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The effect of sagittal and rotational malalignment of distal humeral fractures on elbow mobility: a cadaveric study.

W. EERENS[1], J. DUERINCKX[1,2], L. VAN MELKEBEKE[1], D. MATHIJSEN[3], L. POPLEU[3], R. VAN RIET[4,5], P. CAEKEBEKE[1,2]

[1]Ziekenhuis Oost-Limburg, department of Orthopaedic surgery and traumatology, Schiepse Bos 6, 3600 Genk, Belgium; [2]University of Hasselt, faculty of Rehabilitation sciences, Martelarenlaan 42, 3500 Hasselt, Belgium; [3]University of Hasselt, faculty of Medicine and Life Sciences, Martelarenlaan 42, 3500 Hasselt, Belgium; [4]University Hospital Antwerp, department of Orthopaedic surgery, Wilrijkstraat 10, 2650 Edegem, Belgium; [5]AZ Monica, Department of orthopedic surgery, Stevenslei 20, 2100 Deurne, Antwerp, Belgium.

Correspondence at: Pieter Caekebeke, Schiepse Bos 6, 3600 Genk, Belgium. Phone: +3289 32 6118 - Email: Caekebeke.pieter@hotmail.com

This study aims to investigate the correlation between axial and sagittal malrotation of distal humerus fractures and elbow mobility. A transverse distal humerus fracture was generated in 5 cadaveric specimens. Rotation of the distal humeral fragment was performed on the medial column with a stable lateral column, as well as rotation of the lateral column with a stable medial column. Elbow flexion and extension range of motion were measured and repeated with an additional 5° and 10° of sagittal flexion and extension fracture deformity. All 4 fracture types suffered extension loss with increasing rotation. A peak extension loss was found within the range of 10-14° rotational deformity. A significant decrease in flexion of up to 50° was found in type MS2 fractures due to the interference of the radial head and the humeral metaphysis. Conversely, increased flexion motion was found in MS1 types. Fracture types and rotational malalignment should be considered when analyzing distal humeral fractures to predict future mobility with conservative treatment. The radial head seems to be the dominant factor in type MS fractures to predict flexion increase or limitation, while the extension limitation will gradually increase in both LS and MS type fractures. Future in vivo radiological and clinical studies are needed to validate these results.
Level of Evidence: 3b.

Keywords: Elbow, Fracture, rotation, sagittal, malunion, distal, humerus, stiffness.

INTRODUCTION

Distal humeral fractures account for approximately 1-2% of all fractures in adults and about 12-17% of pediatric fractures[1–3]. These fractures exhibit a bimodal distribution within the population, manifesting either in the young, due to high-energy trauma or in the elderly following low-energy falls[4]. Given their complexity and frequent complications, managing these fractures poses significant challenges for orthopedic surgeons. Treatment approaches encompass conservative and surgical methods[5-7].

Open reduction and internal fixation (ORIF) has become the preferred approach for displaced distal humeral fractures in adults, aiming to achieve stable fixation while restoring length and rotation[8-11]. However, complications of ORIF reach up to 35%, and the risk is higher in elderly patients due to factors such as osteoporosis, metaphyseal comminution, compromised soft tissue conditions and general health status[12,13]. Although conservative treatment has a high rate of malunion, some fractures may still be treated conservatively due to the increased risk of complications[14]. Several studies have demonstrated reasonable clinical outcomes in elderly patients with distal humeral fractures managed conservatively, without elbow instability or excessive stiffness[7,9,14]. In general, distal humerus fractures seem to have good osseous healing potential with conservative treatment, but this usually means some degree of displacement has to be accepted (Figure 1)[15].

In the pediatric cohort, supracondylar fractures make up approximately 60% of all elbow fractures. Of these, 95% will display a sagittal extension angulation and in 5% a flexion angulation will be apparent[16]. Displaced unstable fractures are treated with closed reduction with or without percutaneous pinning (CRPP)[1]. When compared to sagittal deviations, it is

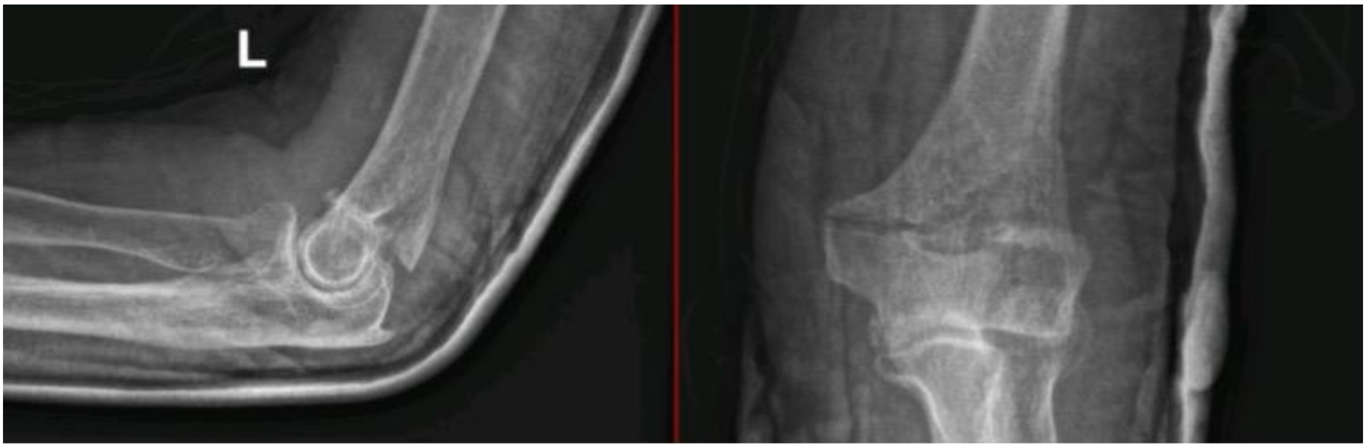

Fig. 1 — Example of a radiographs of patient with a type MS1 fracture pattern treated conservatively.

more difficult however, to assess subtle malrotations intraoperatively using fluoroscopy. Furthermore, unlike sagittal deviations, axial malrotations possess limited remodeling potential[17-18].

