J Shoulder Elbow Surg (2025) 34, e906–e912

ELSEVIER

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

Bone graft augmentation of comminuted radial neck fractures improves the initial stability of plate fixation. A biomechanical study

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Background: Using modern implants, even complex radial head and neck fractures can often be reconstructed. However, metaphyseal comminution is associated with delayed bone healing and an increased risk for loss of reduction. Hence, this biomechanical in-vitro study intended to evaluate the mechanical stability of a bone graft from the ipsilateral proximal ulna in plate fixation of comminuted radial neck fractures.
Methods: Osteotomies at the level of the radial neck with a 3 mm defect were created on 20 fresh-frozen proximal radius specimens to simulate metaphyseal comminution. Fixation was performed with a locking radial head plate in group A and with an additional structural bone graft from the ipsilateral ulna in group B. Cyclic loading from 5-100 N was performed and axial displacement and stiffness were evaluated.
Results: The axial displacement was larger in group A (0.81 ± 0.24 mm) than in group B (0.52 ± 0.27 mm) ($P = .02$). Group B had a higher axial stiffness compared to group A (300 (127-958) N/mm vs. 163 (82-209) N/mm, $P = .015$).
Conclusion: In the case of metaphyseal comminution of radial head/neck fractures, additional bone graft augmentation from the proximal ulna results in significantly increased stability of locking plate fixation. Future clinical research should focus on whether this leads to improved union rates of these challenging fractures.
Level of evidence: Basic Science Study; Biomechanics

Keywords: Bone graft; elbow; fracture; radius; comminuted; ORIF; radial head; radial neck

This study was approved by the local ethical committee of the Medical Faculty of the University of Cologne (reference number: 23-1335).

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Fractures of the proximal radius represent the most frequent type of elbow fracture. The incidence is reported to be 2.5 per 10,000 individuals annually, with an average age of presentation at 43 years.[10] The predominant trauma mechanism is a fall on the outstretched arm.[5] As the radial head plays a crucial role in forearm movement and axial

https://doi.org/10.1016/j.jse.2025.01.032

load transmission, and contributes to elbow joint stability, restoring the structural integrity and physiological function is vital.[12] These fractures range in severity from simple, nondisplaced fractures to complex, displaced, comminuted fractures, potentially accompanied by soft tissue injuries.[5] The treatment options vary according to the severity of the fracture, extending from conservative treatment to surgical interventions aimed at restoring the anatomical position of the radial head and neck.[9] Comminuted fractures prove to be a challenging operation even for advanced surgeons. Whenever possible, the aim is to preserve the native anatomy, in this case, the radial head. Possibilities of radial head reconstruction have been improved by the development of fixed-angled, anatomical plates. This is also indicated by better long-term results for preserving the radial head in contrast to radial head arthroplasty.[14] Although this should be confirmed by more recent studies. Additionally, fixing these fractures successfully may reduce inherent risks of radial head arthroplasty such as overstuffing and chondrosis of the capitellum. Therefore, the current treatment of choice, especially for younger patients, involves open reduction and internal fixation (ORIF) using fixed-angle plates and/or screws.[14] The prolonged time of consolidation, especially after on-table reconstructions, leads to increased risks of failure of fixation.[9] There is a growing emphasis on innovative procedures aiming to improve the primary construct stability and load-bearing capacity of the osteosynthesis. Consequently, the question arises whether augmentation of plate fixation with a bone graft from the ulna offers biomechanical advantages and thus potentially increases the consolidation rate of these fractures. Therefore, this study hypothesized that the biomechanical stability of comminuted radial neck fractures is improved by the use of an ulna bone graft.

Methods

Biomechanical setup

Twenty fresh-frozen elbow specimens without any noticeable deformity, degeneration, or previous pathology were available for this study. The soft tissues were removed and the proximal 10 cm of the radius were harvested by using a bone saw (see Fig. 1).

