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The physiological range of the Böhler's angle in the adult Croatian population

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ABSTRACT

Background: To examine the relationship of the Böhler's angle with age, sex, and laterality, and to analyze the interrater agreement.
Methods: After 248 digital lateral radiographs of the foot were submitted to exclusion criteria, three raters independently measured the Böhler's angle on the remaining 130 X-rays in PACS. The variables were analyzed with correlation coefficients, and one-way ANOVA. The repeated measures of ANOVA were computed across age groups (30–39, 40–49, 50–59, and 60–69 years). The interrater agreement was calculated using intraclass correlation coefficient (ICC).
Results: The mean value of the Böhler's angle was $34 \pm 5^{\circ}$ ($21–46^{\circ}$). It was not related to age (in general [$p = 0.057$], and across groups [p from 0.107 to 0.122]), sex ($p = 0.344$; $p = 0.342$), and laterality ($p = 0.618$; $p = 0.617$). The interrater reliability was almost perfect (ICC = 0.94).
Conclusions: The Böhler's angle was not related to age, sex, and laterality, whereas the interrater agreement was almost perfect.

1. Introduction

In his invited lecture on treatment of calcaneal fractures at the annual meeting of the American Orthopaedic Association, in Chatham, Massachusetts, in June 1930, an Austrian surgeon from Vienna, Lorenz Böhler (15 January 1885, Wolfurt in Vorarlberg, Austria — 20 January 1973, Vienna, Austria) [1–3], advocated for the restoration of the physiological angle connecting the superior aspects of anterior calcaneal process and posterior subtalar facet and the superior aspect of posterior subtalar facet with posterior calcaneal tuberosity [4,5] (Fig. 1). Up until then, surgeons have aimed to reconstruct the "normal" width of the fractured heel, and Böhler, often regarded as the greatest authority on the treatment of fractures in the first half of the twentieth century [2], and the "father" [3] or the "pope" [6] of traumatology, was first to recognize the significance of the posterior weight-bearing facet of the *os calcis* [5].

Apart from the original term, the tuber (joint) angle [4,5,7,8], numerous synonyms can nowadays be found in the literature, such as Boehler's [7], calcaneal [8], Boehler [9], critical [10], and salient [10] angle.

According to Böhler, the physiological range of the angle is 30–35° [4]. The decreased values seem helpful in diagnosing calcaneal fractures [8] (Fig. 2), as well as in their surgical management [8], and might be of use in anthropometric studies with regard to archaeology and forensic medicine [11]. Even so, to the best of our knowledge, no previous investigation has documented the physiological ("normal") range of the Böhler's angle in the adult Croatian population.

In that regard, the aim of our study was to examine the relationship of the Böhler's angle with age, sex, and laterality, as well as to analyze the interrater agreement.

2. Materials and methods

2.1. Materials

A retrospective cross-sectional study was conducted in August 2016 at the Clinical Institute of Diagnostic and Interventional

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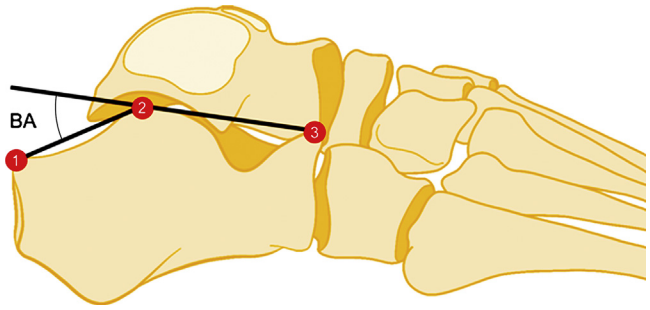

Fig. 1. Construction of the Böhler's angle. 1: Posterior calcaneal tuberosity; 2: superior aspect of posterior subtalar facet; 3: superior aspect of anterior calcaneal process; BA: Böhler's angle.

Radiology in Zagreb University Hospital Center. We meticulously followed the 59th revision of the Declaration of Helsinki (World Medical Association Assembly, Seoul, 2008). Although the research design was retrospective, the approval from the ethics committee was obtained.

A total of 248 digital lateral radiographs of the foot, taken between 1st and 15th of July 2016, was potentially eligible for inclusion in the study. However, the digital lateral radiographs of the foot depicting: (1) arthritic changes of the ankle (66/118), (2) calcaneal fractures (25/118), (3) osteomyelitis (10/118), (4) ankle deformities (3/118), (5) tumors of the calcaneus and the neighboring bones (10/118), and (6) those perceived as technically inadequate (for example, too oblique) (4/118) were excluded from the study. This left a final total of 130 digital lateral radiographs of the foot eligible for review (Fig. 3).