This study aimed to investigate the impact of malrotation and angulation in transverse metaphyseal humeral fractures on elbow mobility. We hypothesize that certain fracture patterns cause marked reduced flexion-extension mobility due to their rotational or sagittal deformity, thereby enhancing the ability to predict functional outcomes and the need for further open or closed reduction in such fractures.

MATERIALS AND METHODS

Cadaveric dissection

Dissection was performed by a single surgeon (W.E) on 5 upper extremity specimens of 4 individuals in the cadaver lab of a university. There were no signs of arthritis, previous elbow surgery or trauma in any of the specimens. The elbows were completely stripped of all muscle, leaving the lateral and medial ligamentous complexes of the elbows intact. Soft tissue removal was necessary to ensure adequate and reproducible pin positioning across the different specimens. A capsulectomy was performed and the olecranon fossa and coronoid fossa were exposed. An AO type 13A2.3 extraarticular, simple transverse fracture was made using an oscillating saw. Afterwards, a Hoffman external fixator was used to fix the fracture in different degrees of displacement. Two 4.0mm transverse self-drilling pins were placed parallel to the posterior humeral cortex in the middle third of the humerus. A half-wire 4.0mm pin was drilled trans-epicondylar in the humerus. A multiplanar framework was constructed with carbon rods so that the distal fragment could be manipulated in flexion and extension as well as in internal or external rotation (Figure 2).

A digital multiplanar angle protractor (DXL360S, Nogolo, 0.01° accuracy) was used to measure the

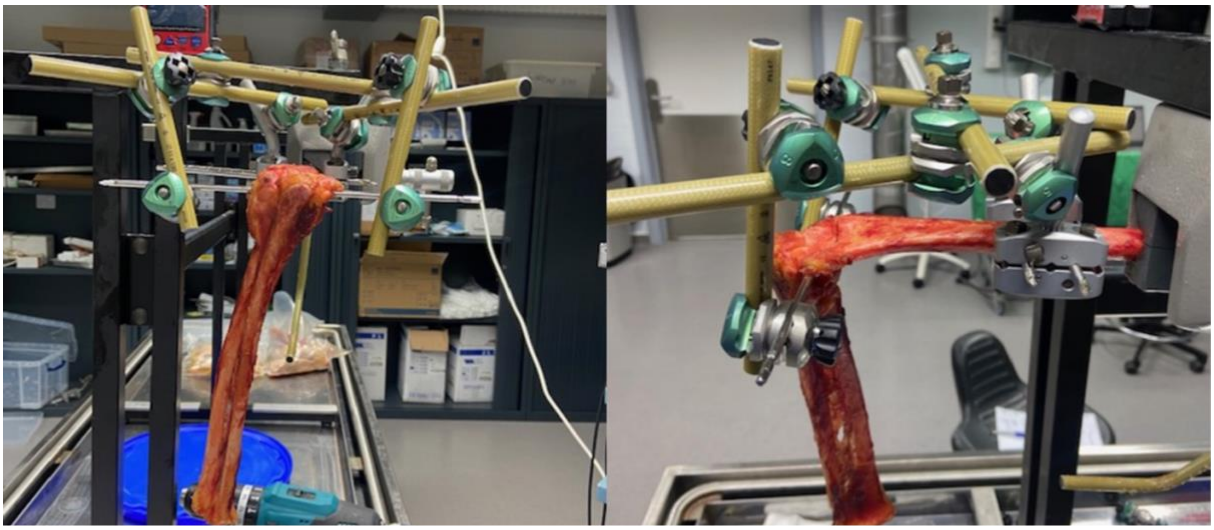

Fig. 2 — Example of a setup of the experiment.

degrees of deviation, with up to 2 decimal places. Mobility of the elbow was measured without axial rotation or sagittal malalignment of the fracture, to obtain a baseline value for each specimen. Flexion and extension were measured when there was osseous contact between the forearm and the humerus. In flexion this means when the radial head or coronoid process were in contact with the humerus. In extension this means when the tip of the olecranon contacts the humerus. The degrees between these two points Is measured as the range of motion (ROM). The reference point on the humerus was the posterior humeral cortex placed horizontal. The crista of the ulna was used as a reference of the forearm. Rotation was measured using the posterior condylar axis of the humerus. Elbow flexion and extension were measured while progressively rotating the medial column in internal (Type LS1) and external (Type LS2) rotation in the axial axis, with the lateral column kept stable using a 1.6mm K-wire placed centrally in de stable column. In this way, it could act as a center of rotation. One single K-wire provided sufficient stability due to the additional stability provided by the external fixator which was loosened and fixed in every measurement position after checking the degrees of axial and sagittal deformity using the digital angle protractor. We performed repeat measurements to assure sufficient stability. Increments of 2 degrees of external or internal rotation fracture displacement were used per step and these sequences were repeated with an additional 5° and 10° of extension and 5° and 10° of flexion of the fracture in the sagittal axis. Adding rotation was discontinued when there was no remaining osseous contact with the rotating column. No more than 10° of sagittal deformity was tested since in our opinion such abnormalities are indicated for ORIF. All measurements were repeated while rotating the lateral column in internal (Type MS1) and external (Type MS2) rotation with a stable medial column (Figure 3). Finally, the same measurements were performed for simulated rotational deformity around the central axis of the humerus. The measurements were performed once by a single measurer.

Statistical analysis

Descriptive statistics were performed for each fracture type, with different deviations in the sagittal plane.

