Obere Extremität 2020 · 15:130–136
<https://doi.org/10.1007/s11678-020-00572-2>
Received: 3 October 2019
Accepted: 16 April 2020
Published online: 7 May 2020
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Moritz Bergmann¹ · Jan El-Barbari² · Felix Porschke² · Paul A. Grützner² · Thorsten Guehring³ · Marc Schnetzke^{2,4}

¹ Clinic for Orthopedics and Trauma Surgery, Center for Orthopedics, Trauma Surgery and Spinal Cord Injury, Heidelberg University Hospital, Heidelberg, Germany

² Clinic for Trauma and Orthopaedic Surgery, BG Trauma Center Ludwigshafen at the University of Heidelberg, Ludwigshafen on the Rhine, Germany

³ Shoulder and Elbow Surgery, Arcus Sportclinic Pforzheim, Pforzheim, Germany

⁴ ATOS Clinic Heidelberg, German Joint Center Heidelberg, Heidelberg, Germany

Reliability of dynamic fluoroscopy for medial elbow stability in the presence of radial head resection

A cadaveric study

The radial head is the most frequently injured bone of the elbow in adults [3]. In about 33–39% of cases, radial head fractures are associated with concomitant injuries, including elbow dislocations and tear of the lateral and medial collateral ligaments [32, 33]. Complex elbow instability is still challenging, even for expert elbow surgeons [11, 29]. The challenge in the treatment of complex elbow instabilities is to identify and treat all injuries essential for elbow stability to enable early functional treatment. The literature is still divided on whether radial head excision is inferior to radial head replacement as a treatment option for isolated radial head fractures [5, 14, 19]. In the presence of medial collateral ligament (MCL) tears with valgus instability, performing radial head replacement is recommended to prevent chronic instability [7, 18]. However, in cases without associated MCL injuries, several studies have shown excellent results of radial head excision in the short, mid, and long term for both younger and older patients [10, 12, 14, 30].

To date, no clear diagnostic algorithm has been established that allows for an intraoperative decision regarding the severity of MCL injuries after radial head resection (RHR). Intraoperative dynamic flu-

oroscopy might be one diagnostic modality to rule out a clinically relevant MCL injury. Dynamic fluoroscopy is a reliable diagnostic tool for assessing elbow stability after severing the ligamentary stabilizers, as Schnetzke et al. could show in an experimental study [28]. The aim of this cadaveric study was to examine whether intraoperative fluoroscopy is reliable for assessing medial elbow stability in the presence of RHR and different stages of MCL dissection in a cadaveric study.

Materials and methods

Preparation of specimens and test protocol

This study was approved by the local ethics committee of the board of the Medical Profession of Rhineland-Palatinate in Mainz (No. 837.113.17/10947). In this cadaveric study, six adult upper limbs (three left elbows and three right elbows; four female and two male cadavers; mean age 74 years, range 68 to 84 years) from bodies donated to science were provided by the Department of Anatomy of the Medical University of Graz by courtesy of the Anatomical Donation Program of the University of Graz. These limbs were embalmed with

Thiel's method to maintain anatomic consistency, functionality, color, and prevent induration of tissue [31]. Dissection of the limbs was performed along the scapula, leaving humerus, elbow, forearm, and hand intact.

The specimens were included in the study when mobility was at least 0–0–140° in extension/flexion and 75–0–75° in pronation/supination. Exclusion criteria were defined as limited range of motion, obvious instability, possible bone defects assessed under radiographic diagnosis, and visible soft tissue damage or surgical scars on the upper arm, elbow, or forearm. Each specimen was fixed in a custom-built radiolucent framework (■ Fig. 1) to precisely set and maintain flexion, extension, and rotation of the forearm. Each humerus was fixed 20 cm above the joint line with either 0° extension or 30° flexion. A Kirschner wire was used to maintain the respective position during measurements. A second Kirschner wire was inserted 5 cm proximal to the wrist laterally into the distal radius to additionally maintain pronation or supination of the forearm. This method was used in a previous study of Schnetzke et al., establishing itself as a reliable method to allow repeated measurements [28].

