Does Malpositioning of the Arm Influence Radiographic Range of Motion Measurement?

Julien Chapleau, Pierre-Yves Lagacé, Fanny Canet, Nicola Hagemeister, Dominique Rouleau

Abstract— **Purpose: Radiographic range of motion measurement of the elbow has been shown to be both precise and reliable. For this method to be used routinely in research studies, it is important to describe its limits regarding: (1) rotation of the arm from the perfect lateral position and (2) the length of humerus and ulna visible on the radiograph.**

Material and Methods: A 3D bone reconstruction was performed from an upper limb CT scan. Planar radiographs were simulated for rotations of the elbow within a range of ±30o from the perfect lateral position. The field of view was modified, ranging from five visible centimeters of diaphysis on the radiograph to full visibility of the upper limb.

Results: The disparity was less than 2.5° (mean=0.68°, SD=0.43°) when the flexed arm was rotated between -30.0° (external rotation, ER) and + 18.0° (internal rotation, IR). When considering the extended arm, measured angles differed by less than 2.5° (mean=0.79°, SD=0.57°) within a range of -15.0° (ER) to +30.0° (IR). When a minimum of 12 cm of humerus and ulna, from the capitellum, were visible on the radiograph measured angles varied very slightly (mean disparity of 0.71°, SD= 0.71°). Finally a qualitative description of the appearance of the radiographs was included to help surgeons estimate acceptable degrees of rotation.

Conclusion: Range of motion (ROM) measurement shows consistent results, despite 15 to 30 degrees of internal or external rotation. The middle third of the humeral and ulnar diaphyses should be visible on the radiographs to ensure the validity of measurement. Radiographic ROM measurement is still recommended over the goniometer for research purposes because of its high reliability and precision. Moreover, malpositioning of the elbow should not jeopardize results since it will most likely be an angle measurement variation of less than 2.5°.

I. Introduction

Precise elbow range of motion (ROM) measurement is critical for elbow integrity assessment [1, 2]. The goniometer is frequently used due to its simplicity and accessibility. However, a recent publication has shown that a radiographic elbow ROM measurement is more reliable and precise than standard goniometry[3]. This method uses bony landmarks, which are visible on lateral radiographs of the elbow, to measure the flexion angle. Hence, it is less susceptible to external factors such as the evaluator's experience or arm morphology. However, it presupposes that the arm is optimally aligned on the radiograph.

The value of lateral radiographs for the diagnostic of elbow displacement or fractures is well established [4-7]. Despite the high number of elbow radiographs required by emergency doctors and orthopedic surgeons, a perfect lateral radiograph is rarely seen. Skibo et al. reviewed 74 radiographs from a pediatric population and only 9% were considered true lateral views [8]. In extreme cases, malpositioning of the elbow during radiograph acquisition leads to false condylar fracture diagnosis. The length of humeral and ulnar diaphysis visible on the radiographs is also known to vary considerably in clinical practice. The degree of internal/external rotation and the length of bone which is visible on the radiograph both influence the appearance of the elbow and we hypothesize that it could alter the reliability of the radiographic ROM measurement method. Hence, it is essential to evaluate their impact on measured values to validate the use of radiographic ROM measurement in research studies. In this work, radiographs were simulated with varying degrees of rotation and visible lengths of bone to determine thresholds for which ROM measurement is reliable. A description of the appearance of the distal humerus in internal and external rotation will also be reported to help surgeons estimate if the elbow is indeed placed in neutral rotation on a lateral radiograph.

II. Material and Methods

A right arm specimen from a 50 year-old man without any sign of musculoskeletal pathology, except for light osteoarthritis on the humeral head, was used in this study. The specimen was first scanned with the elbow in full flexion with a slice thickness of 0.5 mm and spacing of 0.5 mm. The bones were then segmented using the SliceOmatic software (Tomovision, Magog, Canada) and surface models of individual bones were generated. Slight smoothing of the surfaces was performed to provide a realistic visual appearance of the bone models.

Axes for bone rotations and translations were set in accordance with the International Society of Biomechanics (ISB) guidelines for the definition of joint coordinate systems [9]. According to these guidelines, elbow flexion/extension was simplified as the rotation of the forearm complex around the line connecting the lateral and medial epicondyles [9, 10]. Humeral rotation axis, i.e.