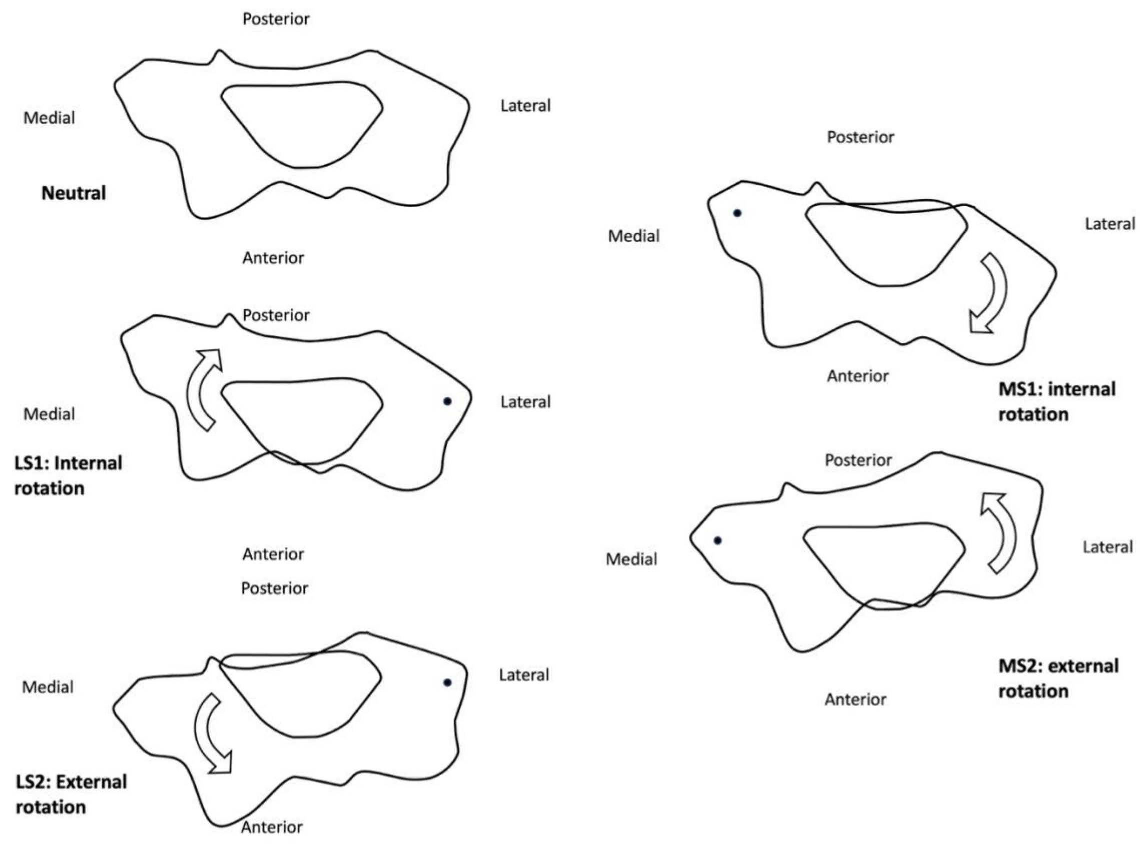

Fig. 3 — Diagram showing the different setups. Rotation of the distal humeral fragment was performed of the medial column in internal (Type LS1) and external (Type LS2) rotation with the lateral column in a stable position, as well as internal (Type MS1) and external (Type MS2) rotation of the lateral column, with a stable medial column. The black dot is indicating the stable column. The arrow signifies the direction of rotation.

We determined flexion and extension deviations; the mean, minimum, maximum and standard deviation were determined for each rotational deviation. The data were analyzed using linear mixed models. The main analysis was performed with rotations up to 14°, afterwards, there were very few observations with a high risk of extrapolation. Analysis was performed in SAS9.4.

RESULTS

A comprehensive analysis of the measurements is shown in additional supplementary Table 1. Rotation increased from 2 to 14° in all cadavers. Four cadavers had bony contact up to 20°. As the measurements were stopped when there was no bony contact, the endpoint of measurement differed between specimens. No significant differences were seen between the first and second measurements. There were no cases where motion was limited prior to bony impingement. An overview of the different fracture setups can be found in Figure 3.

Neutral Fractures

In Type LS1 fractures, elbow flexion limitations increased progressively with internal rotation. At 2° rotation, the limitation was 1.6°, rising to 4.4° at 6°, 7.6° at 10°, and 8.8° at 14° of rotation. Elbow extension limitation also increased with internal rotation, from 2° at 2°, to 3.6° at 6°, 6° at 10°, and 8.6° at 14° of rotatation.

For Type LS2 fractures, elbow flexion limitation remained stable from 0.6° at 2° rotation to -1.2° at 6°, -3.4° at 10°, and -1° at 14° of rotatation. In contrast, elbow extension limitation increased, from 3.8° at 2°, to 4° at 6°, 7.8° at 10°, and 12.2° at 14°.

Type MS1 fractures displayed a minimal decrease in elbow flexion limitation, from -0.4° at 2° rotation to -1.6° at 6°, -3.4° at 10°, and -2.6° at 14° of rotation. Extension limitation remained relatively stable, from 3.4° at 2°, to 2° at 6°, 3.2 at 10°, and 5.3° at 14°.

Type MS2 fractures exhibited a significant increase in elbow flexion limitation, beginning at 2.6° at 2° rotation and rising to 16° at 6°, 27.4° at 10°, and 43° at 14°. Extension limitations also increased, from 0.6° at 2°, to 0.8° at 6°, 1.8° at 10°, and 7.8° at 14°.

Fractures with rotation around the center axis of the distal humerus showed no significant differences in elbow flexion or extension with increasing internal or external rotation.

Fractures with 10° Sagittal Extension Deformity

In Type LS1 fractures with a 10° sagittal extension deformity, elbow flexion limitation increased progressively with internal rotation. At 2° rotation, the limitation was 1.2°, rising to 3.2° at 6°, 5° at 10°, and 12.6° at 14° of rotation. Extension limitation also increased, starting at 0.6° at 2°, and reaching 2.6° at 6°, 6.2° at 10°, and 8.3° at 14° of rotation.

For Type LS2 fractures with the same sagittal extension deformity, elbow flexion limitation decreased slightly with increasing internal rotation, from 0.4° at 2° rotation to –2.8° at 6°, 0.4° at 10°, and -1.33° at 14° of rotation. Extension limitation increased from 1.6° at 2°, to 3.4° at 6°, 6° at 10°, and 9.7° at 14° of rotation.

