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BASIC RESEARCH

Does Radiographic Beam Angle Affect the Radiocapitellar Ratio Measurement of Subluxation in the Elbow?

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Abstract

Background Radial head alignment is the key to determine elbow reduction after treatment of subluxations or Monteggia fractures. The radiocapitellar ratio (RCR) quantifies the degree of subluxation, by evaluating radial head alignment with the capitellum of the humerus; this ratio is reproducible when measured on true lateral radiographs of nonsubluxated elbows. However, the impact of beam angulation on RCR measurement is unknown.

Questions/purposes Our hypotheses were that the RCR of the nonsubluxated elbow would remain in the normal range as the beam angle changed and that the RCR variability would increase for the subluxated elbow with small deviations in the beam angle.

Methods Radiographs were taken of six healthy cadaveric extremities using beam angles ranging from −20° to 20° along the inferosuperior axis and from −20° to 20° along the dorsoventral axis. The same views then were taken of the six arms with anterior radiocapitellum subluxation followed by posterior radiocapitellum subluxation. RCRs were measured by one observer. As a reference value, the RCR was measured in the 0° to 0° position and the difference between each RCR in a nonreference position was subtracted from each RCR reference to obtain the delta-RCR. An ANOVA was performed to assess the main and interactive effects on the RCR measured in each C-arm position compared with the RCR measured on a true lateral radiograph.

Results The RCR remained in the normal range even as the beam angle of the C-arm varied between −20° and 20°. The position of the beam did not affect the RCR in anteriorly subluxated elbows ($p = 0.777$), whereas RCR variation increased especially in the presence of posterior radial head subluxation when the C-arm position was 10° or more out of plane ($p = 0.006$). The inferosuperior malposition of the C-arm had a greater impact on quantification of radial head alignment measurement. Despite that, the RCR measurement is reliable in reduced and subluxated elbows on lateral radiographs with a C-arm position deviation of as much as 20°.

Conclusions Identification of a subluxated elbow could be made on any lateral radiograph with a beam angulation deviation of as much as 20°. This suggests that the RCR is a useful diagnostic tool for clinical and research purposes, although for subluxated elbows, it is important to pay careful attention to the inferosuperior position of the C-arm.

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Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.
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Introduction

The elbow consists of three articulations: the radiocapitellar (RC), ulnohumeral, and proximal radioulnar joints, that together permit flexion-extension and pronation-supination. Radial head subluxations are commonly associated with Monteggia fractures [1, 2] and most frequently with posterior subluxations compared with anterior subluxations [11]. To detect subluxations of the elbow, lateral radiographs are used and tools have been developed to gauge radial head subluxations: the radiocapitellar line (RCL) for the pediatric elbow [16] and the radiocapitellar ratio (RCR) for the adult elbow [12]. Both methods use lateral radiographs taken after trauma but the patient's position and the elbow's position are not always optimal. It has been shown that a deviation of the laterality of the elbow on the radiograph could induce measurement errors with the RCL method [10, 17], but no study has evaluated the effect of beam angulation on the RCR measurement.

The effect of radiographic beam angulation has been studied for several joints in the body [5, 6]. Regarding the elbow, the appearance of distal fragment malrotation as a radiographic parameter in the evaluation of distal radial fractures has been reported [7]. In that study, it was shown that malrotation was easiest to see on a 45° oblique pronated radiographic view.

In 2011, Rouleau et al. [12] proposed a method to assess elbow stability. More specifically, they measured the radiocapitellum joint translation and the RCR and determined that, in the healthy (nonsubluxated) elbow, the radial head is aligned with the capitellum on the true lateral radiograph and that the RCR ranges from 13% anteriorly to −5% posteriorly (mean, 4%; SD, 4%).

The effect of varying the radiographic views on this method's accuracy, for nonsubluxated and/or subluxated elbows, is unknown. The goal of our study was to evaluate how small deviations of beam shooting angle affect the RCR measurement for nonsubluxated, anteriorly subluxated, and posteriorly subluxated elbows.