Fixation was performed using an anatomical locking plate (TriLock Radial Head Buttress Plate 2.0 mm, (A-4656.69), Fa. Medartis, Basel, CH). The plate was fixed to the shaft bicortically with one cortical screw and 2 locking screws. Five locking screws were inserted in the radial head without penetration of the far cortex (see Fig. 2).

Afterwards, a 3 mm defect zone orthogonal to the shaft, at the level of the radial neck immediately distal to the articular cartilage, was created with an oszillating saw. This was done to simulate metaphyseal comminution. After randomization in 2 groups, group A received plate fixation only, while in group B, a bone graft was harvested from the ipsilateral metaphyseal ulna and additionally implanted into the defect zone. The aspired bone graft

Figure 1 Isolated proximal radius after excision from the elbow.

should be press-fit in the defect zone, not exceed the outer cortex of the radius and not reach the cortex on the side of the plate osteosynthesis. It was harvested from the metaphyseal ulna by

Figure 2 Radial head with osteosynthesis.

incising the ulna as seen in Figure 3. approximately in an area 5 mm wide and 5 mm long with an oscillating saw and extracting the bone graft with a chisel, so that an approximately 3 mm thick graft was extracted. The graft size was adjusted to not exceed the outer cortex of the radius. It was then placed on the opposite side of the plate osteosynthesis. No additional cancellous bone was used.

The shaft of the radius was then secured in polymethylmethacrylate and mounted vertically in a servohydraulic testing machine (Zo10; Zwick/Roell, Ulm, Germany). In order to mimic the articulation of the capitulum humeri with the radial head, a sphere was fixed to the mobile traverse of the testing machine and then placed on the articular surface of the radial head. Thus, downward movement of the mobile traverse leads to compression forces onto the proximal radius (Fig. 4).

A preload of 5 N was applied. Then, an axial pressure of up to 100 N across 1000 cycles with a speed of 1 mm/s was applied. A maximal vertical movement of 10 mm was established as the criterion for failure, at which point the testing would be stopped. The threshold chosen exceeded the defect zone size, as oscillation might lead to more vertical movement. Both the applied force, in N, as well as the depth of compression, in mm, were documented.

Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics (version 29.0 for Mac; IBM Corp., Armonk, NY, USA). Results are presented as median (min – max) and/or mean ± standard deviation depending on the distribution. Student's T-test was applied for normally distributed data, the Mann–Whitney-U Test for non-normally distributed data. A P value of $<.05$ was considered statistically significant.

Results

Specimen characteristics

The mean age of the body donors was 75 ± 12 years. The specimens were derived from 9 female and 11 male donors. Ten left and 10 right specimens were used. At the site of the defect zone, the mean diameter was measured 15.1 ± 1.1 mm. There was no statistical difference in age or diameter of the radial neck between the 2 groups ($P = .15$, $P = .16$, respectively).

Biomechanical results

The results of the individual specimens are included in Table I.

The mean compression was 0.67 ± 0.29 mm. The axial displacement was larger in group A (0.81 ± 0.24 mm) than in group B (0.52 ± 0.27 mm) ($P = .02$). For the first 500 cycles, an overall compression of 0.64 ± 0.28 mm was measured. Group A had a larger axial displacement (0.79 ± 0.21 mm) than group B (0.49 ± 0.26 mm) ($P = .011$). The last 500 cycles showed a mean axial displacement of 0.70 ± 0.31 mm. For those cycles, group A also had a larger axial displacement (0.84 ± 0.26 mm) than group B (0.56 ± 0.29 mm) ($P = .036$) (see Fig. 5).

The mean stiffness was 178 (82-958) N/mm, for the first 500 cycles 185 (89-1011) N/mm and for the last 500 cycles 172 (76-906) N/mm. Group B showed significantly higher stiffness (300 (127-958) N/mm vs. 163 (82-209)N/mm, $P = .015$).

