BASIC STUDY

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The effect of pronation and inclination on the measurement of the hallucal distal metatarsal articular set angle

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Objective: In this study, we tried to evaluate the effect of pronation and the inclination of the first metatarsal on the measurement of distal metatarsal articular angle (DMAA) in 10 cadaver first metatarsals.

Methods: Ten cadaver first metatarsals were fixed to a device. This device can change the inclination and pronation angles of the metatarsal. 15-30-45 degrees of inclination and 0-10-20 degrees of pronation were applied to the metatarsals. After applying radio-opaque putty to the medial and lateral articular edges and metatarsal dorsal diaphyseal ridge, the X-ray and digital images were taken at different degrees of inclination and pronation. A graphics software did the measurement of DMAA. The statistical analysis was done by paired sample t-test.

Results: The inclination had no effect on DMAA ($p>0.1$). The pronation of the first metatarsal was found to have a positive effect on DMAA ($p<0.005$). As the degree of pronation increased, the degree of DMAA was found to also increase. We found no difference between the measurements of the X-ray and the digital images.

Conclusion: According to the current data, the measurement of DMAA is not suitable for making clinical and surgical decisions. The inclination of the first metatarsal can change, depending on the height of the medial longitudinal arch. By doing this study, we are trying to simulate the pes cavus and pes planus deformity on the radiologic measurement of pronation of the hallux. According to our results, inclination has no effect on the measurement of DMAA. However, the measurement of DMAA is expected to be dependent on the rotational deformity of the hallux.

Key words: Distal metatarsal articular angle; hallux deformity; inclination; pronation.

The most common pathologic entity of the first metatarsal, hallux valgus, is the result of lateral deviation of the great toe and medial deviation of the first metatarsal. Other studies have shown that 2 to 4% of the population has this deformity.[1]

The clinicians use various radiographic measurements to evaluate the hallux valgus deformity and choose the most appropriate surgical procedure. One of the most important radiographic angle measurements is the distal metatarsal articular angle (DMAA). This angle is the quantification of the angle from the slope between the longitudinal axis of the first metatarsal and the line that conjuncts the lateral and the medial edges of the distal metatarsal articular surface. The normal range of the

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angle is -2.6 degrees to 8.6 degrees (a mean of 5 degrees).[2] DMAA is a useful measurement of the hallucal metatarsal articular orientation for the preoperative evaluation.[3]

In addition, a number of other studies have analyzed the inter-evaluator variability of the DMAA measurement. The deformity of the first ray is also dependent on the hallucal rotation.[4] The hallux valgus deformity must be evaluated in three planes because the first metatarsal is a three-dimensional bone and the deformity is also dependent on the other anatomic structures.[5,6]

Many studies have been done to evaluate the variability of DMAA by the observers or radiological methods. On the other hand, there are positional factors that may affect the evaluation of DMAA, such as the inclination and rotation of the first metatarsal. As the rotation of the first metatarsal has an effect on the hallux valgus deformity of the first toe, it also has an effect on the radiographic angular measurements relatively. Inclination and rotation of the hallux can change the angular measurements when deciding the treatment of the deformity.

The purpose of the current investigation was to establish the effect of pronation and inclination angles on the measurement of the DMAA of the hallux.

Materials and methods

Ten dry cadaver first metatarsal bones were included in the study (Fig. 1). Radio-opaque putty was applied to the medial-lateral distal articular ridges of the metatarsals and metatarsal dorsal diaphyseal ridge (Fig. 2). The metatarsals' proximal articular parts were fixed to a rod with radio-opaque putty, as their distal inferior articular axis was perpendicular to the plane. The bone and the rod, which were fixed with the putty, were stable when the manipulations were applied on the device. The rod and the metatarsal were fixed on the radiolucent device, and the rod was fixed to a protractor (Fig. 3). Inclination and pronation of the metatarsals could be changed by this device. The plantar surface of the metatarsal head was placed parallel to the floor and the tip of the head was leaned on the small step on the table (the table of the device) and this was determined as neutral rotation. The rotational axis was changed by the rotation of the rod, and the angle of the rotation was measured by the goniometer which was fixed on it. The inclination was changed by moving the rod superiorly and inferiorly to the floor, according to the three inclination angles, which were prepared by three hinges on the device.

