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The Baumann Angle: An Analysis from Theory to Practice

O ângulo de Baumann: Uma análise da teoria à prática

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Abstract

Objective To analyze how the Baumann angle (BA) is affected by inadequate radiographic inclinations.

Methods The study was performed from radiographs of the distal humerus of children aged 3 to 10 years. The BA measurements performed by five observers were compared, and each radiograph was evaluated for its quality as "adequate" or "inadequate." The correlation between radiographic quality and the normality of the angles was evaluated.

Results Sample was composed of 141 patients, 44% between 3 and 6 years of age and 56% between 7 and 10. We observed the BA between 52.01 and 89.82 degrees, with about 16% of the measurements outside the normal limits of the literature. A total of 33.3% of the evaluated radiographs were classified as "inadequate". On the BA measurements outside the normality parameter, we observed that its proportion was higher among images with inadequate radiographic quality (31.1 vs. 6.2%), and this difference was significant ($p < 0.001$).

Conclusions The BA is a very variable measurement and, alone, it is unreliable for the evaluation of angular deformities of the pediatric elbow, with radiographic quality proven to be an important causal factor of this variability.

Resumo

Objetivo Analisar como o ângulo de Baumann (AB) é afetado por inclinações radiográficas inadequadas.

Métodos Estudo realizado a partir de radiografias do úmero distal de crianças de 3 a 10 anos. Foram comparadas as aferições do AB realizadas por cinco observadores, e cada radiografia foi avaliada quanto à sua qualidade em "adequada" ou "inadequada". A correlação entre a qualidade radiográfica e a normalidade dos ângulos foi avaliada.

Keywords
- elbow joint
- humeral fractures
- radiography
- child

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Resultados Amostra composta por 141 pacientes, 44% entre 3 e 6 anos e 56% entre 7 e 10. Observamos AB entre 52,01 e 89,82 graus, tendo cerca de 16% das medidas fora dos limites de normalidade da literatura. Um total de 33,3% das radiografias avaliadas foram classificadas como "inadequadas". Sobre as medidas do AB fora do parâmetro da normalidade, observamos que sua proporção foi maior entre as imagens com qualidade radiográfica inadequada (31,1% vs. 6,2%), tendo essa diferença se mostrado significativa ($p < 0,001$).

Conclusões O AB é uma medida muito variável e, isoladamente, pouco confiável para a avaliação de deformidades angulares do cotovelo pediátrico, tendo a qualidade radiográfica se mostrado um fator causal importante dessa variabilidade.

Palavras-chave
- articulação do cotovelo
- fraturas do úmero
- radiografia
- criança

Introduction

Supracondylar humerus fractures (SCHF) account for about 3% of fractures in children, corresponding to almost 60% of elbow fractures in the pediatric age group. These are very frequent fractures in children between 3 and 10 years of age, with their peak incidence in the range of 5 to 6 years. The most frequent complications associated with SCHF are nerve lesions, with the most common being anterior interosseous nerve injury, arterial lesions, specifically brachial artery, and varus cubit deformity.[1]

The angular deformity of the elbow in the coronal plane has been described as one of the most common complications of supracondylar fractures in children, with reports of incidence of varus ulna of up to 26% in fractures in Gartland-II extension inadequately treated.[2] There is consensus in the literature that anatomical fracture reduction and its maintenance must be radiographically documented to avoid this deformity.[3,4] Köberle[5] described the importance of the proper position of the forearm in immobilization to avoid the occurrence of angular deformities, while Patriota et al.[6] and Carvalho et al.[7] investigated the efficacy of fracture fixation techniques to maintain the reduction, with positive results.