Fig. 1 ◀ Schematic illustration of the custom-made fixation device. In this example, the measurement of valgus stress with 1 Nm is shown in 30° of flexion and supination after resection of the radial head

Fig. 2 ◀ The distal humeral joint line drawn from the most distal part of the capitulum of the humerus ($h1$) to the most distal part of the medial aspect of the humeral trochlea ($h2$). The landmarks creating the distal ulnar joint line were the most distal point of the medial part of the ulnar joint ($u1$) and the lateral edge of the lateral ulnohumeral joint of the ulna ($u2$). Radiographic measurement of the alpha angle (α ; 13.3° in this example)

Valgus stress was applied under fluoroscopy using four examination conditions: Examiner 1 (MB), Examiner 2 (MS), and torques of 1 Nm and 2 Nm. The torques of 1 and 2 Nm at the level of the elbow joint were created by pulling forces of either 5 or 10 N. This was achieved using a calibrated electric force scale 20 cm distal to the joint line perpendicular to the forearm. In previous studies, loads between 0.75 and 2 Nm were used to determine the stabilizing involvement of

ligaments [9, 23]. In addition to the two standardized forces of 1 and 2 Nm, the stability tests were performed by two examiners in order to be able to draw conclusions about the reliability of the examination and transferability to the clinical setting. Examiner 1 is an assistant physician without experience in stability testing of elbow joints and Examiner 2 is an experienced shoulder and elbow surgeon with high expertise in stability diagnostics of elbow joints. The examinations

were performed in four different elbow positions: 0° extension and pronation, 0° extension and supination, 30° flexion and pronation, and 30° flexion and supination.

The elbow specimens underwent a sequential procedure comprising three stages: 1) stress tests with intact ligamentous and osseous stabilizers, 2) RHR 0.5 cm below the head, and 3) additional dissection of the complete MCL from its humeral insertion.

RHR was performed through the lateral approach (Kocher approach), the dissection of the MCL was performed through the Hotchkiss approach. Through a longitudinal intersection of the flexor tendons, dissection of the MCL was achieved while leaving flexor tendons intact.

Radiographic measurement

Examination of the elbow specimens was performed under dynamic fluoroscopy. Each valgus stress test was documented by an anteroposterior fluoroscopic image of the elbow. For calculation of the extent of joint angulation, the alpha angle was determined. Alpha was defined as the angle between the distal humeral and the proximal ulnar joint line adopted from a previous study (◻ Fig. 2; [1, 27, 28]). Before the examinations started, the native alpha angle was determined for each specimen in each elbow position without applying valgus stress. Joint angulation was then calculated by the difference between this native alpha angle and the alpha angle during the examinations.

A blinded examiner performed the measurements on a viewing monitor with the picture archiving and communication system OsiriX (Bern, Switzerland) and on a digital light-emitting diode screen with adjustable brightness and contrast. The image was enlarged six times to precisely set the markings for determination of the alpha angle and to ensure highest measurement accuracy. Alpha was rounded to the first decimal place.

Statistics

The alpha angle was measured three times according to the radiographic measure-

M. Bergmann · J. El-Barbari · F. Porschke · P. A. Grützner · T. Guehring · M. Schnetzke

Reliability of dynamic fluoroscopy for medial elbow stability in the presence of radial head resection. A cadaveric study**Abstract**

Background. The aim of this study was to examine whether dynamic fluoroscopy is reliable for assessment of medial elbow stability in the presence of radial head resection and different stages of medial collateral ligament (MCL) dissection in a cadaveric elbow model.

Materials and methods. Six intact elbow specimens were measured for joint angulation while applying valgus stress in four examination conditions (Examiner 1, Examiner 2, 1 Nm, 2 Nm) in four different elbow positions (fully pronated or supinated at 0° of elbow extension and 30° of elbow flexion). The elbow specimens were examined for valgus stress in

three stages: (1) intact, (2) after radial head resection, and (3) after subsequent dissection of the complete MCL. Anteroposterior radiographs of the elbow were made at each stage to determine joint angulation. Intraclass correlation coefficients (ICCs) were calculated. **Results.** In intact elbows, mean joint angulation ranged from $2.2^\circ \pm 2.0$ (1 Nm) to $5.2^\circ \pm 2.3$ (Examiner 1). Radial head resection did not increase joint angulation during valgus stress, regardless of joint position and examination condition (Examiner 1: 5.5° ; Examiner 2: 5.0° ; 1 Nm: 2.6° , 2 Nm: 3.9°). Additional dissection of the MCL led to significantly higher joint angulation during

measurements with the standardized torques (1 Nm: 12.4° ; 2 Nm: 23.3°). Very good to excellent ICCs for joint angulation between Examiner 1 and Examiner 2 (0.861 to 0.959) were found.