Our hypotheses were that the RCR of the nonsubluxated elbow would remain in the normal range as the beam angle changed and that the RCR variability would increase for the subluxated elbows with small deviations in the beam angle.

Materials and Methods

Six cadaveric upper extremities with no identified pathologic conditions (undamaged and nonarthritic), including two male left arms, two female left arms, one male right arm, and one female right arm (age range, 24–78 years; mean, 53 years; SD, 23 years), were used for this study. Radiographs were first taken of the six upper extremities with the elbow nonsubluxated. The beam was set to a reference condition of 0° to 0° when the shadows of the bottom of the trochlear sulcus, of the periphery of the capitellum, and of the medial facet of the trochlea formed three concentric arcs [8]. This shooting angle of 0° along the inferosuperior axis and 0° along the dorsoventral axis corresponds to a lateral view. For each upper extremity, the C-arm of the x-ray table was positioned such that 49 views (including the 0° to 0° reference point) were taken with radiographic beam angles of −20° to 20° for the inferosuperior position (Fig. 1) and for the dorsoventral position (Fig. 2). The intermediate values that were used were −10°, −5°, 0°, +5°, and +10°.

The same views were taken again in the anterior subluxation and posterior subluxation conditions (Fig. 3). First, anterior subluxations were made manually after removing the annular ligament. Second, posterior subluxations were

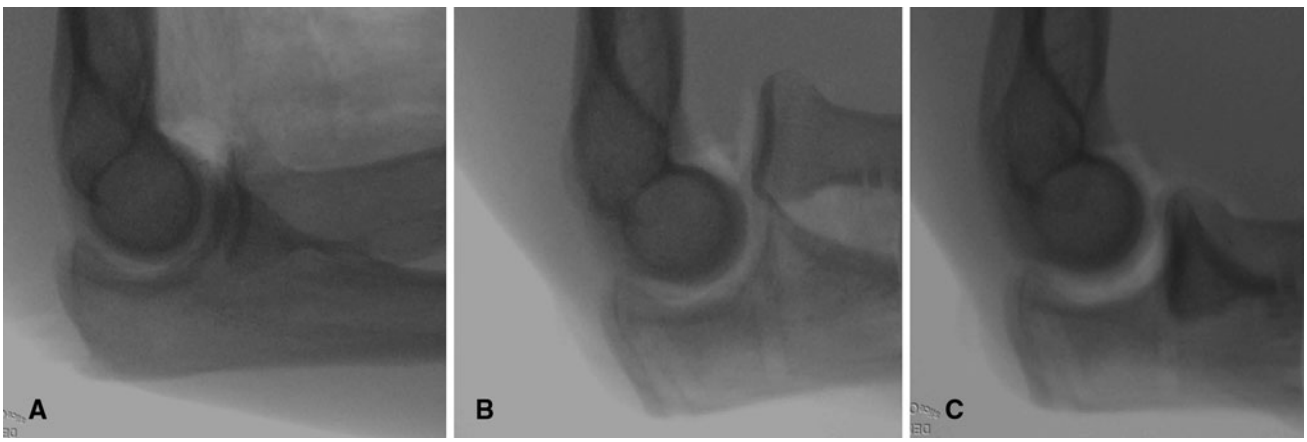

Fig. 1A–C True lateral radiographs of (**A**) a nonsubluxated elbow, (**B**) anteriorly subluxated elbow, and (**C**) posteriorly subluxated elbow are shown.