In clinical practice, the loading angle of the upper limb is widely used to evaluate possible angular deformities. Radiographically, the Baumann Angle (BA) is the most used measurement for these fractures' quality of reduction. The BA corresponds to the angle formed between the long axis of the humerus diaphysis, traced by the center of the medullary canal, and the line drawn by the chapter physis in the anteroposterior radiographic incidence, being widely used as a comparative angle to the contralateral side and having values between 64 and 81 degrees considered as normal.[8,9] Visibility of at least 7 cm of the distal humerus on radiographic images increases the accuracy of this measurement.[10] It has been observed, however, that the wide range of 17 degrees considered as normal variability for BA raises questions regarding its reliability and, although validated to confer the alignment of the post-reduction fracture, there are reports of inconsistencies in this measure, both intra and interobservers.[10]

Our hypothesis is that one of the factors causing this problem is the difficulty of obtaining true coronal radiographic incidences of the elbow in daily practice.

The primary objective of this study is to analyze how the angles traced between the long axis of the humerus diameter and the axis of the chapter physeal line in normal elbows are affected by inadequate inclinations of radiographs and to analyze the intra- and interobserver variations of BA measurements, and the secondary objectives are: 1) to describe the measurements of the angles obtained in our sample, comparing them by age group; 2) to evaluate the percentage of BA measurements in our sample that are outside the normality standard described in the literature.

Methods

This is a retrospective study authorized and approved by the Research Project Manager System and the Research Ethics Committee of a Brazilian tertiary hospital, carried out from radiographs of the distal humerus of children, already obtained and archived in the imaging diagnosis sector of the hospital. The exemption from obtaining a Free and Informed Consent Form was requested and authorized.

Inclusion Criteria

This study included 141 consecutive radiographs of children treated at our service from September 2006 to March 2020 that met the following criteria:

1. Children aged between 3 and 10 years.
2. Radiographs taken in the anteroposterior direction of the elbow, with at least 7 cm of the distal humerus visible in the image.

Exclusion Criteria

Radiographs that presented any of the following alterations were excluded from this study:

1. Acute or previous ipsilateral humerus, radius or ulna fractures.
2. Bone or joint changes.

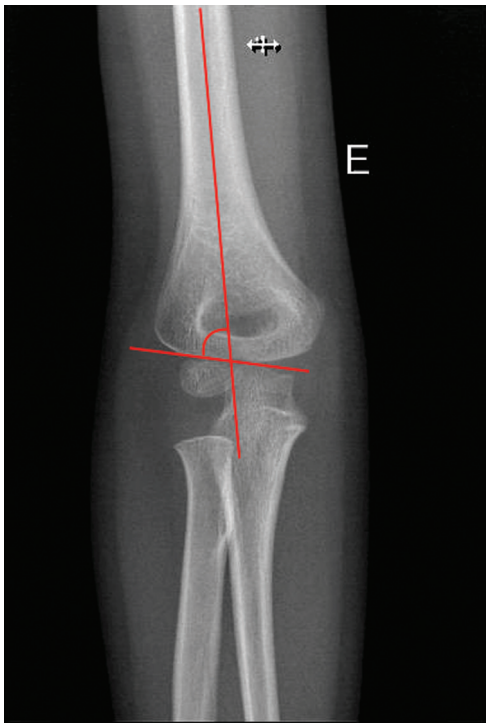

Fig. 1 The Baumann angle.

Data Analysis

The 141 radiographs of normal elbows were anonymized, numbered from 1 to 141, and submitted to BA measurement by the observers, as indicated in ►**Figure 1**. The measurements of the angles were performed digitally in the Carestream Viewer system in Digital Imaging and Communications in Medicine (DICOM) format images, through the tools available in the system itself. Five observers participated in the study: a second and a third year residents skilled in Orthopedics and Traumatology, an orthopedist specializing in Pediatric Orthopedics, and two senior Pediatric Orthopedists. Each observer performed three measurements of the sequenced radiographs, on different dates, with at least one week of interval between measurements. After the measurements, the radiographs were divided considering half of the age group of the sample (3–10 years), with the youngest group being composed of radiographs of children aged 3 to 6 years, and the oldest group being composed of radiographs of children aged 7 to 10 years. The angles measured were compared according to the normality pattern established in the literature and the intra- and interobserver variations of the BA measurements were analyzed. Each radiograph was evaluated by a consensus of two specialists regarding its quality as "adequate" or "inadequate", according to parameters proposed by Pace et al.[11] Thus, radiographs with radioulnar overlap (percentage of ulna width at the level of radio tuberosity that is overlapped by the medial edge of the radio) ranging between 0.1 and 0.5 were considered "adequate" and those outside this parameter were "inadequate". With these data, the correlation between radiographic quality and normality or not of the measured angles was evaluated.