Type MS1 fractures with a 10° sagittal extension deformity showed minimal change in elbow flexion limitation, which ranged from -0.4° at 2° rotation to -3° at 6°, -5° at 10°, and 0° at 14° of rotation. Extension limitation increased, starting at 1.0° at 2°, rising to 4.8° at 6°, 8.4° at 10°, and 12° at 14° of rotation.

In Type MS2 fractures, elbow flexion limitation increased significantly, from 0.6° at 2° rotation to 6.6° at 6°, 13.6° at 10°, and 27° at 14° of rotation. Extension limitation also increased, from 0.6° at 2°, to 4° at 6°, 6.6° at 10°, and 10.7° at 14° of rotation.

Fractures with 10° Sagittal Flexion Deformity

For Type LS1 fractures with a 10° sagittal flexion deformity, elbow flexion limitations increased, starting at 1° at 2° rotation and increasing to 4° at 6°, 8.2° at 10°, and 8.8° at 14° of rotation. Extension limitations increased slightly, from -0.2° at 2°, to -2.2° at 6°, 2.6° at 10°, and 5.4° at 14° of rotation.

Type LS2 fractures with a 10° sagittal flexion deformity displayed slightly decreased elbow flexion limitations, from -0.8° at 2° rotation to -3.4° at 6°, -4.6° at 10°, and 0.4° at 14° of rotation. Extension limitations increased more, from 1.6° at 2°, to 4° at 6°, 8.8° at 10°, and 7.7° at 14° of rotation.

In Type MS1 fractures with a 10° sagittal flexion deformity, elbow flexion limitations decreased ranging from 1.2° at 2° rotation to -3.6° at 6°, -6.2° at 10°, and-7.7° at 14° of rotation. Extension limitations increased from 0.4° at 2°, to 5.4° at 6°, 10.2 at 10°, and 10.5° at 14° of rotation.

For Type MS2 fractures, elbow flexion limitations were substantial, increasing from 1° at 2° rotation to 17.4° at 6°, 32.2° at 10°, and 45.7° at 14° of rotation. Extension limitations increased from -0.4° at 2°, to -0.8° at 6°, 3.2° at 10°, and 6.8° at 14° of rotation.

A graphical representation of the mean values and patterns is shown in Figures 4-7. Figure 4 shows the flexion difference where type MS2 fractures show a significant flexion limitation compared to the other

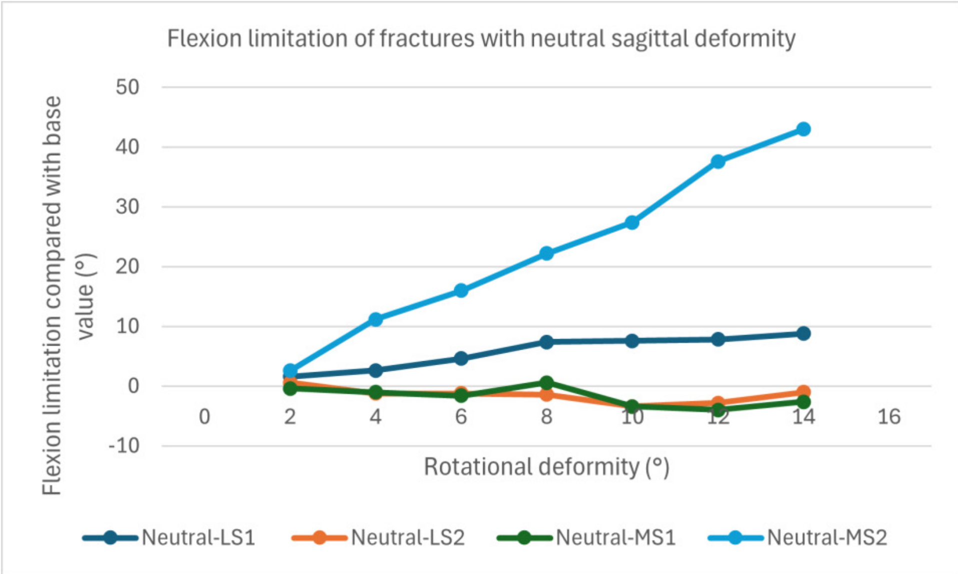

Fig. 4 — Shows the flexion limitation for the fractures types with no sagittal deformity. On the y-axis is the flexion limitation compared with the base value in degrees. On the x-axis is the degrees of rotational malalignment.