No external founding was used for this research.

J. C. Author is with the University of Montreal, Montreal, CAN (e-mail: juchapleau@gmail.com)

P. Y. L. Author was with the Ecole de Technologie Supérieure de Montreal, Montreal, CAN. (e-mail: pierre-yves.lagace.1@ens.etsmtl.ca)

F. C. Author is with the Hopital du Sacre-Coeur, Montreal, CAN. (e-mail: fanny.canet@crhsc.rtss.qc.ca)

N. H. Author is with the Ecole de Technologie Supérieure de Montreal, Montreal, CAN. (e-mail: nicola.hagemeister@etsmtl.ca)

D. M. R. Author is with the Hopital du Sacre-Coeur, Montreal, CAN (corresponding author phone: 1-514-338-2222 *3427; fax: 514-338-2694; e-mail: dominique.rouleau@umontreal.ca).

shoulder internal (IR) or external (ER) rotation, is defined as the line joining the midpoint between the lateral and medial epicondyle and the center of the humeral head [9]. Pro-supination is the rotation of the radius along the line connecting the centers of the radial and ulnar heads. [9].

Following the reconstruction process, the arm model was placed in full extension using custom 3D visualization software. Then, for each of the flexion and extension positions, the forearm was placed in neutral position as required by the ROM measurement technique[3]. The two resulting arm postures were validated for morphologic accuracy, i.e. congruity of articular surfaces, by a fellowship trained elbow surgeon. For each arm posture simulated radiographs were generated at varying degrees of arm rotation and for varying visible bone lengths.

Simulated radiographs were generated using the same 3D visualization software and processed in Matlab (The MathWorks Inc., Nattick, USA) to simulate variations in humerus and ulna lengths visible on film (Fig. 1).

Figure 1. Length restriction. Examples of simulated radiographs of the same flexed elbow with various humerus and ulna shaft lengths visible. A) The smallest frame dimensions: 5cm of bone from the capitellum appear on film. B) 12cm. C) 28cm of the humerus are visible.

Twenty four (24) radiographs were produced, with visible humerus and ulna lengths starting from the center of the capitellum and ranging from 5cm to 28 cm (with 1cm increments between each simulation). On the 28 cm radiograph, the ulna and radius are complete and the beginning of the humeral neck widening is seen. The same number of images were obtained for the fully flexed (n=24) and extended (n=24) elbow.

Malpositioning of the arm on the X-ray table was then simulated by applying varying degrees of IR and ER to the humerus (Fig. 2).

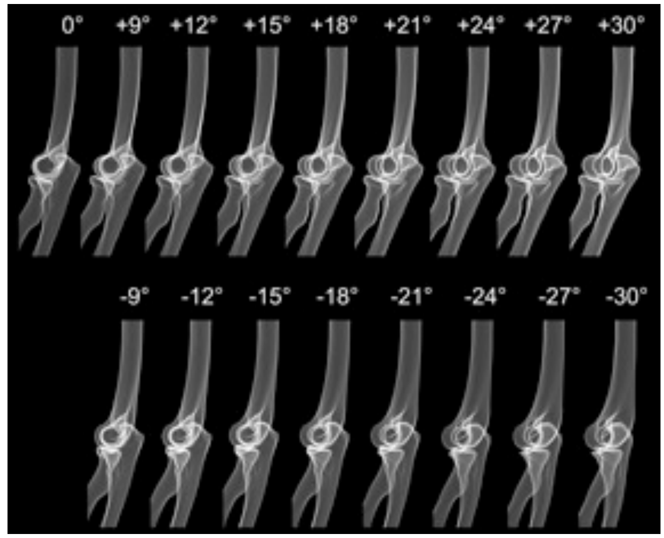

Figure 2. Rotation malpositioning. Simulated radiographs for different degrees of rotation from a perfect lateral view of the extended elbow (0°). A positive value represents an internal rotation whereas negative is assigned to an external rotation.

The perfect lateral position of the elbow was assigned 0^o of humeral rotation. To our knowledge, no clear guidelines exist for the definition of a lateral elbow radiograph, but authors tend to agree that the trochlear sulcus and the capitellum should appear superimposed, allowing a clear view of the ulnohumeral articular space[8, 11]. The applied humeral rotations ranged from -30° (ER) to +30° (IR), with 3° increments between radiographs, for a total of 21 images for each position.