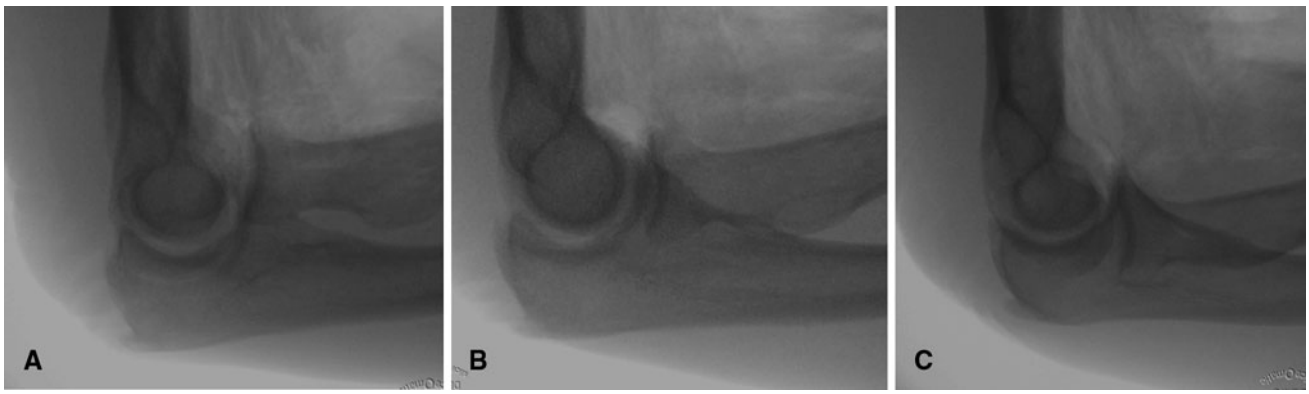

Fig. 2A–C Radiographs of (**A**) a nonsubluxated elbow with 20° inferior beam angulation, and (**B**) the same nonsubluxated elbow in neutral position, and (**C**) with 20° superior beam angulation are shown.

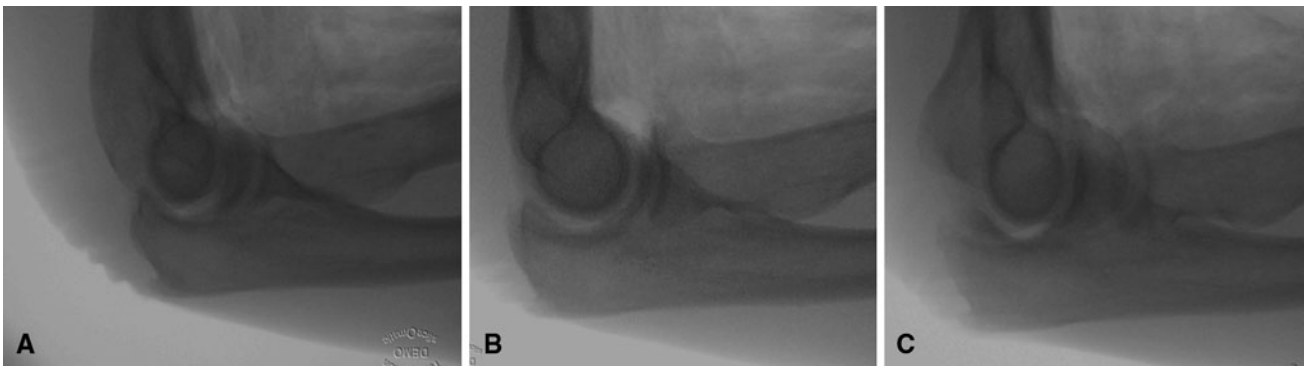

Fig. 3A–C Radiographs of a (**A**) nonsubluxated elbow with 20° dorsal beam angulation, and (**B**) the same nonsubluxated elbow in neutral position and (**C**) with 20° ventral beam angulation are shown.

made manually after removing the radial collateral ligament and ulnar collateral ligament. The level of subluxation was made randomly.