The sample size was calculated to estimate the means of the angles traced according to the study by Shank et al.,[12] in which a standard deviation (SD) of 6° was observed in the BA measurements. Using this variability estimate, a sample size of 141 radiographs would be sufficient to build a bilateral 95% confidence interval with a size of 1°.

The sample size estimation calculations were performed with the aid of the Power Analysis and Sample Size (PASS, NCSS, LLC. Kaysville, UT, US) software version 14.0, using a 5% significance level.

The correlation between radiographic quality and BA was calculated with the chi-square test. In addition, the agreement of intra- and interobserver measurements was verified and stratified by radiographic quality. The agreements were verified by the Intraclass Correlation Coefficient (ICC) and the results were presented from the mean and SD, ICC, and their respective confidence intervals and *p*-values. The agreement coefficients were compared to the classification present in Altman,[13] which considers coefficients lower than 0.2 as poor, those between 0.2 and 0.4 as reasonable, those between 0.4 and 0.6 as moderate, those between 0.6 and 0.8 as good, and those above 0.8 as excellent.

The analyses were carried out in the Statistical Package for the Social Sciences (SPSS, IBM Corp. Armonk, NY, USA) software, version 26.0, and a significance level of 5% was adopted.

Results

The sample consisted of 141 radiographs, 65 (46.1%) of female patients and 76 (53.9%) of male patients. Additionally, 62 (44%) patients were aged between 3 and 6-years-old and 79 (56%) were between 7 and 10-years-old. The 141 radiographs were analyzed by the five observers, who performed each angular measurement three times, totaling 2,115 BA measurements. We verified the agreement of intra- and interobserver measurements, stratified by level of experience of the observers. All angles measured presented good or excellent levels of intra- and interobserver agreement. The results are listed in ►**Tables 1** and **2**. There was no difference in the values of the angles between the female and male genders, and the experience of the observers did not significantly affect the results.

Each observer performed three BA measurements for each radiography. In measurements 1, we obtained angles with an average of 70.81°, SD of 6.12°, with a minimum value of 52.01° and a maximum of 89.82°. In measurements 2, the mean was 70.79°, SD was 5.86°, minimum of 53.04° and maximum of 85.78°. Finally, in measurements 3, the average was of 70.41°, SD was 6.07°, minimum of 62.38° and maximum of 88.03°.

We verified the percentage of BA measurements different from the values considered normal in the literature (64–81°). Considering the percentage in the three measurements performed for each radiograph and the percentage per observer, 17.4% of measurements 1, 15.2% of measurements 2, and 16.3% of measurements 3 were outside the normal limits. The results are presented in ►**Table 3**.

Table 1 Agreement of intraobserver measurements

Measures	Average	SD	ICC
Observer 1			
Med. 1	71.61	5.85	
Med. 2	71.38	5.98	
Med. 3	70.63	5.96	
Baumann			0.863
Observer 2			
Med. 1	70.11	6.07	
Med. 2	69.81	5.70	
Med. 3	69.67	5.69	
Baumann			0.909
Observer 3			
Med. 1	71.15	6.69	
Med. 2	70.48	6.34	
Med. 3	69.95	6.42	
Baumann			0.876
Observer 4			
Med. 1	70.27	5.44	
Med. 2	70.51	4.84	
Med. 3	69.78	5.20	
Baumann			0.764
Observer 5			
Med. 1	70.90	6.43	
Med. 2	71.78	6.22	
Med. 3	72.01	6.72	
Baumann			0.911

Abbreviations: ICC, intraclass correlation coefficient; SD, standard deviation.