One blind observer measured the flexion angle on the 90 (2x24 + 2x21) randomly ordered radiographs. According to the measurement method definition, the flexion angle is formed by the dorsal mid-third edge of the ulna and the dorsal edge of the humeral shaft[3] (Fig. 3).

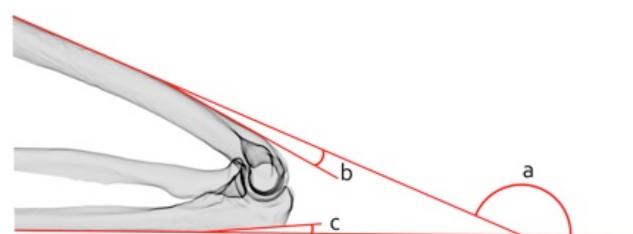

Figure 3. Angle definitions. Radiographic flexion angle (a) is measured from the dorsal edge of the humerus and ulna. Lines must be placed along the mid-third portion of the shafts to avoid the distal humerus dorsal angulation (b) and proximal ulna dorsal angulation (c).

III. RESULTS

Randomized images were analyzed with SliceOmatic (Tomovision, Magog, Canada). The geometric model had a terminal flexion (TF) angle of 157.50° and a terminal extension (TE) angle of 20.10° as measured in ideal conditions, i.e. in a perfect lateral position (0^o of humeral rotation) and with the full upper limb visible on the radiograph (28 cm radiograph). These angles were considered to be the true TF and TE values. Rotation angles were defined as positive for internal rotation (IR) and negative for external rotation (ER).

There was a difference of less than 2.5° (mean=0.68°, SD=0.43°) between the true and the measured value, depending on the rotation of the flexed arm (TF) between -30.0° and + 18.0°. For TE, measured angles differed by less than 2.5° (mean=0.79°, SD=0.57°) within a range of -15.0° to +30.0° (Fig. 4 – A, B).

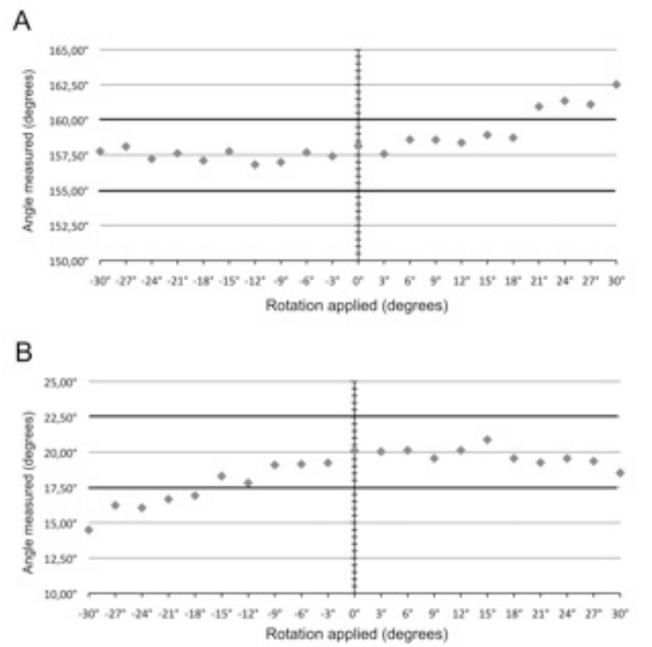

Figure 4 – A, B. Measured flexion angles. Bold lines represent the ±2.5° inter-rater error from the original 157.50° (TF) and 20.10° (TE) values. A) Rotation simulation for the flexed elbow. Internal rotation is defined as a positive value while negative angles are associated to external rotations. B) Rotation simulation for the elbow placed in terminal extension.

The measurements are considered constant when more than 12cm of humerus and ulna are visible on the radiograph for both TF and TE. Mean difference for TF is 0.68° (SD=0.81°) and 0.71° (SD=0.71°) for TE. When the radiographic frame dimensions were under those values, there was more than a 2.5° difference with the true value. Errors further increased with the extended elbow when only 5 to 11cm of the humerus were visible, in which case the measured differences ranged from 2.96° to 6.93° from the true extension value (Fig. 4 – C, D).