The RCR then was determined from the randomized radiographs using SliceOmatic software (Tomovision Inc, Magog, Quebec, Canada), which allows tracing circles, lines, enhancing, and performing measurements on radiographic images such as distance or angle. The evaluator was blinded for beam angulation and radial head translation. The minimal distance from the center of the capitellum to the center of the radial head was assessed following the method described by Rouleau et al. [12]. As a reference value, the RCR (for the six arms in the three subluxation conditions) was measured in the 0° to 0° position (true lateral radiograph). The difference between each RCR in a nonreference position was subtracted from each RCR reference to obtain the delta-RCR.

All measurements were made by one observer (FM). To evaluate interobserver agreement, 50 radiographs were randomly selected and the measurements to calculate the RCR were done once by a medical student (FM) and repeated once again by an engineer specialized in musculoskeletal imaging (FC) [14]. Both evaluators had been trained by a fellowship-certified orthopaedic surgeon (DR). An intraclass correlation coefficient (ICC) then was calculated to ensure good interobserver agreement.

To evaluate the effect of beam angulation, an ANOVA study for repeated measures was conducted to analyze the main and interactive effects of radiographic beam angulations (inferosuperior and dorsoventral) and of elbow subluxation (nonsubluxated, anteriorly subluxated, and posteriorly subluxated) on the delta-RCR [3].

Results

In the nonsubluxated elbow, the RCR did not vary significantly with the position of the C-arm whether it was moved in the inferosuperior or dorsoventral directions.

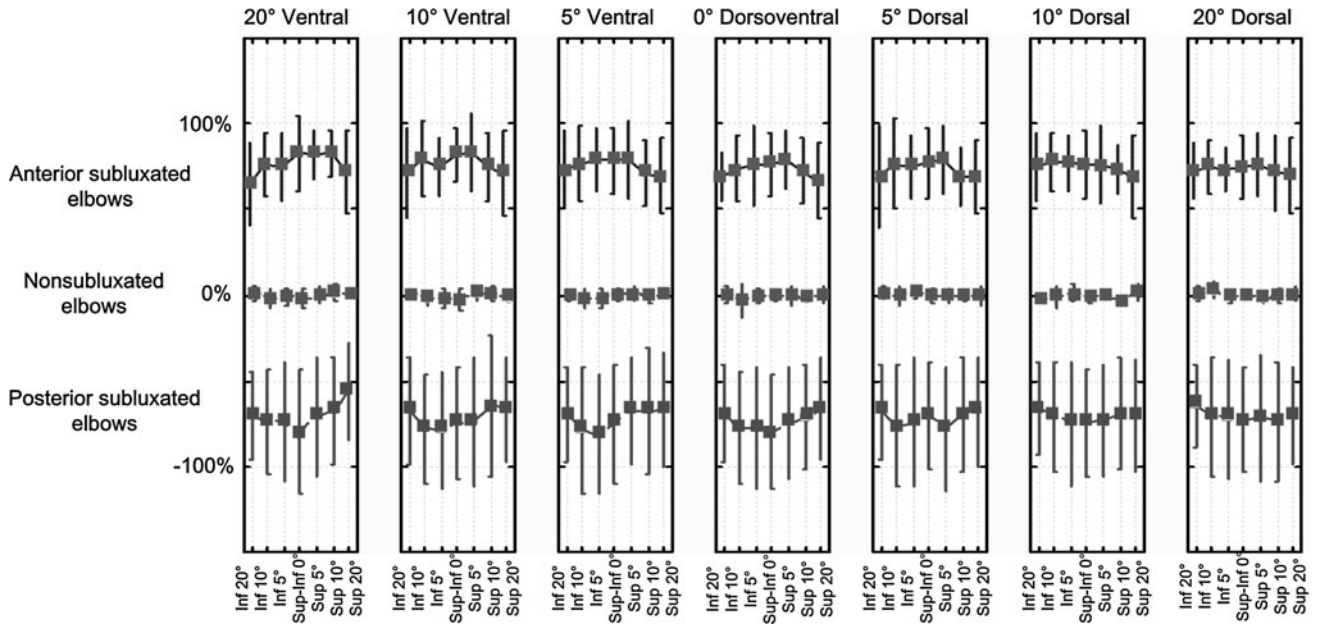

Fig. 4 Means and standard deviations of each delta RCR as a function of beam angulation (inferosuperior and dorsoventral) and of elbow condition (nonsubluxated, anteriorly subluxated, or posteriorly subluxated). Inf = inferior; Sup-Inf = superoinferior; Sup = superior.