We should point out, though, that the digital lateral radiographs of the foot depicting: (1) the enthesopathy of the Achilles tendon (13/130) and the plantar aponeurosis (1/130), (2) the calcaneal spur (9/130), (3) the supramalleolar fracture of the fibula (1/130), and (4) those taken through the immobilization material (6/130) were included in the study.

2.2. Methods

The Böhler's angle was measured in Picture Archiving and Communication System (PACS) by three independent raters: a senior radiology resident (MŠ), a junior (DN) and a senior (MP) radiologist.

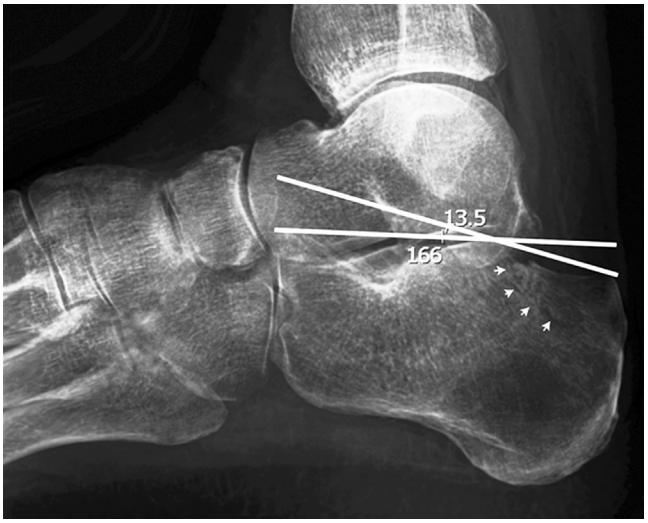

Fig. 2. Calcaneal (beak) fracture (*arrows*) with the decreased value of the Böhler's angle (only 13.5°).

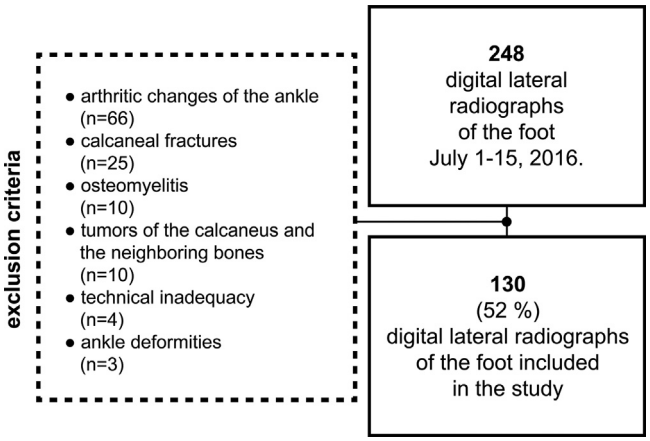

Fig. 3. Flow chart of the study.

On the digital lateral radiographs of the foot, the Böhler's angle was formed by two lines connecting the superior aspects of anterior calcaneal process and posterior subtalar facet and the superior aspect of posterior subtalar facet with posterior calcaneal tuberosity [4,5,9] (Fig. 4).

2.3. Statistical analysis

Statistical analysis was carried out using appropriate software for biostatistics (MedCalc, version 11.3.0.0.; MedCalc Software bvba, Ostend, Belgium), as well as statistical power calculations (G*Power software, version 3.1.9.2., Franz Faul, Kiel University, Germany).

Fig. 4. Construction of the Böhler's angle on the digital lateral radiograph of the left foot.

All reported *p*-values were 2-tailed with a level of <0.05 indicating statistical significance.

D'Agostino–Pearson test was used to analyze the normality of data distribution.

The mean values of the Böhler's angles for each of the digital lateral radiograph of the foot were defined as the sum of the normally distributed values obtained by each of the three raters divided by 3.

