finally, in this study, performance description for selected arthroscopic portals in a simulated setting of radial head fracture osteosynthesis was focused primarily. The nature of the study did not allow investigating on local pathologies of the soft tissues. Nevertheless, care was taken in evaluating the specimens for any visible signs of previous trauma, gross instability or deformity.

Future anatomical studies with dedicated setting are needed to investigate the relation between the distal AM and AL portals and the neurovascular structures of the elbow, especially to clarify the safety of modified AL portals.

Conclusions

The use of modified, distal AM and AL portals permits to obtain α angles closer to the radiocapitellar plane than standard AM and AL portals. This is expected to correlate with a superior biomechanical performance of fixation. Good reproducibility of Kirschner wire placement from distal AM and AL portals was observed among different examiners.

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Author contributions DC: study design, data collection, original draft preparation; PA: study design, surgical procedures; FL: study design, data collection; AL: statistical analysis, figures and tables; EG: surgical procedures, anatomical illustrations; LPM, CB: manuscript correction; DE: surgical procedures, manuscript correction; KW: study design, surgical procedures, manuscript correction.

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Compliance with ethical standards

Conflict of interest Author DC declares that he has no conflict of interest. Author PA declares payment for development of educational presentations from Arthrex, outside the submitted work. Author FL declares that he has no conflict of interest. Author AM declares that she has no conflict of interest. Author EG declares that he has no conflict of interest. Author LPM declares consultancy for Arthrex, Medartis and Tornier, outside the submitted work; payment for travel/accommodations expenses from Arthrex, Medartis and Tornier, outside the submitted work; institutional grants from Medartis and Tornier, outside the submitted work. Author CB declares that he has no conflict of interest. Author DE is educational consultant for AO and educational consultant for Lima. Author KW declares consultancy for Arthrex, Medartis and Tornier, outside the submitted work; payment for travel/accommodations expenses from Arthrex, Medartis and Tornier, outside the submitted work; institutional grants from Medartis and Tornier, outside the submitted work.

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