Conclusion. Dynamic fluoroscopy is a reliable diagnostic tool for determining medial elbow stability in the presence of radial head resection and different stages of MCL dissection.

Keywords

Radial head fracture · Radial head arthroplasty · Supination · Pronation · Medial collateral ligament

Zuverlässigkeit der dynamischen Durchleuchtung zur Beurteilung der medialen Ellenbogenstabilität nach Radiuskopfresektion. Eine Leichenstudie**Zusammenfassung**

Hintergrund. In der vorliegenden Leichenstudie wurde untersucht, ob die dynamische Durchleuchtung ein zuverlässiges diagnostisches Verfahren zur Beurteilung der medialen Ellenbogenstabilität nach Radiuskopfresektion und stufenweiser Durchtrennung des medialen Kollateralbands (MCL) darstellt.

Material und Methoden. Bei 6 intakten Ellenbogenpräparaten wurde manuell durch 2 Untersucher sowie standardisiert durch 2 Drehmomente von 1 Nm und 2 Nm ein Valgusstress unter dynamischer Durchleuchtung in 4 Gelenkstellungen (in 0° oder 30° Beugung, mit proniertem oder supiniertem Unterarm) ausgeübt. Die Stabilitätstestung der Ellenbogenpräparate erfolgte in 3 Stadien: (1) intaktes

Präparat, (2) nach Radiuskopfresektion und (3) anschließend nach Resektion des MCL. In jedem Stadium wurden anteroposteriore Durchleuchtungsaufnahmen des Ellenbogens angefertigt, um die Gelenkangulierung zu bestimmen. Es wurden Intraklassen-Korrelationskoeffizienten (ICC) berechnet. **Ergebnisse.** Bei intakten Ellenbogen betrug die Gelenkangulierung $2,2^\circ \pm 2,0$ (1 Nm) bis $5,2^\circ \pm 2,3$ (Untersucher 1). Die Radiuskopfresektion führte nicht zu einer Zunahme der Gelenkangulierung, unabhängig von Gelenkposition und Untersucher bzw. Drehmoment (Untersucher 1: $5,5^\circ$; Untersucher 2: $5,0^\circ$; 1 Nm: $2,6^\circ$, 2 Nm: $3,9^\circ$). Die zusätzliche Durchtrennung des MCL führte zu einer deutlich höheren Gelenkangulierung

(1 Nm: $12,4^\circ$; 2 Nm: $23,3^\circ$). Eine sehr gute bis exzellente Übereinstimmung der Ergebnisse der dynamischen Durchleuchtung zwischen Untersucher 1 und Untersucher 2 lag vor (ICC: 0,861–0,959).

Schlussfolgerung. Die dynamische Durchleuchtung stellt ein zuverlässiges diagnostisches Verfahren zur Beurteilung der medialen Ellenbogenstabilität nach Radiuskopfresektion und stufenweiser Durchtrennung des MCL dar.

Schlüsselwörter

Radiuskopffraktur · Radiuskopprothese · Supination · Pronation · Mediales Seitenband

ment described above, and mean values were calculated. In the event of elbow dislocations, quantitative measurement of alpha is impossible. In these cases, the mean value of joint angulation was calculated using the alpha angles of the elbows which did not happen to dislocate.

The radiographic measurement was conducted by Examiner 1 (MB), 100 randomly selected radiographic measurements were conducted twice. This was done to determine intra- and interrater reliability regarding the measurement of

alpha. The radiographic measurements were repeated at intervals of 2 weeks by Examiner 1 and separately by Examiner 2 (MS).