Table 1. Difference between RCR on angulated and true lateral radiographs

Subluxation condition	delta RCR								
	Dorsoventral angulations only			Inferosuperior angulations only			Combined angulations*		
	Range	Mean	SD	Range	Mean	SD	Range	Mean	SD
Healthy (nonsubluxated) elbow	−7.6% to 7.8%	−0.4%	3.7%	−17.7% to 8.6%	0.1%	4.5%	−17.7% to 10.3%	0.2%	4.0%
Elbow with anterior subluxation	−12.8% to 33.6%	1.0%	9.4%	−45.6% to 26.8%	−4.8%	13.9%	−45.6% to 39.8%	−1.4%	12.2%
Elbow with posterior subluxation	−37.5% to 23.2%	6.2%	10.6%	−30.9% to 36.4%	9.8%	10.8%	−38.7% to 36.4%	8.7%	10.8%

* Combined angulation includes all combinations of beam angulations from −20° to 20° around the dorsoventral axis and inferosuperior axis; RCR = radiocapitellar ratio.

For the nonsubluxated elbow condition, the delta-RCR was 0.1% (SD, 4.5%) in the inferosuperior axis, −0.4% (SD, 3.7%) in the dorsoventral axis, and 0.2% (SD, 4.0%) for both axes combined. The ANOVA study confirmed that both radiographic beam positions have no impact on RCR measurements in nonsubluxated elbows (Fig. 4).

In the case of anterior radial subluxation, the position of the C-arm had an impact on the RCR, particularly when the C-arm was moved in the inferosuperior direction; the RCR was within the acceptable limit when the malalignment was within 5°, but exceeded the acceptable limit when it was greater than 10°. For the anterior subluxated condition, the delta RCR was −4.8% (SD, 13.9%) in the inferosuperior axis, 1% (SD, 9.4%) in the dorsoventral axis, and −1.4% (SD, 12.2%) for both axes combined (Table 1).

In the case of posterior radial subluxation, the position of the C-arm influenced the RCR, particularly when the C-arm was moved in the inferosuperior direction. For the posterior subluxated condition, the delta RCR was 9.8% (SD, 10.8%) in the inferosuperior axis, 6.2% (SD, 10.6%) in the dorsoventral axis, and 8.7% (SD, 10.8%) for both axes combined. The delta RCR for posterior subluxation had greater variability than the delta RCR for anterior subluxation. There is no overlapping of the SDs, meaning that we always can detect a nonsubluxated elbow from a subluxated elbow. For anterior and posterior elbow subluxations, the dorsoventral beam position had no impact on RCR measurements ($p = 0.777$) but the inferosuperior beam position increased the differences in the RCR measurements ($p = 0.006$) (Table 2).

For elbows in the nonsubluxated condition, the reference RCRs ranged between −4.9% and 2.7% (mean, −0.7%; SD, 3.2%; 95% CI, −4.0% to 2.7%). For anterior subluxation, the reference RCRs ranged between 50.1% and

Table 2. Main and interactive ANOVA effects on the delta RCR

Inputs	p value
Radiocapitellum alignment, inferosuperior positions and dorsoventral positions	0.221
Radiocapitellum alignment and inferosuperior positions	0.006
Radiocapitellum alignment and dorsoventral positions	0.777
Inferosuperior positions and dorsoventral positions	0.156
Radiocapitellum alignment	< 0.001
Inferosuperior positions	0.879
Dorsoventral positions	0.127

ANOVA = analysis of variance; RCR = radiocapitellar ratio.