According to the exact bivariate normal model, to discover a relationship $r \geq 0.25$ ($r^2 = 0.06 = 6\%$) at $\alpha = 0.05$ with 0.80 statistical power, a total of 123 digital lateral radiographs of the foot was necessary. Since the mean value of the Böhler's angle data did ($p = 0.538$), but the age did not ($p < 0.0001$) follow the normal distribution pattern, the relationship between these two variables was examined using Spearman's rank correlation coefficient (r_s). If statistically significant, the size of correlation would be interpreted according to Mukaka [12]: 0.00–0.30 negligible, 0.30–0.50 low, 0.50–0.70 moderate, 0.70–0.90 high, and 0.90–1.00 very high.

To examine the relationship of the mean value of the Böhler's angle with nominal variables such as sex and laterality (i.e. the side of the body), point-biserial correlation coefficient (r_{pb}) and one-way analysis of variance (ANOVA) were utilized. Also, the repeated measures of ANOVA were computed across four age groups (30–39, 40–49, 50–59, and 60–69 years), with Tukey–Kramer *post-hoc* testing, if needed. In addition, Bonferroni correction for multiple comparisons was applied with regard to *p*-values and confidence intervals (CI).

The interrater agreement was calculated using intraclass correlation coefficient (ICC). Landis and Koch [13] interpreted ICC as follows: 0.00–0.20 slight, 0.21–0.40 fair, 0.41–0.60 moderate, 0.61–0.80 substantial, and 0.81–1.00 almost perfect agreement.

3. Results

The demographics of the cohort are shown in Table 1. The mean value of the Böhler's angle of the uninjured calcanei in the adult Croatian Caucasian population was $34 \pm 5^\circ$ ($21–46^\circ$). The notched box-and-whisker plots of age, sex, laterality, and measurement groups with regard to the mean value of the Böhler's angle are depicted in Fig. 5.

The mean value of the Böhler's angle was not associated with age ($n = 130$, $r_s = -0.167$, $p = 0.057$). Furthermore, there was no statistically significant difference with regard to the mean value of the Böhler's angle across the four (30–39, 40–49, 50–59, and 60–69 years) age groups ($n = 28$, $F = 2.10$, p from 0.107 to 0.122), and no linear ($t = -1.854$, $DF = 27$, $p = 0.075$), quadratic ($t = -1.472$, $DF = 27$, $p = 0.153$) or cubic ($t = 0.906$, $DF = 27$, $p = 0.373$) trend was detected.

The mean value of the Böhler's angle was independent of sex ($n = 130$, $r_{pb} = -0.08$, $p = 0.344$; $F = 0.910$, $p = 0.342$), and laterality ($n = 130$, $r_{pb} = 0.04$, $p = 0.618$; $F = 0.251$, $p = 0.617$).

The interrater reliability was almost perfect (ICC = 0.94, 95% CI = 0.92, 0.95).

4. Discussion

Our study has shown that the mean value of the Böhler's angle in the adult uninjured calcanei of the Croatian Caucasian population was independent of age, sex, and laterality, whereas the interrater agreement was almost perfect.

The calcaneus is the most commonly fractured tarsal bone, notwithstanding the fact that the fractures of the tarsus are relatively infrequent [14]. In adults, the calcaneal fractures account for 1–2% of all fractures [7,8,15]. The most frequent causes of these fractures are falls from height [7,8,11,15–17], slipping from stairways [17], jumps [11], the impact of twisting forces [11], and motor vehicle accidents [7,15,16].

It is known that the intraarticular calcaneal fractures distort all its angles, including the Böhler's angle [18]. Therefore, the measurement of the Böhler's angle can help in diagnosing calcaneal fractures, as proven in the emergency department routine [7].

Uninjured calcanei exhibit higher mean values of the Böhler's angle in comparison with the injured heel bone [19]. The values $<20^\circ$ have 99% both sensitivity and specificity for detection of calcaneal fractures [20]. The values $<15^\circ$ are an indication for surgical reduction of the fracture [17,21]. It should be noted that inaccurate evaluation of the Böhler's angle might cause under- or overtreatment [15] (Fig. 6). The postoperative values of the angle relate to functional recovery with regard to the intraarticular calcaneal fractures [22]. In contrast, although it has been shown that decreased values of the Böhler's angle (close to 0°) have significant prognostic value in predicting long-term morbidity, and that an anatomic reduction of the angle has a positive effect on the patient outcome [15,23], the increased values of the Böhler's angle after open reduction and internal fixation do not correlate with improved clinical outcome scores [24], raising some doubts whether surgical restoration of the angle improves the clinical result [24]. Yet, as an accepted method of fracture displacement evaluation, the Böhler's angle has a prognostic value in predicting morbidity associated with calcaneal fractures [14,20,25], especially if fractures are impacted and not displaced. It is also easily and reliably measured using a simple plain or digital lateral radiograph of the foot which is widely available, economical, and exposes the patient to relatively low levels of ionizing radiation, unlike the computed tomography (CT) scanning of the patient's contralateral extremity.