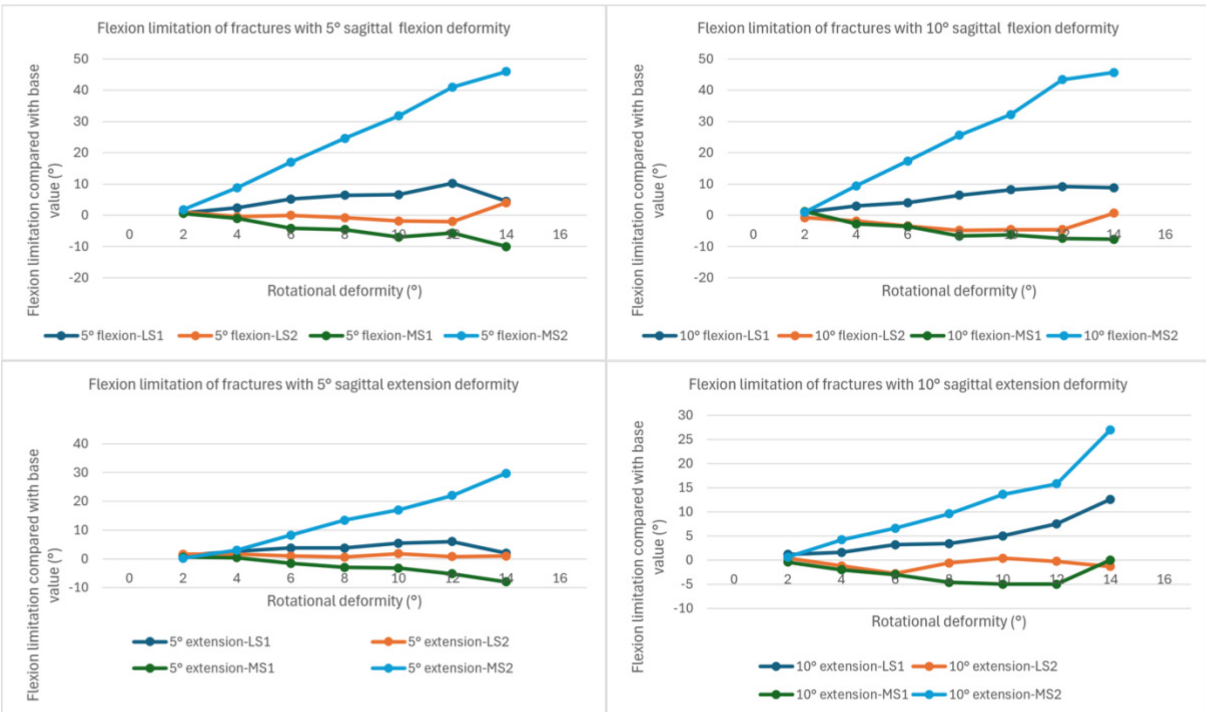

Fig. 5 — Shows the flexion limitations for the fracture types with different sagittal deformities. On the y-axis is the flexion limitation compared with the base value in degrees. On the x-axis is the degrees of rotational deformity.

fracture types ($p<0.05$) without sagittal deformity. Figure 5 shows the flexion differences for fractures with sagittal deformities. Figures 6 and 7 show the gradual extension limitation for all fracture types with increasing rotation.

DISCUSSION

Displaced distal humeral fractures in adults are typically treated surgically. However, due to their complexity, complications are relatively common. In the elderly population with diminished bone mineral density, poor soft tissue conditions and comorbidities, patient selection is crucial. Obert et

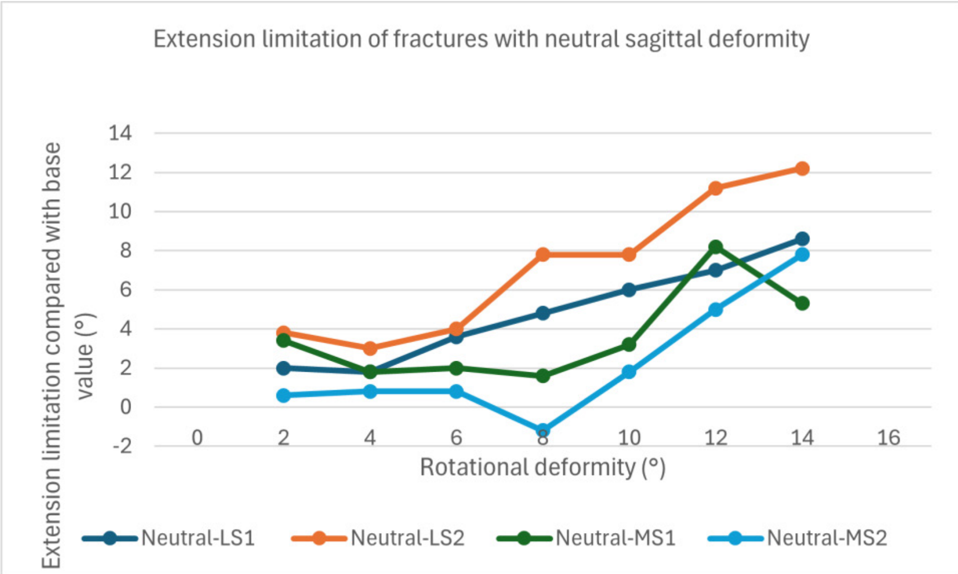

Fig. 6 — Shows the extension limitation for the fractures types with no sagittal deformity. On the y-axis is the extension limitation compared with the base value in degrees. On the x-axis is the degrees of rotational malalignment.

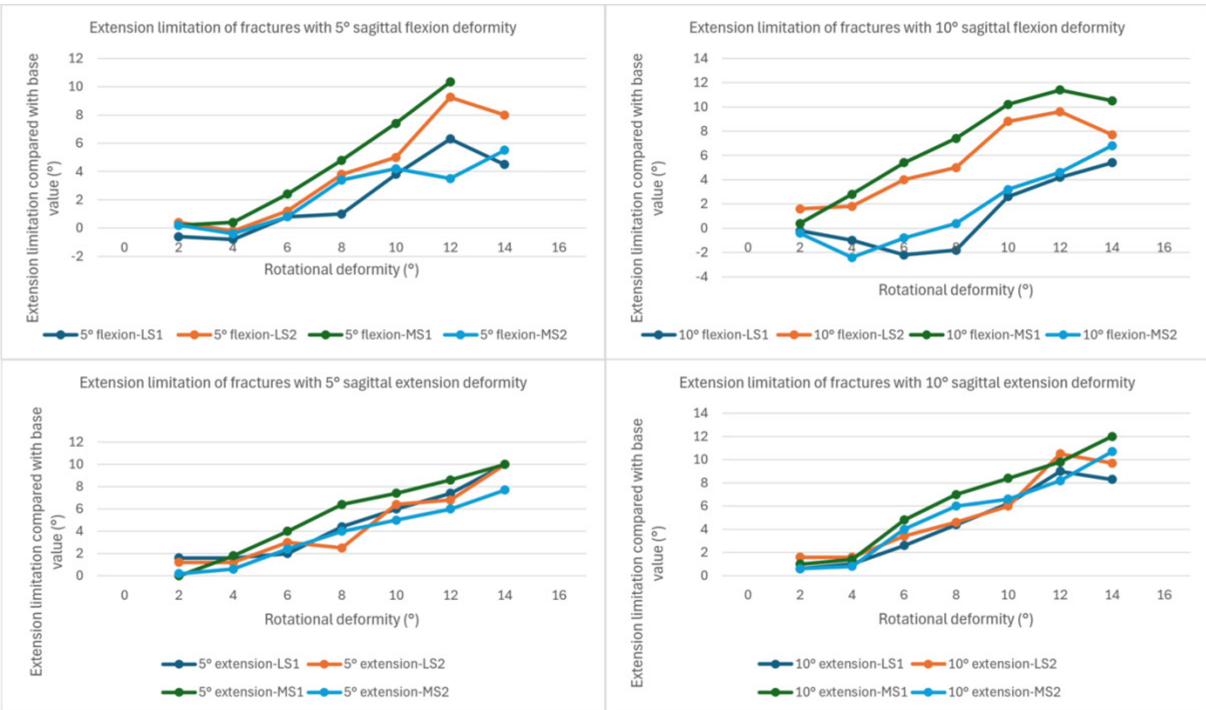

Fig. 7 — Shows the extension limitation for the fractures types with different sagittal deformities. On the y-axis is the extension limitation compared with the base value in degrees. On the x-axis is the degrees of rotational malalignment.