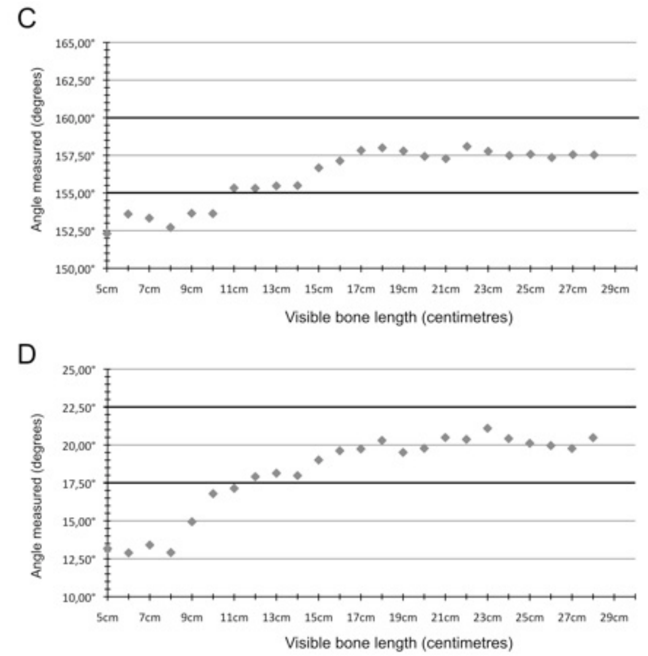

Figure 4 – C, D. Measured flexion angles. Bold lines represent the ±2.5° inter-rater error from the original 157.50° (TF) and 20.10° (TE) values. C) Length variation for the flexed elbow. D) Length variation for the elbow placed in terminal extension.

IV. Discussion

The radiographic elbow ROM measurement method previously assumed that the elbow is in a perfect lateral position and that most of the upper limb is visible on the radiograph. However, these conditions are difficult to meet in clinical practice. This study aimed to describe the limits of this method regarding (1) the malpositioning of the arm in rotation and (2) the length of the humerus and ulna visible on the radiograph.

The threshold at which a ROM measurement was considered to be non-valid was set at 2.5°. This value was determined by a previous reliability study on 200 elbow radiographs. Two separate evaluators measured ROM on radiographs and 95% of their results differed by less than 2.5°.

For the arm model used in this study, radiographs had to include a minimum of 12 cm of humerus and ulna for proper ROM measurement. If less humeral shaft was visible, the observer may have been misled by the dorsal angulations of the distal humerus or proximal ulna. The dorsal angulation of the distal humerus results from the anterior offset, which is described as the anterior position of the condyles from the humeral shaft axis on a lateral view[12] (Fig. 3). The proximal ulna dorsal angulation (PUDA) has an average value of 5.7° (range: 0 to 14.0°) and its apex is located at 47mm (34 to 78mm) from the olecranon tip[13]. Therefore the observer should not rely on the first centimeters of humerus and ulna closest to the elbow since both the PUDA and anterior offset may result in underestimation of the flexion angle (Fig. 4 – C, D).

The cutoff points of length and rotation (up to 30°) represent extreme values which are rarely seen in clinical practice because such radiographs are usually rejected and the arm repositioned. The middle third of the humerus shaft is generally seen and a perfect lateral view is not needed. Fifteen degrees of rotation, or more, on a radiograph is easily detected and in such a case the arm can be repositioned.

A. *Qualitative observations*

The risk of humeral rotation is greater when positioning the upper limb on an x-ray table in an extended position rather than a flexed position. In an extended position the humerus can in fact easily rotate with minimal forearm movement. On the contrary, malpositioning is easier to detect in flexion because the hand is soon lifted from the table when the flexed arm is in ER. Internal rotation (IR) is rarely seen in flexion and it is very limited if the hand lies on the x-ray table.

One can consider that an elbow radiograph is in a true lateral position when the trochlear sulcus and the capitellum appear superimposed[8, 11]. However, there is no criterion to estimate the degree of rotation on a radiograph. Observation of the appearance of the distal humerus can provide estimates of whether the rotation is small enough to produce an acceptable true lateral radiograph. First, the capitellum can be identified, as it is always aligned with the radial head. When it is the most anterior point of the distal humerus it means that the elbow is in internal rotation or that the X-rays are oriented in such a way that the radiograph is taken from a postero-lateral angle. The opposite is seen for an external rotation. In fact, as the elbow rotates, the radial head appears to be in a posterior position and the trochlea moves forward.