In the first 500 cycles Group B showed improved stiffness to 331 (135-1011) N/mm compared to 165 (89-214) N/mm ($P = .015$). For group B, the stiffness was also significantly higher in the last 500 cycles (261 (119-906) N/mm vs. 161 (76-203) N/mm, $P = .035$) (see Fig. 6).

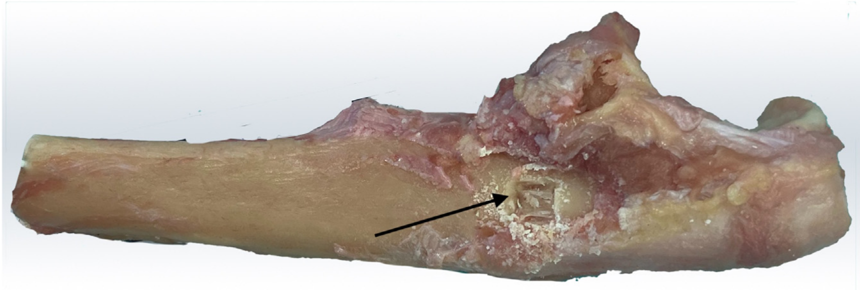

Figure 3 Ulna with defect zone of obtained bone graft.

Figure 4 Proximal radius with plate fixation and bone graft placed in the test machine for testing.

Discussion

This study shows that the stiffness of radial neck fractures treated by plate osteosynthesis can be improved by using a bone graft from the proximal ulna. This may further improve the possibilities of preserving the radial head in these fractures, as this has been considered more reliable than radial head arthroplasty. In the management of complex radial head fractures with metaphyseal comminution, radial head arthroplasty was long considered the most suitable treatment option. However, advances in plate designs now offer the potential to preserve the joint even in complex cases. Boulas et al demonstrated that ORIF yields superior biomechanical stability compared to both excision and conservative treatment of those fractures.[2] Nevertheless, from a clinical perspective, the treatment of comminuted radial head fractures remains challenging. The most relevant risk associated with ORIF in such cases is failure of fixation due to delayed union. Fracture healing is influenced by multiple factors, encapsulated in the ''diamond concept,'' which states that biomechanical stability is equally needed for fracture healing as other factors.[7] Those other factors include osteoinductive mediators, osteogenic cells, and the osteoconductive matrix. All factors are needed for a successful bone healing response. This study focused on the improvement of the biomechanical stability. Recent studies, including a meta-analysis of biomechanical trials, have shown that anatomical locking plates offer superior biomechanical stability compared to other fixation methods in the treatment of proximal radius fractures.[3,16] Earlier studies using nonanatomical plates indicated comparable results between screw fixation and plate osteosynthesis for uncomminuted radial neck fractures.[4,8] If a defect zone is present, screw osteosynthesis could only be possible with a loss of length or with reduced biomechanical stability. Plate-osteosynthesis should be the preferred implant choice in these cases. It still raises the question of whether biomechanical stability can be further enhanced. Our findings indicate that additional bone graft augmentation results in improved axial stability, increased stiffness, and reduced axial displacement. Alhough these improvements are limited to those fractures that can be treated by plate-osteosynthesis, excluding nonreconstructable fractures.

Burkhart et al evaluated various options for ORIF of radial head and neck fractures. The authors demonstrated that anatomical locking plates provide the most stable results. However, the study group did not examine the additional usage of bone graft augmentation and the plate used

Table I Individual specimen demographics and overall average results of the tested parameters

Specimen no.	Gender	Age	Group	Average compression depth in mm	Average stiffness in N/mm
1	male	76	A	1.05	105
2	male	72	A	0.59	200
3	female	85	A	1.33	82
4	male	76	A	0.77	155
5	female	85	A	0.76	160
6	female	67	A	0.69	175
7	male	72	A	0.71	167
8	male	46	A	0.68	177
9	male	58	A	0.98	127
10	male	63	A	0.58	209
11	female	88	B	0.34	378
12	female	80	B	0.37	412
13	female	88	B	0.67	178
14	female	67	B	0.29	474
15	male	77	B	0.16	958
16	male	77	B	0.30	468
17	male	67	B	0.66	202
18	male	89	B	1.01	127
19	female	93	B	0.83	150
20	female	67	B	0.61	221

in this study was a more modern design. Consequently, the average axial stiffness of 36 N/mm might be lower than the axial stiffness observed in our study.[3]