100.6% (mean, 75.5%; SD, 17.7%; 95% CI, 57.0% to 94.1%), and for posterior subluxation, the reference RCRs ranged between −126.7% and 39.7% (mean, −80.0%; SD, 31.8%; 95% CI, −113.9% to −46.6%) (Table 3).

The ICC for the interobserver agreement was 0.90.

Discussion

Misalignment of lateral radiographs is frequent during clinical evaluation of elbow reduction [15]. Therefore, it is important to know how beam angulation may affect the diagnosis. The goal of our study was to evaluate how small deviations of beam shooting angle would affect the RCR for the elbow in nonsubluxated, anteriorly subluxated, and posteriorly subluxated conditions. To answer this question, the radiocapitellar ratio (RCR) was quantified on six cadaveric upper extremities with three conditions: nonsubluxated, anteriorly subluxated, and posteriorly subluxated and with various beam angulations ranging from −20° to 20° around the inferosuperior and dorsoventral axes. The hypotheses were that the RCR of the nonsubluxated elbow would remain in the normal range as the beam angle changed and that the RCR variability would increase for the subluxated elbow with small deviations in the beam angle.

This study has some limitations. First the beam angulations were limited to 20°. However it is likely that beam deviations up to 30° would not alter the results of this study; in addition, a radiograph with a beam deviation of 30° would likely be rejected and retaken. Second, the RCR was measured only on nonsubluxated, anteriorly subluxated, and posteriorly subluxated elbows without any closed disorder such as a fracture. A fracture may affect the RCR measurement. A study of clinical cases representing various elbow disorders would be needed to address this point. Finally, the level of difficulty to measure the RCR depending on beam angulation was not analyzed in this study. This measure could have added information on which beam angulations are better to have a clearer view of the radiograph from the clinician's point of view.

Our findings suggest that the RCR was not affected by changes in beam angle for the nonsubluxated elbow, but that it was affected for the subluxated elbow. This suggests that the absence of elbow subluxation can be confirmed with confidence from radiographic images with a beam angle of as much as 20° deviation in the inferosuperior or dorsoventral directions.

For anterior and posterior radial subluxations, as little as 5° deviation in the inferior direction may lead to an RCR measurement beyond the acceptable threshold found in healthy subjects (4% ± 4%) [12]. A RCR of 10% corresponds, for example in a capitellum with a diameter of 25 mm, to 2.5 mm of anterior deviation. This means that the position of the C-arm is especially important when measuring the degree of anterior and posterior radial subluxation because even slight misalignment of the C-arm may affect the measured RCR. These results are also in agreement with those of Lee et al. who showed that malrotation of the elbow is better seen on a 45° oblique pronated radiographic view [7].

Moving the C-arm in the dorsoventral direction does not influence RCR. It could be explained by the RCR itself which is a measure of the deviation of the axis passing through the center of the radial head compared with the center of the capitellum [12]; thus, this distance does not change on the radiograph when the C-arm turns on the same plane. Regardless, the difference between the mean RCRs is more important with anterior and posterior subluxations than with nonsubluxated elbows. The bigger variability and larger range between the RCRs found with posterior compared with anterior radial subluxation may be explained in part by the overlapping of bones in posterior subluxation, which makes RCR measurement more difficult (Fig. 5). That is, some confusion between the trochlea

Table 3. Measurements of RCR in lateral position as reference

Subluxation condition	Number of cases	Range	Mean	Standard deviation	95% CI
Healthy (nonsubluxated) elbow	6	−4.9% to 2.7%	−0.7%	3.2%	−4.0% to 2.7%
Elbow with anterior subluxation	6	50.1% to 100.6%	+75.5%	17.7%	57.0% to 94.1%
Elbow with posterior subluxation	6	−126.7% to −39.7%	−80.0%	31.8%	−113.9% to −46.6%

RCR = radiocapitellar ratio.