Agreement between measurements of the same rater at different times and between different raters were assessed by intraclass correlation coefficients (ICCs) with 95% confidence intervals (CIs). ICCs (model 2,1) were also used for comparison of joint angulation with applied valgus stress in stages 1 to 3 of Examiner 1 and Examiner 2, Examiner 1

and 1 Nm, and Examiner 1 and 2 Nm. ICCs were rated as poor (<0.4), fair (0.40–0.59), good (0.6–0.74), very good (0.75–0.89), or excellent (>0.90).

Interobserver variability for the occurrence of elbow dislocations was calculated with Cohen's kappa. Its agreement strength was concluded in accordance with the recommendations of Landis and Koch [17].

Table 1 Results of valgus stress tests performed with each examination method

	Mean joint angulation and SD (degrees)		
	Intact	RHR	RHR + MCL
<i>0° flexion, supination</i>			
Examiner 1	5.3 ± 2.3	6.1 ± 3.3	^b
Examiner 2	4.7 ± 2.7	4.8 ± 2.2	^b
1 Nm	2.0 ± 2.4	3.3 ± 3.0	6.9 ± 7.0
2 Nm	3.2 ± 2.6	4.5 ± 2.7	17.3 ± 10.0
<i>0° flexion, pronation</i>			
Examiner 1	5.5 ± 4.4	4.9 ± 2.8	^b
Examiner 2	5.0 ± 3.0	4.3 ± 2.6	^b
1 Nm	2.6 ± 1.8	2.1 ± 2.5	12.6 ± 6.5
2 Nm	4.1 ± 2.6	3.0 ± 2.6	19.5 ± 12.2 ^a
<i>30° flexion, supination</i>			
Examiner 1	5.2 ± 1.5	6.0 ± 1.6	^b
Examiner 2	4.7 ± 2.0	5.4 ± 1.4	^b
1 Nm	2.3 ± 2.5	1.9 ± 2.0	12.2 ± 8.7
2 Nm	3.3 ± 2.3	3.8 ± 2.0	27.3 ± 4.9 ^a
<i>30° flexion, pronation</i>			
Examiner 1	4.8 ± 1.0	5.1 ± 1.6	^b
Examiner 2	4.8 ± 1.0	5.8 ± 1.8	^b
1 Nm	1.8 ± 1.4	2.9 ± 2.1	17.8 ± 6.2
2 Nm	3.3 ± 0.6	4.1 ± 2.2	29.0 ± 6.6

RHR radial head resection, MCL medial collateral ligament, SD standard deviation

^aAt least one of the six elbows dislocated during the stress test

^bAll elbows dislocated during the stress test and calculation of mean and SD was not possible

Table 2 Elbow dislocations in stage 3

Valgus stress (RHR + MCL transected)	Elbow dislocations, no. (%)
Examiner 1	72/72 (100)
Examiner 2	72/72 (100)
1 Nm	0/72 (0)
2 Nm	12/72 (17)

RHR radial head resection, MCL medial collateral ligament, SD standard deviation

Results

Radiographic measurement

The intra- and interrater reliability for radiographic measurement of the alpha angle showed excellent agreement, with 0.998 (95% CI 0.996–0.999) for intrarater reliability and 0.974 (95% CI 0.954–0.986) for interrater reliability.

Results of examination

In intact elbows, mean joint angulation ranged from $2.2^\circ \pm 2.0$ (1 Nm) to $5.2^\circ \pm 2.3$ (Examiner 1). Isolated RHR did not increase joint angulation during valgus stress, regardless of joint position and examination condition (Examiner 1: 5.5° ; Examiner 2: 5.0° ; 1 Nm: 2.6° , 2 Nm: 3.9°). Additional dissection of the MCL led to significantly higher joint angulation during measurement with the standardized torques (1 Nm: 12.4° ; 2 Nm: 23.3°) and to elbow dislocation during the valgus stress test of both examiners (Table 1). Forearm rotation (pronation or supination) had no influence on the size of alpha in any of the four examination methods ($p \geq 0.350$).

Fig. 3 visualizes the results of valgus stress at each stage in 30° of flexion and supination of the elbow.