In clinical practice – especially if there is a comminution zone at the metaphysis or in case of on-table reconstructions – failure of fixation can be observed frequently. This is still observed when using anatomical locking plates. In our study, the additional bone graft augmentation significantly improved biomechanical properties. This suggests an increase in primary overall construct stability. A reduced risk of early failure of fixation could subsequently be achieved, although this has to be proven in clinical studies. Additionally, with improved stiffness, possible compression and loss of length of comminuted radial neck fractures might be improved. The implementation of a bone graft might also improve primary length reconstruction and therefore improved range-of motion and stability of the elbow, although this has to be proven in clinical studies as well. Further studies are needed to determine the optimal grafting techniques in this situation. Comparing both groups, the use of bone grafts in our study also demonstrated a greater variance in data as 2 of the 10 examined specimens showed a higher stiffness without presenting themselves as a statistical outlier. The reason for that might be attributed to the characteristics of the bone graft used: Constructs were likely stiffer when the bone graft contained a higher proportion of cortical bone or was more effectively press-fitted into the fracture zone. As reported by the literature, the mean cortical thickness of the ulna is around 1 mm.[17] A part of the used bone graft was therefore cancellous bone and this proportion may impact the results. Future research should investigate whether bone grafts sourced from other locations, with a higher cortical bone content, might further enhance outcomes, though the potential risks associated with different harvest sites must be weighed. Studies were able to show that the ulna is prone to comparably low donor-site morbidity risks.[1,6,11] For scaphoid non-unions a comparative study of bone grafts from the distal radius vs. those from the iliac crest was performed. It did not demonstrate superior outcomes or reduced adverse events with iliac crest grafts.[15] Moreover, Ribak et al recently highlighted the ulna as a viable bone graft donor site for upper limb defects in a cadaveric study.[13] When placing the bone graft periosteal stripping might occur and placement of the graft medially after placement of the plate might by difficult especially in posttraumatic swollen tissues due to limited access. Thus, despite acknowledging the variance observed among the different specimens tested—attributable primarily to individual bone quality and characteristics of the bone graft from the body donors—the significant increase in stiffness observed in our biomechanical testing should encourage surgeons to consider the addition of bone graft augmentation in complex fractures of the radial head with metaphyseal comminution. This is particularly advisable, given the minimal donor site morbidity associated with bone graft harvesting, suggesting its potential for routine implementation in clinical practice. Ultimately, this approach could facilitate a faster rehabilitation process, crucial not only for patients with compromised bone quality but also for individuals with high functional demands, such as young and active patients, especially athletes aiming for an early return to competition. Beyond potentially reducing the risks associated with revision surgery, the improved primary stability may lead to earlier return to full weight bearing.

The limitations of this study include the production of the defect zone, the chosen loading protocol and the tested forces. In clinical fractures, this defect zone may show different patterns. However, preceding biomechanical studies used the same procedure, as a reproducible fracture-zone creates better comparability within one study as well as between different studies.[3] The performed loading protocol was chosen to be comparable to the previous studies on this topic.[3,8] Other loading protocols might yield deviating results. Additionally, our study primarily focused on axial loads, while the proximal radius is also subject to rotational longitudinal forces, which warrant further investigation. Nevertheless, prior research has shown that findings related to axial stiffness can yield consistent insights applicable to other types of forces as well.[3] Further, in terms of primary construct stability, the axial load-bearing capacity is the most