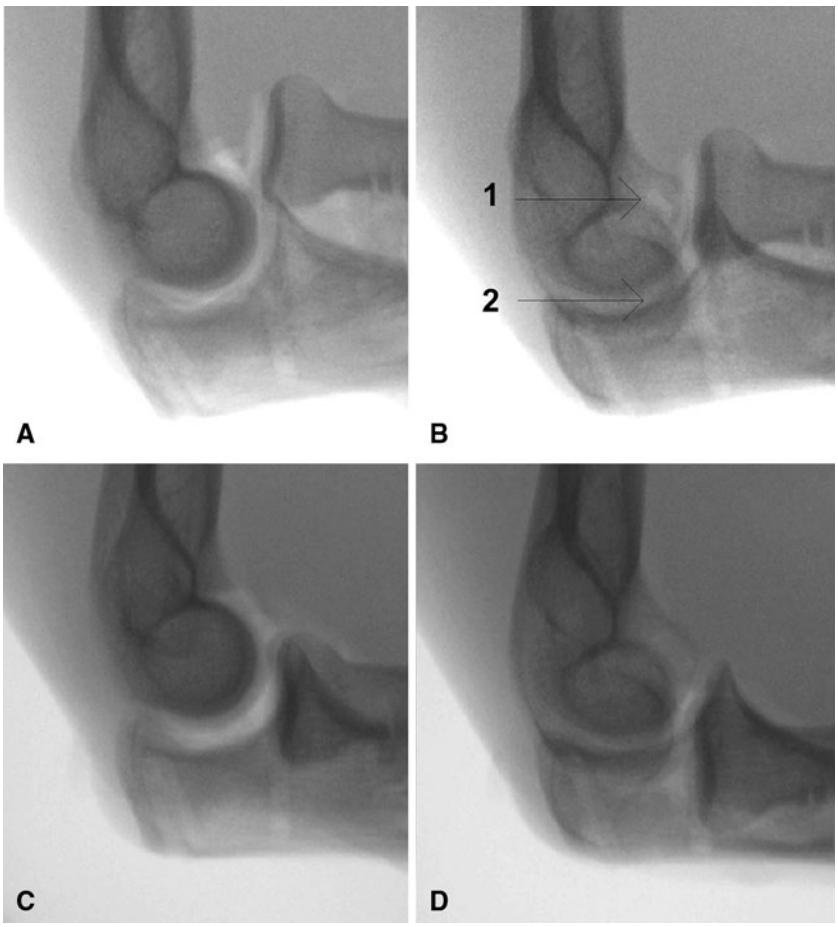

Fig. 5A–D An anteriorly subluxated elbow in (**A**) neutral position, and (**B**) with 20° superior beam angulation are shown. The number 1 indicates the trochlea and 2 the capitellum. (**C**) A posteriorly subluxated elbow in neutral position and (**D**) with 20° superior beam angulation are shown.

and capitellum is possible when the beam is angulated in the inferosuperior direction, such that the trochlea may appear to be closer than the capitellum (Fig. 5) [2].

Because radial head subluxation is the first step in the mechanisms of elbow instability, it is important to quantify its translation [4, 9, 13]. Important intraoperative decisions on ligament reconstruction or use of external fixators are based on elbow stability in pronation and supination at 45° to 60° flexion [4, 9, 13]. These expert recommendations are based on radial head alignment. Our study showed these algorithms can be used only to a maximum of 20° in the presence of beam malalignment. This range is realistic in practice, therefore, RCR can be recommended for clinical use.

We found that when looking at the radiograph of a reduced elbow, a true lateral radiograph is not crucial to confirm the diagnosis of a subluxated elbow, but the inferosuperior alignment of the C-arm is important to correctly assess the RCR. RCR measurement is a relevant clinical and research tool to evaluate elbow subluxations on lateral radiographs even with a C-arm beam deviation of as much as 20°.

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