While exerting valgus stress, RHR alone did not lead to elbow dislocation. RHR with dissection of the MCL caused dislocation in 54% of the valgus stress tests (156 of 288 examinations; Table 2). The interobserver agreement between these valgus stress tests was substantial regarding the occurring elbow dislocations for Examiner 1 and Examiner 2 ($\kappa = 0.899$). Very good to excellent ICCs (0.861 to 0.959) between

Table 3 Intraclass correlation coefficients (ICC) with calculated 95% confidence intervals

		ICC	CI 95%
Stage 1 (intact)	Examiner 1/Examiner 2	0.861	[0.797; 0.906]
	Examiner 1/1 Nm	0.714	[0.596; 0.802]
	Examiner 1/2 Nm	0.754	[0.650; 0.831]
	Examiner 2/1 Nm	0.774	[0.676; 0.845]
	Examiner 2/2 Nm	0.808	[0.722; 0.869]
	1 Nm/2 Nm	0.863	[0.799; 0.908]
Stage 2 (RHR)	Examiner 1/Examiner 2	0.923	[0.867; 0.956]
	Examiner 1/1 Nm	0.579	[0.355; 0.740]
	Examiner 1/2 Nm	0.710	[0.535; 0.826]
	Examiner 2/1 Nm	0.606	[0.389; 0.759]
	Examiner 2/2 Nm	0.708	[0.531; 0.826]
	1 Nm/2 Nm	0.695	[0.512; 0.818]
Stage 3 (RHR + MCL)	Examiner /Examiner 2	NA	–
	Examiner 1/1 Nm	NA	–
	Examiner 1/2 Nm	NA	–
	Examiner 1/1 Nm 1	NA	–
	Examiner 2/2 Nm	NA	–
	1 Nm/2 Nm	0.765	[0.476; 0.905]

RHR radial head resection, MCL medial collateral ligament, CI confidence interval

Fig. 3 ▲ Joint angulation during the valgus stress test in 30° of flexion and supination of the forearm with variation of the different examination conditions. *RHR* radial head resection, *MCL* medial collateral ligament

Examiner 1 and Examiner 2 for joint angulation were found in all stages of examination. Overall, good to excellent ICCs (≥ 0.705) were found for valgus joint angulation except for stage 2 between Examiner 1 and 1 Nm. In these cases, the ICCs were rated as fair (Table 3). Determination of the ICC between the examiners and the standardized forces in the last stage was not possible, because there was dislocation of the elbows in the examinations and therefore no alpha angle could be determined.

Discussion

The present study revealed that a reliable assessment of medial elbow stability in the presence of RHR is possible with the help of dynamic fluoroscopy. Very good to excellent ICCs for mean joint angulation were achieved between the two examiners in all stages of the examination. Joint angulation in intact elbow specimens was less than 4.7–5.5° during valgus stress tests of both examiners, regardless of joint position. With RHR, joint angulation did not change (4.8–6.1°). Additional dissection of the MCL led to significantly higher joint angulation (1 Nm: 12.4°; 2 Nm: 23.3°) or elbow dislocation (Examiners 1 and 2). The rotation of the forearm (pronation or supination) had no influence on the measured alpha angle, regardless of examination method and stage ($p \geq 0.350$). Therefore, for reasons of practicability,

the authors recommend performing the stability test in supination of the forearm.

About 50% of associated injuries to the elbow with radial head fractures involve clinically relevant ligamentous injuries, which can lead to long-term instability [21]. Authors report that radial head fractures are often associated with medial collateral ligament damage—from minor ligamentous injuries to complete ruptures—resulting in variable degrees of valgus instability [4, 15, 25]. Approximately 10% of patients with radial head fractures have obtained massive damage to their ligaments, including complete rupture of the lateral or medial collateral ligament or a combination of both [32]. Evaluating this damage of the MCL is still controversial, as many ligamentous lesions can remain subclinical and the need for repair is still difficult to determine [21]. A combination of physical examination, the subjective feeling of apprehension, instability, localized pain, extension loss, and imaging leads to the diagnosis of elbow instability, but objective empirical data are still lacking [6, 24, 26, 35].