The radiographic calcaneal angles exhibit a wide range of physiological limits and distributions with respect to different populations. Therefore, the body of evidence on the physiological values of the Böhler's angle seems rather confusing, with no generally accepted ranges [8]. It would seem that different populations have different reference values [26], whereas different authors tend to use different ranges [21] (Table 2). However, we could be fairly certain to claim that the values of the Böhler's angle follow a normal distribution [8].

The outcomes on relationships of the Böhler's angle with various other variables are likewise conflicting. According to some authors, there seems to be no statistically significant differences

Table 1
Demographics of the cohort.

Sex	Patients	Digital lateral radiographs of the foot	Age median (years) (95% CI)	Left	Right
Female	74 (57%)	74 (57%)	50 (46, 53)	36 (58%)	38 (56%)
Male	56 (43%)	56 (43%)	46 (41, 51)	26 (42%)	30 (44%)
Total	130	130	49 (45, 51)	62 (48%)	68 (52%)

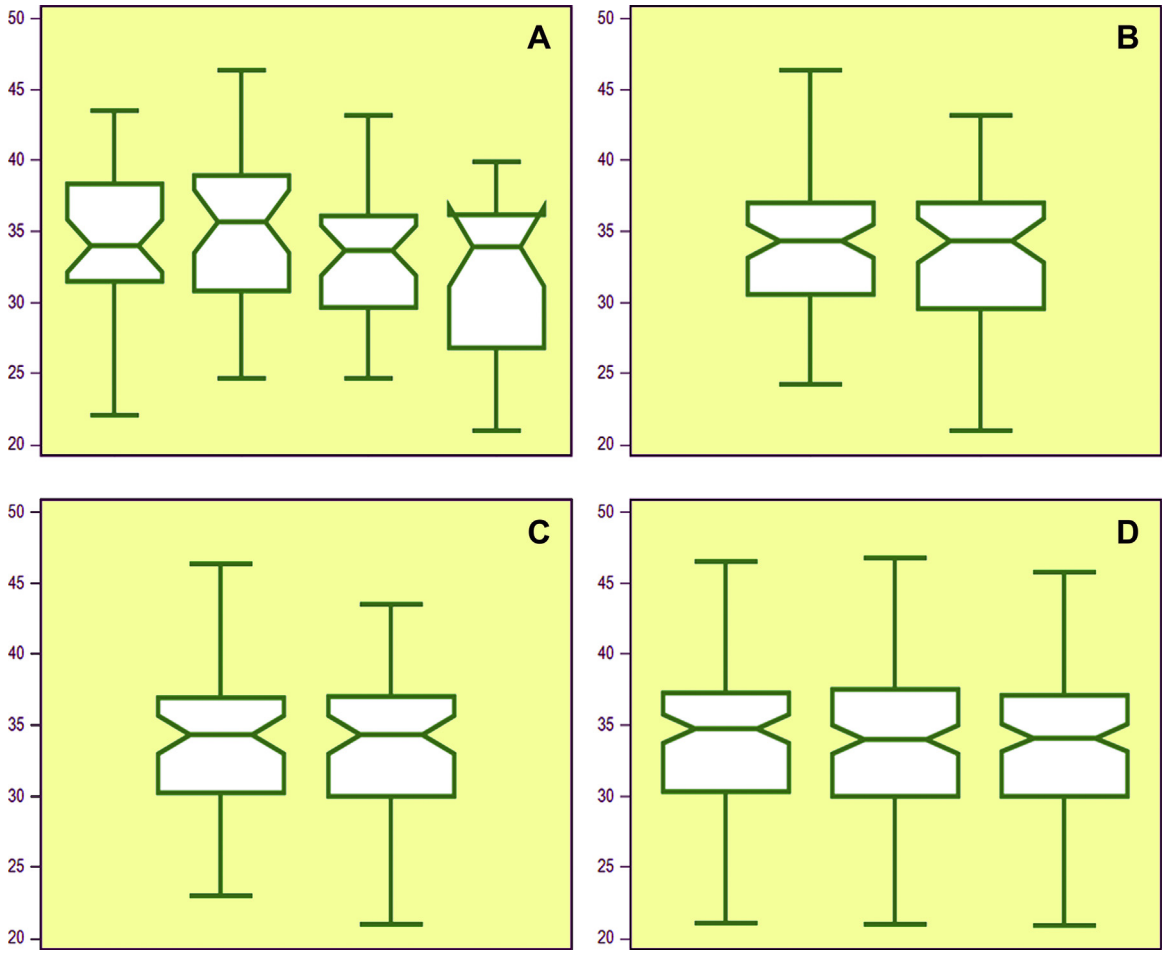

Fig. 5. Notched box-and-whisker plots of age, sex, laterality, and measurement groups (*x*-axes) with regard to mean value of the Böhler's angle (*y*-axes). A: age groups: 30–39, 40–49, 50–59, and 60–69 years (*from left to right*); B: sex groups: females (*left*), and males (*right*); C: laterality groups: left (*left*), and right (*right*); D: measurement groups: the 1st, 2nd, and 3rd rater (*from left to right*).

between the values of the Böhler's angle and age [8,26–28], sex [8,10,26,27,29–31], laterality [8,10,26,27,29], angle of the central beam [29], patient's occupation [10], and the residence [10]. On the contrary, few authors have found that the values of the Böhler's angle differ with age [10,11,32,33], as well as sex [11,33]. In children, the mean value of the Böhler's angle appears lower [34] whereas in adults, a negative correlation with age was documented [10]. However, the other negative correlation available in the literature, the one with the body mass index (BMI), was not statistically significant [10].

With regard to other calcaneal angles, the outcomes are equally mixed. Apparently, no statistically significant relationship exists between the Böhler's angle and the Gissane's angle [10,26,27]. Yet, there seems to be a statistically significant positive correlation between the Böhler's angle and, for example, the calcaneal compression angle (CCA) [10].