al. evaluated the complication rate of fractures in patients >65 years treated with ORIF[12]. They found a complication rate as high as 44%, most commonly ulnar nerve neuropathy, mechanical failures and wound dehiscence[12]. Navarro et al. found very low evidence for one treatment option over another for diaphyseal or distal fractures of the humerus, in elderly patients[19]. Batten et al. reported good healing potential and functional outcomes in patients treated conservatively, with early mobilization under the guidance of a physiotherapist[14]. Complication rate was 1.7%, and 93% of patients reported no pain at rest[14]. Pidhorz et al. evaluated conservative treatment using 6-8 weeks of cast immobilization[7]. Although there was an extra-articular malunion in 70% of the cases, there was a low complication rate and patients reported satisfactory functional clinical outcomes[7]. Little is known, however, about which fracture type, and how much rotational and sagittal malalignment of may be accepted for conservative treatment.

In the pediatric population, displaced supracondylar fractures are often treated with CRPP. Malrotation is a common complication[15,20,21]. Rotational spurs are detected in 5.6-23% of the cases based on previous studies[15,20,21]. Sagittal deformities have remodeling potential, mainly in children under 7 years of age[11]. Remodeling potential of rotational deformities is very limited[17]. Nevertheless, Greve et al. concluded that standalone axial malrotation, after transverse pediatric distal humerus, is not an indication for revision surgery[20]. They showed no significant functional difference or range of motion compared with the contralateral side after a mean follow-up of 7.3 years. However, no distinction was made with regards to the direction of malrotation. According to our results, medial stable type MS2 fractures should not be accepted in pediatric distal humerus fractures given their substantial flexion limitation. Another recent study demonstrated that elbow function, particularly the range of flexion, may be compromised by malrotation deformities up to six months postoperatively. These findings support our results, which indicate that malrotation primarily affects the range of flexion[22]. Unlike adult fractures, pediatric fractures cannot be directly assessed intraoperatively for reduction. Supracondylar humerus fractures in children commonly displace in two directions: posteromedial and posterolateral. For posteromedial displaced fractures, pronation of the forearm is typically used, while supination is employed for posterolateral displacements, with the periosteum aiding the reduction. After fixation, strict profile and coronal fluoroscopy should be performed to assess rotation; if reduction is inadequate, a K-wire can serve as a joystick, and in selected cases, open reduction may be required.

Significant axial malrotation is a risk factor for the development of cubitus varus deformity (CVD), the triad which can be described as varus, hyperextension, and medial internal rotation[23]. Significant malrotation deformities diminish the contact area of the fracture fragments which could lead to secondary collapse[24]. Gedikbas et al. showed that from a group of 88 supracondylar fractures treated with CRPP; 3 of 4 patients who developed a CVD had more than 20 degrees of rotational deformation[24]. Mahaisavariya et al. measured an average internal rotation deformity of 16.2 degrees in patients undergoing corrective osteotomies for CVD[25]. Our study shows that even small axial malrotations combined with sagittal deformities can cause marked functional limitations. Specifically type LS1 fractures with medial internal rotation as seen in CVD show only limited flexion limitation with increasing malrotation. We cannot determine whether this would be a risk factor for the development of CVD at a later stage.

In both the pediatric and adult populations, little is known about small rotational abnormalities of up to 20 degrees, combined with sagittal flexion and extension deformities on elbow mobility. Our study shows that rotational malalignment of transverse distal humerus fractures, influences flexion and extension mobility of the elbow. Type LS fractures showed minimal flexion limitation with growing rotational malalignment. These could be considered for conservative treatment, especially in the elderly population with multiple comorbidities. Type MS fractures showed an increase or decrease in flexion mobility. Type MS2 fractures specifically showed a limitation of flexion due to contact between the radial head and lateral humeral metaphysis. We showed flexion limitation of up to 51° is possible with 16° of rotational deformity. Conservative treatment of this type of fracture may lead to poor results. Whether the limitation in motion is acceptable depends on the individual needs of the patient. Previous studies suggest that a flexion range of up to 120° is generally sufficient for daily activities. However, this recommendation has become somewhat controversial as the demands of modern society, such as frequent cell phone use, may require greater flexibility[26]. Therefore, it is essential to discuss the range of motion expectations with the patient. Conversely, Type MS1 fracture showed an increase in flexion and may be better suited for conservative treatment (Figure 8). All fracture patterns lead to decreased extension with increasing rotational malalignment in this cadaveric setup. We suspect that this can be explained by the faster osseous contact between the tip of the olecranon and the humerus, given that during rotation the ideal axis of movement of the olecranon is disturbed. In general, the osseous extension limitation in our study remained limited at around 10° with increasing axial malrotation.