Table 2 Agreement of interobserver measures

Observers	Average	SD	ICC	Confidence Interval (ICC. 95%)	
				Inf.	Sup.
Baumann			0.843	0.800	0.879
Observer 1	71.20	5.66			
Observer 2	69.86	5.65			
Observer 3	70.52	6.22			
Observer 4	70.19	4.75			
Observer 5	71.56	6.28			

Abbreviations: ICC, intraclass correlation coefficient; SD, standard deviation.

Among the 141 images evaluated, 47 of them (33.3%) were classified as "inadequate", and 94 (66.7%) as "adequate". In total, 705 BA measurements were performed on radiographs considered inadequate and 1,410 on appropriate radiographs. Images with adequate radiographic quality presented higher mean values of BA measurements. ►**Table 4** contains the abstracts of BA measurements 1, 2, and 3 of all observers in the whole sample, according to radiographic quality.

Table 3 Percentage of angle measurements compared to normality pattern

Measure versus Observer	Baumann angle within normal limits			
	No		Yes	
	n	%	n	%
Measure 1				
Observer 1	22	15.6%	119	84.4%
Observer 2	25	17.7%	116	82.3%
Observer 3	30	21.3%	111	78.7%
Observer 4	18	12.8%	123	87.2%
Observer 5	28	19.9%	113	80.1%
Total (n = 705)	123	17.4%	582	82.6%
Measure 2				
Observer 1	24	17.0%	117	83.0%
Observer 2	23	16.3%	118	83.7%
Observer 3	22	15.6%	119	84.4%
Observer 4	16	11.3%	125	88.7%
Observer 5	22	15.6%	119	84.4%
Total (n = 705)	107	15.2%	598	84.8%
Measure 3				
Observer 1	19	13.5%	122	86.5%
Observer 2	23	16.3%	118	83.7%
Observer 3	26	18.4%	115	81.6%
Observer 4	20	14.2%	121	85.8%
Observer 5	27	19.1%	114	80.9%
Total (n = 705)	115	16.3%	590	83.7%

We also observed that, for adequate radiographs, 93.8% of the angles measured were within the normal values of the literature and 6.2% were outside the reference values; while for inadequate radiographs 68.9% of the angles were within normal range and 31.1% were outside the limit of these parameters. This difference was significant ($p < 0.001$), as shown in ►**Table 5**.

In addition, we noted the variation of BA by age group, as shown in ►**Table 6**. The interobserver agreement coefficients verified at the angles of patients aged 3 to 6-years-old were excellent (coefficients greater than 0.8), while lower coefficients were observed in older patients (7–10 years, coefficients greater than 0.7).

Discussion

Varus ulna deformity is one of the most common complications of SCHF in children and, to date, the most widely used

Table 4 Baumann angles (summary of measurements 1, 2, and 3 of all observers), according to radiographic quality

	Radiographic quality			
	Adequate		Inadequate	
Baumann: measure 1				
Mean and SD	71.64	5.02	69.15	7.61
Minimum and maximum	56.74	89.82	52.01	87.17
Median and quartiles	71.67	68.8–74.81	69.62	63.39–74.18
Baumann: measure 2				
Mean and SD	71.55	4.73	69.28	7.43
Minimum and maximum	55.00	84.56	53.04	85.78
Median and quartiles	71.90	68.66–74.67	69.35	63.5–73.94
Baumann: measure 3				
Mean and SD	71.21	4.91	68.80	7.66
Minimum and maximum	57.02	85.87	52.38	88.03
Median and quartiles	71.21	68–74.41	68.71	63.28–73.96

Abbreviation: SD, standard deviation.