The results of our study support the independence of the mean value of the Böhler's angle with regard to age, sex, and laterality, and we feel inclined to the majority of authors who have reached the similar conclusions. These facts are not merely of academic importance, yet bear concrete practical benefits, of use in everyday work. For example, in bilateral calcaneal fractures of adults, one could ask if previous plain or digital lateral radiographs of the foot were available. Since the value of the Böhler's angle does not seem to depend on the patient's age, at least according to the majority of the relevant studies, including ours, the value of the Böhler's angle obtained from the previous radiographs might be considered as the patient's reference value [35]. Moreover, the traditional rule of thumb is to class the value of the Böhler's angle with the value of the patient's contralateral extremity. In our study, there was no statistically significant difference of the values between the feet. This is in keeping with results of similar studies in the English-language literature, estimating the value of the Böhler's angle in the British [8], Saudi Arabian [26], Turkish [27], Malawian [31], Egyptian [10], and Indian [36] population. On that account, our results suggest that in the unilateral calcaneal fractures, the value of the Böhler's angle of the intact side could be taken as the patient's reference value [10,35]. This has already been shown to statistically reduce operative time and might lead to better understanding of the patient's calcaneal anatomy, although, it, eventually, may not allow for more anatomic reduction [16].

At length, the interrater agreement was almost perfect, which is equivalent to other authors [15]. Curiously enough, a recent study on population in central Serbia [33] mentioned an ICC calculation between two raters in the methodology section, yet did not refer to it anywhere else in the article.

The main limitation of our study was its retrospective design. Ideally, the relation of the Böhler's angle with age might be studied on the same individual at different ages through his life, just as the study of laterality might compare both the values of the left and the right Böhler's angle of each individual. However, almost all relevant research was not designed in this manner, and as we primarily wanted to analogize, we have outlined a comparable study. Furthermore, the digital radiographs of the foot were used to