Measurement of the rotational deformity may be challenging. Computed tomography (CT) scans could be used. Rotational malalignment is measured as the angle between the trans epicondylar axis and the posterior cortex of the distal humerus and ideally, compared with the contralateral side. The von Laer's ratio, which is often used in pediatric populations to

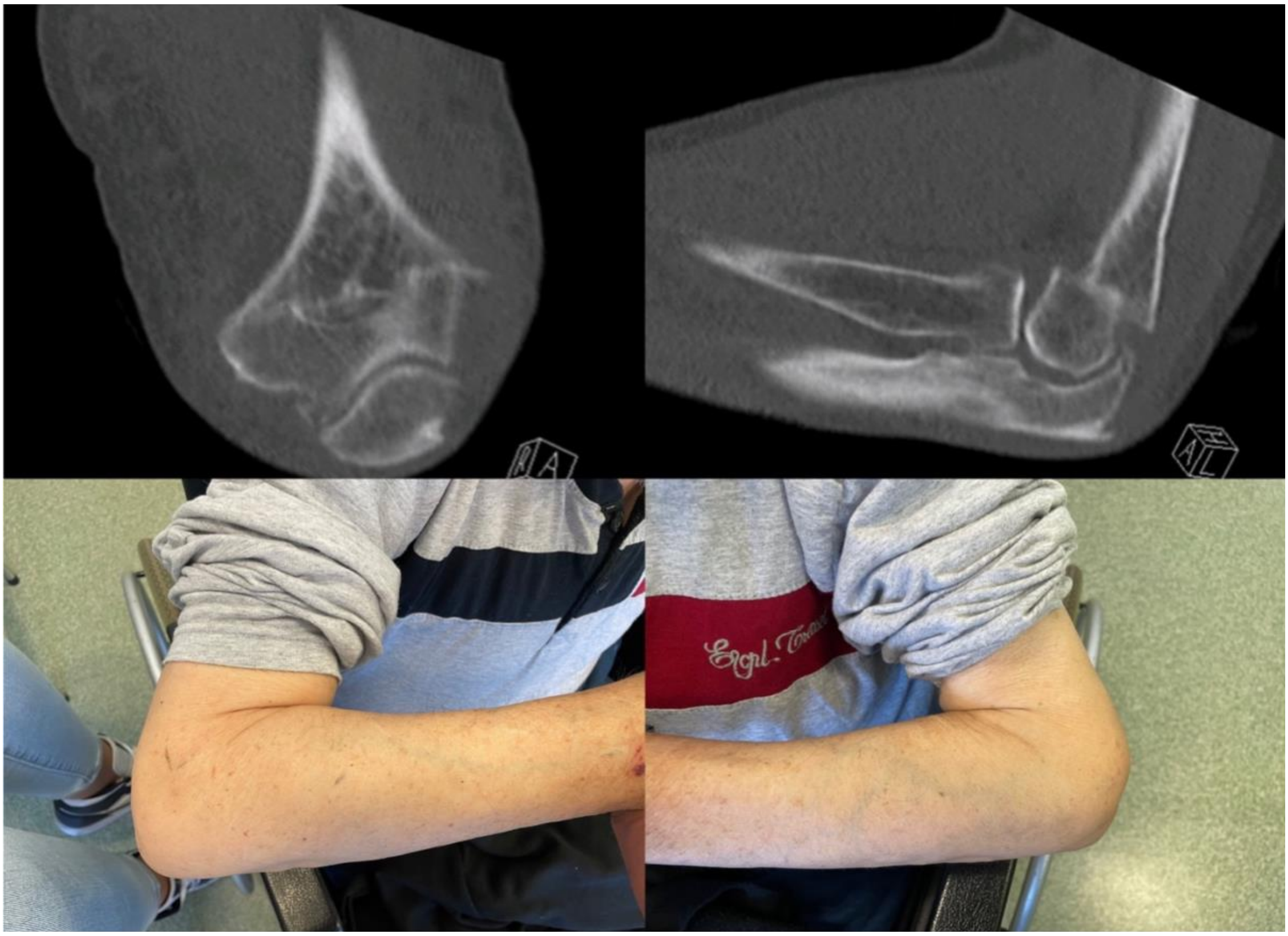

Fig. 8 — Shows the CT image of a MS1 type fracture. Below is the flexion of this patients at 6 weeks. The right image is the affected side with 10° increased flexion compared to the uninjured side.

evaluate the presence of a malrotation on standard radiographs in combination with a bony spur does not measure degrees of malrotation[23]. In the pediatric population, rotational malalignment can be measured on standard radiography of the elbow and upper arm using the technique of Henderson et al.[27] Henderson's technique uses the ratio of dimensions of the distal humerus in anteroposterior and lateral elbow radiographs. It has a 98% reliability with 5 degrees of accuracy at rotations of 15 to 55 degrees. In our setup with malrotation of up to 20 degrees, this technique is less useful in clinical practice due to the larger margin for error. One might consider performing a CT both pre- and postoperatively to adequately measure any malrotation. A preoperative CT would also allow for preoperative planning.

It is essential to acknowledge the limitations of present cadaveric study. We only analyzed 5 specimens due to financial considerations. This may lead to a low power. Further large scale investigation may be useful to validate the results. As the angle measurements were performed by a single measurer there is a possibility of error. However, as we performed multiple measurements, we are confident these were reproducible. This study focused solely on measuring flexion and extension limitations and did not investigate other relevant clinical outcomes. In addition, we focused primarily on bone conflict and not on soft-tissue limitations such as fibrosis and capsular contractions which could alter the clinical outcome. Further investigation is needed to evaluate the possible influence of soft tissue retractions and impingement. The muscles were also removed prior to measurements. This may influence the clinical outcomes in malrotation cases. However, as the motion limitation of muscles is mainly by active function this could not be evaluated in present cadaveric study.

The effect of post-operative care on potential loss of reduction is an important factor that was not evaluated in the present study. A cast that is too short may create a hinge effect, potentially leading to loss of reduction. Further research is needed to assess the impact of postoperative factors, such as cast immobilization, on the stability of the reduction and long-term outcomes.

Future research could expand these finding of present study by considering a broader range of outcome parameters, including functional scores and patient-reported outcomes measures to provide a more comprehensive understanding of the impact of distal humerus fractures and malalignment on elbow function.

Table SI. — Descriptive analysis of the results according to sagittal and rotational malalignment for each fracture pattern. A positive value in the flexion column means an increase in flexion limitation. A negative value means an increase of flexion. A positive value in the extension column means an increase in extension limitation. A negative value means an increase of extension. N= number of specimens, NA= Not applicable, SD= standard deviation, Avg: average result, Min: minimum, Max: maximum. Average rotation given in degrees.