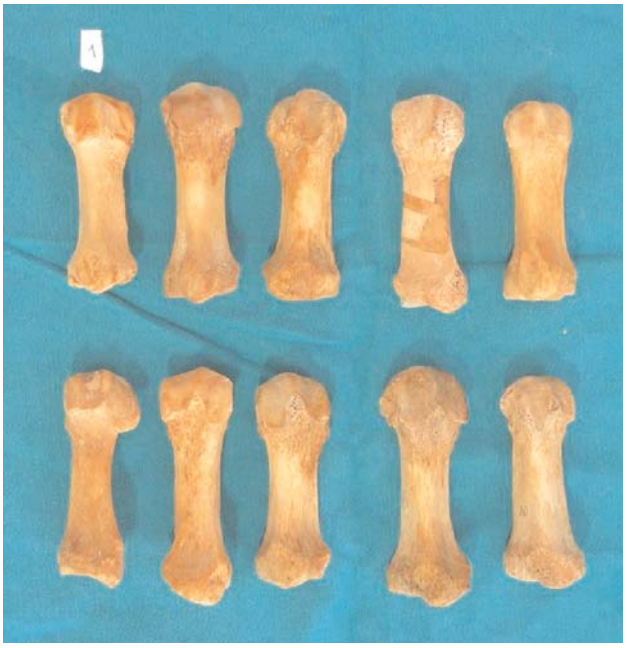

Fig. 1. The dry cadaver first metatarsal bones. [Color figure can be viewed in the online issue, which is available at www.aott.org.tr]

Fig. 2. Radio-opaque putty applied to the medial-lateral distal articular ridges of the metatarsals and metatarsal dorsal diaphyseal ridge. [Color figure can be viewed in the online issue, which is available at www.aott.org.tr]

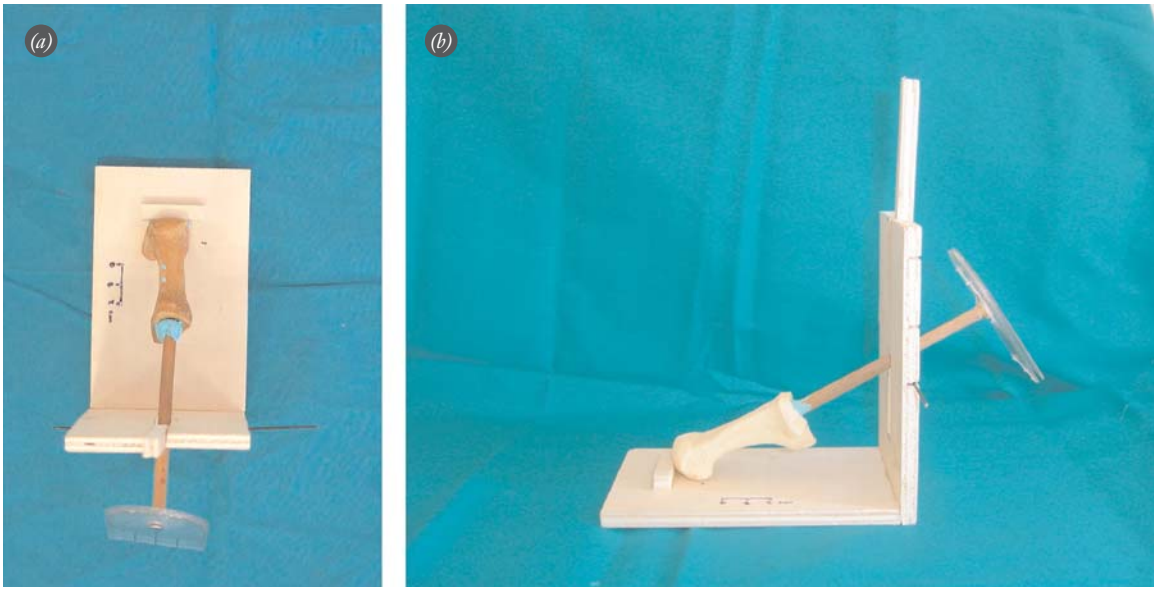

Fig. 3. **(a, b)** The attachment of the first metatarsal bone to the device. [Color figure can be viewed in the online issue, which is available at www.aott.org.tr]

15-30-45 degrees of inclination and 0-10-20 degrees of pronation were applied to the bones. Plain radiographic and digital photographic images of the metatarsals were taken at different degrees of inclination and pronation, while they were attached to the device. (Figs. 4 and 5).

Radiographic and photographic appearances of the metatarsals were analyzed on a digital imaging graphic program. The hallucal distal articular set angles were measured at different inclinations and pronations.

Statistical analyses were performed using SPSS v17.0 software (SPSS Inc., Chicago, IL, USA). All numeric variables were expressed as mean±standard deviation (SD). The statistical analysis of the data was made by paired sample t-test. A value for $p<0.05$ was considered statistically significant.

Results

After all distal articular set angles were measured at different pronation and inclination angles, the data was discussed statistically. When the inclination of the metatarsals were increased, there was no change on the DMAA measurements ($p>0.1$). On the other hand, we found that metatarsal pronation had a significantly positive effect on DMAA ($p<0.005$). As the degree of pronation increased, the degree of DMAA was also increased. We observed no statistical differences between measurements of the radiographic and digital photographic images (Tables 1 and 2).