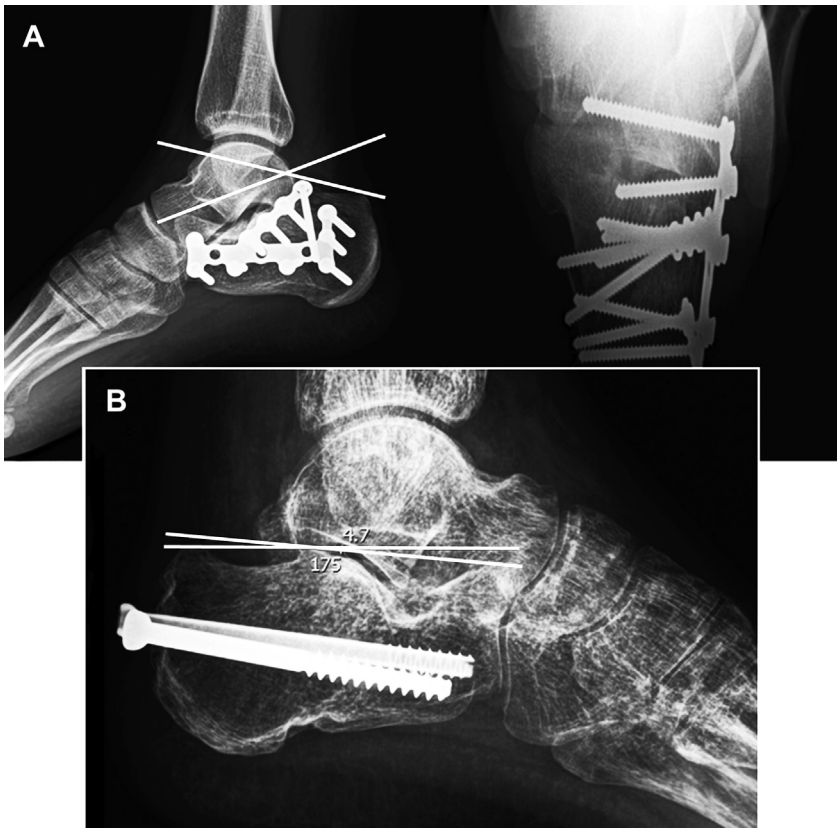

Fig. 6. Postoperative Böhler's angle. A: Successful restoration (>20.0°); B: unsuccessful restoration due to overtreatment (only 4.7°).

Table 2
The previous studies on the physiological range of the Böhler's angle.

Authors	Year of publication	Population	Sample size	Age group (years)	Böhler's angle (mean ± S.D.)	Böhler's angle range (°)
Chen et al. [29]	1991	American	120	16–81	30 ± 6	14–50
Igbigbi and Msamati [31]	2002	Malawian	220	18–54	30 ± 7	14–45
Igbigbi and Mutesasira [11]	2003	Ugandans	206	20–40	36	20–50
Khoshhal et al. [26]	2004	Saudi Arabian	229	15–72	31 ± 6	16–47
Schepers et al. [19]	2007	Dutch	33	18–65	32	25–40
Seyahi et al. [27]	2009	Turkish	268	18–79	34 ± 5	20–46
Boyle et al. [34]	2011	New Zealand	100	30–70	39	26–55
Sengodan et al. [36]	2012	Indian	324	13–74	31 ± 6	18–43
Shoukry et al. [10]	2012	Egyptian	220	20–40	30 ± 4	22–40
Willmott et al. [8]	2012	British	198	16–92	36 ± 4	25–49
Isaacs et al. [20]	2013	Australian	212	Not mentioned	29 ± 4	20–38
Udoaka and Didia [30]	2013	Nigerian	302	Not mentioned	33 ± 3	28–38
Ramachandran and Shetty [17]	2015	South Indian	184	17–75	31 ± 5	20–45
Rokaya et al. [35]	2016	Nepalese	140	15–68	31 ± 5	18–47
Živanović-Mačužić et al. [33]	2016	Central Serbian	225	15–75	34 ± 4	25–50

The means, SD, and range values were rounded off.

measure the Böhler's angle, although we are aware that seldom calcaneal fractures may not be visible on lateral radiographs of the foot [7]. Nonetheless, since the obliquity of the radiographs can influence the measurement accuracy of the Böhler's angle [15], we made sure that all digital radiographs of inadequate technical quality were excluded from the review. Finally, we would like to emphasize the fact that our population consisted solely of Caucasian individuals because this was by far the most common demographic possibility in our geographical setting.

5. Conclusions

The Böhler's angle was not related to age, sex, and laterality, whereas the interrater agreement was almost perfect.

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Conflicts of interest

None.

Declaration of authorship

Guarantor of integrity of the entire study: MŠ; study concepts and design: MŠ, DN, MP, MR; literature research: MŠ, DN; clinical studies: MJ, MŠ, DN, MP; data analysis: MŠ, DN, BK; statistical

analysis: DN, BK; manuscript preparation: MŠ, DN, MP, MR, MJ, BK; manuscript editing: N/A.

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