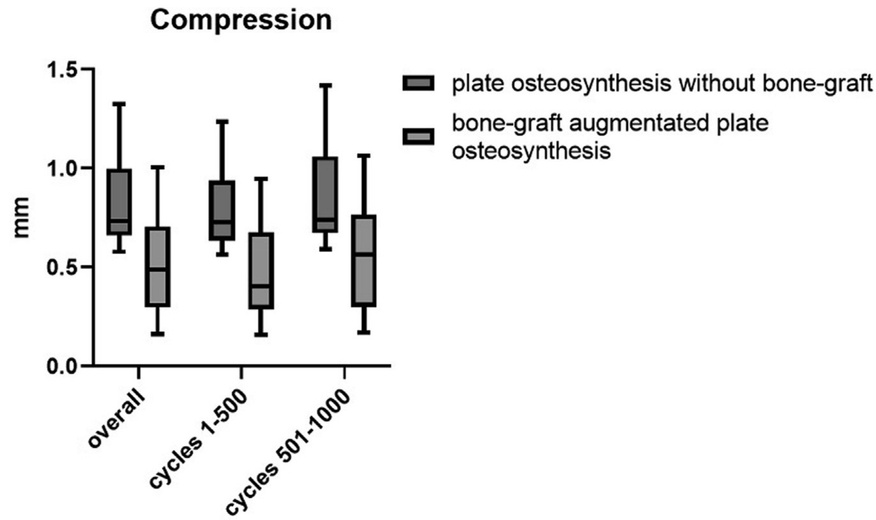

Figure 5 Axial displacement of both groups in mm.

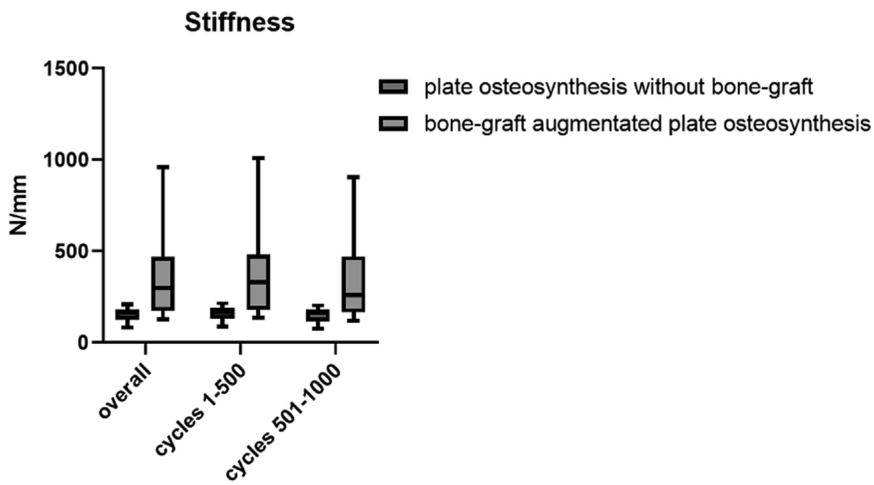

Figure 6 Stiffness of both groups in N/mm.

clinically relevant in terms of fracture healing as it is the main force acting on the radial head.[12] Efforts were made to minimize differences between the groups by selecting specimens from either side of the donor whenever possible, further supported by the lack of statistically significant differences in age and radial neck diameter between the groups.

Conclusion

Our findings demonstrate that additional bone graft augmentation significantly enhances the biomechanical in-vitro stability of plate fixation of comminuted radial neck fractures. Given the minimal morbidity associated with bone graft harvesting from the ipsilateral proximal ulna, its use in clinical practice may be beneficial. The clinical benefits, however, should be further validated in clinical investigations.

Acknowledgments

We thank the anatomical institute of the University of Aachen for providing us with specimens. We thank

Medartis AG, Switzerland, for providing the implants for this study.

Disclaimers:

Funding: The study material was partially provided by Medartis AG.
Conflicts of interest: The authors, their immediate families, and any research foundation with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

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