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REFERENCES

1. Omid R, Choi PD, Skaggs DL. Supracondylar humeral fractures in children. J Bone Joint Surg Am. 2008;90(5):1121–32.
2. Ducic S, Stojanovic B, Lazovic M, Bukva B, Radlovic V, Bumbasirevic V, et al. T-condylar humerus fracture in children: treatment options and outcomes. Int Orthop. 2021 Apr 1;45(4):1065–70.
3. Strauss EJ, Alaia M, Egol KA. Management of distal humeral fractures in the elderly. Injury. 2007 Sep;38(SUPPL. 3):10–6.
4. Robinson CM, Hill RMF, Jacobs N, Dall G, Court-Brown CM. Adult distal humeral metaphyseal fractures: epidemiology and results of treatment. J Orthop Trauma. 2003 Jan;17(1):38–47.
5. Henley MB, Bone LB, Parker B. Operative management of intra-articular fractures of the distal humerus. J Orthop Trauma. 1987;1(1):24–35.
6. Korner J, Lill H, Müller LP, Hessmann M, Kopf K, Goldhahn J, et al. Distal humerus fractures in elderly patients: results after open reduction and internal fixation. Osteoporos Int. 2005;16 Suppl 2(SUPPL. 2).
7. Pidhorz L, Alligand-Perrin P, De Keating E, Fabre T, Mansat P. Distal humerus fracture in the elderly: does conservative treatment still have a role? Orthop Traumatol Surg Res. 2013 Dec;99(8):903–7.
8. O'Driscoll SW. Optimizing stability in distal humeral fracture fixation. J Shoulder Elb Surg. 2005;14(1 SUPPL.):S186–94.
9. Gupta R, Khanchandani P. Intercondylar fractures of the distal humerus in adults: A critical analysis of 55 cases. Injury. 2002 Jul 1;33(6):511–5.
10. Gupta RK. Intercondylar fractures of the distal humerus in adults. Injury. 1996 Oct 1;27(8):569–72.
11. Linhart WE, Kraus T. [Reconstruction of humeroradial joint]. Oper Orthop Traumatol. 2008;20(4–5):396–408.
12. Obert L, Ferrier M, Jacquot A, Mansat P, Sirveaux F, Clavert P, et al. Distal humerus fractures in patients over 65: complications. Orthop Traumatol Surg Res. 2013 Dec;99(8):909–13.
13. Södergård J, Sandelin J, Böstman O. Postoperative complications of distal humeral fractures. 27/96 adults followed up for 6 (2-10) years. Acta Orthop Scand. 1992;63(1):85–9.
14. Batten TJ, Sin-Hidge C, Brinsden MD, Guyver PM. Non-operative management of distal humerus fractures in the elderly: a review of functional outcomes. Eur J Orthop Surg Traumatol. 2018 Jan 28;28(1):23–7.
15. Dodds SD, Grey MA, Bohl DD, Mahoney EM, DeLuca PA. Clinical and radiographic outcomes of supracondylar humerus fractures treated surgically by pediatric and non-pediatric orthopedic surgeons. J Child Orthop. 2015 Feb;9(1):45–53.
16. Saeed W, Waseem M. Elbow Fractures Overview. StatPearls. 2023 Aug 7;
17. Hell AK, Gadomski C, Braunschweig L. Spontaneous humeral torsion deformity correction after displaced supracondylar fractures in children. BMC Musculoskelet Disord. 2021 Dec 1;22(1).
18. Smith L. Deformity following supracondylar fractures of the humerus. J Bone Joint Surg Am. 1965 Dec;47(8):1668.
19. Navarro CM, Brolund A, Ekholm C, Heintz E, Ekström EH, Josefsson PO, et al. Treatment of humerus fractures in the elderly: A systematic review covering effectiveness, safety, economic aspects and evolution of practice. PLoS One. 2018 Dec 1;13(12).
20. Greve F, Müller M, Wurm M, Biberthaler P, Singer G, Till H, et al. Standalone Axial Malrotation after Pediatric Supracondylar Fracture Does Not Seem to Be an Indication for Immediate Postoperative Revision Surgery. Child (Basel, Switzerland). 2022 Jul 1;9(7).
21. Suganuma S, Tada K, Takagawa S, Yasutake H, Takata M, Shimanuki K, et al. Independent predictors affecting the reduction of pediatric supracondylar humerus fractures: a retrospective cohort study. Eur J Orthop Surg Traumatol. 2021 Feb;31(2):399–406
23. Chen C, Zhang Y, Chen H, Sun J, Yao C. The effects of postoperative malrotation alignment on outcomes of Gartland type III/IV paediatric supracondylar humeral fractures treated by close reduction and percutaneous K-wire fixation. J Orthop Surg Res. 2024;19(1):26. doi: 10.1186/s13018-023-04505-x.
23. von Laer L. [The supracondylar fracture of the humerus in children (author's transl)]. Arch Orthop Trauma Surg. 1979 Oct;95(1–2):123–40.
24. Gedikbaş M, Balta O, Öztürk T, Erpala F, Eren MB, Zengin EC. Does rotational deformity cause poor outcomes after pediatric supracondylar humerus fractures? Ulus Travma Acil Cerrahi Derg. 2023 Jul;29(7):811–7.
25. Mahaisavariya B, Laupattarakasem W. Supracondylar fracture of the humerus: malrotation versus cubitus varus deformity. Injury. 1993 Jul;24(6):416–8.
26. Sardelli M, Tashjian RZ, MacWilliams BA. Functional elbow range of motion for contemporary tasks. The Journal of bone and joint surgery American volume. 2011;93(5):471-7. doi: 10.2106/JBJS.I.01633.
27. Henderson ER, Egol KA, van Bosse HJP, Schweitzer ME, Pettrone SK, Feldman DS. Calculation of rotational deformity in pediatric supracondylar humerus fractures. Skeletal Radiol. 2007 Mar;36(3):229–35.