Additionally, the literature is divided on the question as to whether radial head excision is inferior to radial head replacement as a treatment for isolated radial head fractures. Many studies have pointed out the advantages of radial head replacement compared to radial head excision, which appeared to alter elbow kinematics and laxity even with intact

ligaments [2, 7, 16]. However, several studies showed excellent results of radial head excision in the short, mid, and long term for both younger and older patients [10, 12, 14, 30]. In general, in the treatment of radial head injuries, valgus instability constitutes an important determinant of the severity of the injury. In the present study, we introduced dynamic fluoroscopy as a reliable, objective, and valid intraoperative method to assess medial elbow stability in the presence of RHR. To determine medial elbow stability, valgus stress was exerted on the elbows across various examination conditions under dynamic fluoroscopy. With the help of dynamic fluoroscopy, we observed that a radial head fracture had either no valgus instability, with an intact MCL, or gross valgus instability, with a dissected MCL. When applying valgus stress to a radial head resected elbow, our results were almost the same as for uninjured elbows, indicating that the radial head only acts as a secondary stabilizer and offers no contribution to resisting valgus angulation, as also shown in previous studies [13, 20, 22]. Additional MCL dissection led to dislocation in every valgus stress test of both examiners, which underlines the importance of MCL as a primary stabilizer.

This study has several limitations. First, a power analysis was not performed. Analogous to comparable experimental cadaver studies, a case number of six was chosen. Given the lack of dynamic stabilizers of the elbow in the cadaver models that were used in this study, we could only partly represent clinical conditions even though we used a resection and dissection method that leaves common extensor and flexor tendons intact. Another limitation of the study is that the stability test was only performed with intact or completely detached MCL. A stability test with partial rupture, e.g., of the anterior part of the MCL, was not performed. In a previous study, Schnetzke et al. were able to show that dissection of the anterior part of the MCL only leads to a slight increase in joint angulation compared to the intact joint of 2.0 to 2.5° at 1 Nm and 2 Nm, respectively, while exerting valgus stress under fluoroscopy [28]. Therefore, in

the current study, the clinical value of fluoroscopy in the case of clinically relevant MCL damage (complete rupture) was deliberately investigated. A further limitation of the study is the fact that both examiners experienced luxation of the elbow after dissection of the MCL, making quantification using the alpha joint angle impossible.

A further limitation might be that embalming the specimens with the Thiel method is not a common tool to investigate orthopedic ligamentous sectioning studies. The Thiel embalming method might alter the physiological sequence of occurring subluxations and dislocations of the elbow by mechanical degradation of the ligaments [8]. However, a previous study of Völlner et al. concluded that the Thiel method preserves soft tissue conditions that represent those in vivo [34].

Although excellent ICCs for joint angulation were found between Examiner 1 and Examiner 2, further studies should include a third, completely uninvolved individual performing the stress tests and radiographic measurements, so that the results can be transferred to the general population of orthopedic examiners.

Practical conclusion

This study shows that dynamic fluoroscopy is a reliable diagnostic tool for assessing medial elbow stability in presence of radial head resection and in different stages of medial collateral ligament dissection. The results of this study may help the surgeon to decide whether or not a radial head prosthesis is necessary after radial head resection. These considerations usually include factors such as the age of the patient, the extent of the injury based on pre-operative diagnostics and, last but not least, the surgeon's personal preference. With the help of intraoperative fluoroscopy, the surgeon has a reliable and objective instrument at hand to justify his decision.

Corresponding address

Marc Schnetzke, MD
ATOS Clinic Heidelberg,
German Joint Center
Heidelberg
Bismarckstr. 9–15,
69115 Heidelberg, Germany
marc.schnetzke@atos.de

Acknowledgements. This research was financially supported by the AO Foundation (AO start-up grant S-16-99S).

Funding. Open Access funding provided by Projekt DEAL.

Compliance with ethical guidelines

Conflict of interest. M. Bergmann, J. El-Barbari, F. Porschke, P.A. Grützner, T. Guehring, and M. Schnetzke declare that they have no competing interests.

This study was approved by the local ethics committee of the board of the Medical Profession of Rhineland-Palatinate in Mainz (No. 837.113.17/10947). All investigations on humans or human tissues described in this article were carried out with the approval of the responsible ethics committee, in accordance with national law and the Declaration of Helsinki from 1975 (in its current revised form). The investigations were carried out according to the specifications of the Central Ethics Committee of the Federal Medical Council.

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