Table 5 Baumann angle ratio versus radiographic quality

	Radiographic quality				*p*-value
	Adequate		Inadequate		
Baumann					<0.001
Outside the reference parameters	29	6.2%	73	31.1%	
Normal	441	93.8%	162	68.9%	

Table 6 Summary of angles by age group

Comparison	Average	95% CI		*p*-value
		Inferior	Superior	
Baumann				<0.001
3 to 6 years	71.13	70.44	71.82	
7 to 10 years	70.31	69.80	70.83	

Abbreviation: 95% Confidence Interval

radiographic measurement to measure the alignment of the distal humerus after fracture reduction is BA. However, its wide range of normality and inconsistencies found in the literature led us to question its reliability, motivating the analysis of angles traced in normal elbows of our sample and the evaluation of how these angles are altered by inadequate inclinations of radiographs.

The study by Silva et al.,[14] for example, showed that, among five observers, one presented BA measurements with a difference of more than 7 degrees in relation to the measurements of the other four observers for the same radiography. In addition, the results of the study by Shank et al. suggested that 95% of BA measurements by the same observer for the same radiography would have a variability of up to 5°.[12]

In daily practice, it is common to observe that elbow radiographs performed in child patients with distal humerus fractures are not performed in perfect planes. Due to factors resulting from trauma, such as pain, edema, limitation of movement, or presence of immobilizers, along with the low cooperation of children, there may often be some degree of rotation in relation to the projection of the humerus in the true coronal plane. Camp et al. showed that BA presents 6° of variation for every 10° of rotation of the anteroposterior radiography of the elbow.[15] On the other hand, Segal et al.,[16] in a study based on the analysis of tomographic images of elbows, reported that the measured BA were consistent in projections with angles ranging from 70° of internal rotation to 40° of external rotation. However, this consistency was established considering the wide margin of measurement error, which varies around 7°, as within BA normal range.

The normal values for BA, described in the medical literature, range from 64 to 81°.[8,9] However, in our sample of normal elbows, we observed values ranging from 52.01 to 89.82°. Thus, about 16% of the normal elbows studied presented angles outside the normal range. We also found that, in our sample, 33.3% of the radiographs were inadequate regarding rotation in relation to the projection of the humerus in the true coronal plane, demonstrating the difficulty of obtaining adequate radiographs in the practical context. Furthermore, inadequate radiographs resulted in a significant number of BA measurements outside the normal range (31.1%). However, it is worth mentioning that, even on adequate radiographs of normal elbows, we obtained 6.2% of the BA outside the normal range seen in the literature, with absolute values of angles in normal elbows and in appropriate radiographs reaching extremes such as 55° and 89.82°, which supports the hypothesis of low reliability of BA. We also found that, of the total of 1,410 BA measurements in

adequate radiographs, 86 presented a value higher than 81° (varus, the main angular deformity of the SCHF), which could indicate that, even on radiographs of normal elbows, 6% of this sample would be classified as deviated, which could lead to inadequate treatments and clinical practices.

An interesting point was that the interobserver agreement coefficients verified in the angles of patients aged 3 to 6 years were better than the coefficients of the older age group (7–10 years), which may indicate that the accuracy of the angle decreases as the ossification of the distal humerus progresses.

Taking these data in consideration, we believe that the rotation of radiographic projections is one of the main factors that generate the variability observed in the angular measurements presented here, together with the natural variation of the angle itself and the existing variations among the observers.

This study's limitations are the reduced size of the sample for the different age groups, the fact that the measurements were performed in personal computers with different screen sizes and resolutions, and the fact that only the rotational analysis of radiographs was performed, and no possible cephalic or caudal inclinations of the images were evaluated.

Conclusion

It was possible to conclude that, if analyzed in isolation, the BA is a very variable and unreliable measure for the evaluation of angular deformities of the elbow in pediatric patients, and radiographic quality has been shown to be an important causal factor of this variability.

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Conflict of Interests
The authors have no conflict of interests to declare.

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