B. *Limits*

It is important to note that only one cadaveric upper limb was used in this study. A specimen with different bone morphology could have given slightly different results. This doesn't jeopardize our conclusions since our results aimed to explore the effect of malpositioning on the ROM measurement. Of course, the 12 cm threshold is specific to our specimen and would be different according to the arm length. Consequently, measurement should be done on the middle third of the diaphysis, even if it requires 8, 12 or 15 cm. Furthermore, the incidence of X-ray variations in the cephalic-caudal orientation was not assessed. Our study assumed that the X-ray beam had a perpendicular incidence to the arm axis, yet this is not always the case in clinical practice. Such malpositioning is less frequent and important than IR or ER, so it is unlikely that it would have a great impact on ROM measurement. Finally, this study used a CT bone reconstruction to answer a 2-plane radiograph question. This method could help to study other issues where the position of the arm affects its radiographic appearance. For instance, displacement of bone fragments in fracture could look differently according to the rotation of the elbow. Hence the method we described in this study could serve more than one purpose.

V. Conclusion

This study's aim was to explore the limits of the radiographic range of motion measurement method regarding variations of radiograph size and arm rotation. Following radiograph simulations on a C-bone reconstruction, this ROM measurement method is still recommended over the goniometer for research purposes for its high reliability and precision. Precautions must be taken to use the middle third of the diaphyses and not to rely on the PUDA or anteroir offset of the distal humerus. Moreover, a perfect lateral view is preferd but slight rotation is acceptable since it will most likely result in angle measurement variations of less than 2.5°.

References

[1] Docherty, M.A., R.A. Schwab, and O.J. Ma, *Can elbow extension be used as a test of clinically significant injury?* South Med J., 2002. **95**(5): p. 539-41.

[2] Lennon, R.I., et al., *Can a normal range of elbow movement predict a normal elbow x ray?* Emerg Med J., 2007. **24**(2): p. 86-8.

[3] Chapleau, J., et al., *Validity of goniometric elbow measurements: comparative study with a radiographic method.* Clin Orthop Relat Res, 2011. **469**(11): p. 3134-40.

[4] Wolf, J.M., et al., *Acute trauma to the upper extremity: what to do and when to do it.* J Bone Joint Surg Am, 2009. **91**(5): p. 1240-52.

[5] Fritz, R.C. and W.H. Breidahl, *Radiographic and special studies: recent advances in imaging of the elbow.* Clinics in Sports Medicine, 2004. **23**(4): p. 567-80.

[6] Jacob, A. and S. Khan, *Radiology of acute elbow injuries.* Br J Hosp Med (Lond), 2010. **71**(1): p. M6-9.

[7] Rosas, H.G. and K.S. Lee, *Imaging acute trauma of the elbow.* Semin Musculoskelet Radiol, 2010. **14**(4): p. 394-411.

[8] Skibo, L. and M.H. Reed, *A criterion for a true lateral radiograph of the elbow in children.* Can Assoc Radiol J, 1994. **45**(4): p. 287-91.

[9] Wu, G., et al., *ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion--Part II: shoulder, elbow, wrist and hand.* J Biomech, 2005. **38**(5): p. 981-992.

[10] Goto, A., et al., *In vivo elbow biomechanical analysis during flexion: three-dimensional motion analysis using magnetic resonance imaging.* Journal of Shoulder & Elbow Surgery, 2004. **13**(4): p. 441-7.

[11] London, J., *Kinematics of the elbow.* The Journal of Bone and Joint Surgery Am, 1981. **63**(4): p. 529-535.

[12] Brownhill, J.R., G.J. King, and J.A. Johnson, *Morphologic analysis of the distal humerus with special interest in elbow implant sizing and alignment.* J Shoulder Elbow Surg, 2007. **16**(3 Suppl): p. S126-32.

[13] Rouleau, D.M., K.J. Faber, and G.S. Athwal, *The proximal ulna dorsal angulation: a radiographic study.* J Shoulder Elbow Surg, 2010. **19**(1): p. 26-30. Epub .