Discussion

The radiographic angular measurements of the hallux angles are used to assess the severity of hallux valgus

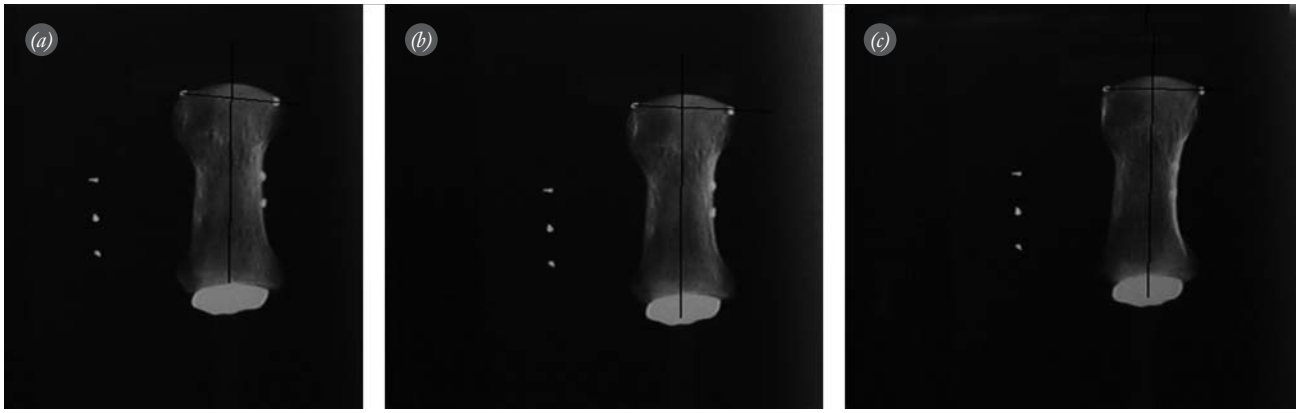

Fig. 4. Radiographic appearances of the metatarsals at 15° of inclination and **(a)** 20°, **(b)** 10° and **(c)** 0° of pronation.

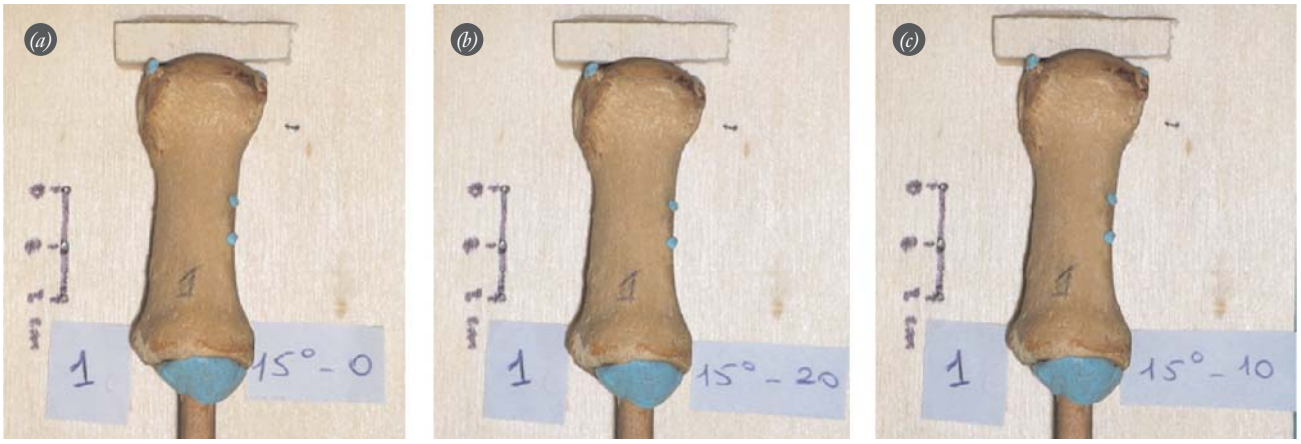

Fig. 5. Digital photographic appearances of the metatarsals at 15° of inclination and **(a)** 0°, **(b)** 20° and **(c)** 10° of pronation. [Color figure can be viewed in the online issue, which is available at www.aott.org.tr]

deformities and to decide for the best operative technique for the proper correction.[7]

Rossi and Ferreira stated that the success of the hallux valgus surgery was judged by the improvements of the angles.[8] One of these important angles is DMAA. DMAA of the first metatarsal is important for preoperative evaluation and for making a decision about the surgical procedure.

When a test or measurement has the same results while in the same conditions, it is reliable and has no variability. The studies emphasize that the radiographic measurement of the DMAA may not be reliable because of the difficulty in determining the exact reference points on the medial and lateral edges of the distal articular surface.[9] Several studies have shown a wide range of variability in radiographic measurements of the DMAA.[9]

Eustace et al.[4] emphasized by a cadaver study that pronation and varus deviation of the first metatarsal are linked. Both of them play a role in the hallux valgus deformity. As the inter-metatarsal angle increases, the pronation of the hallux also increases.

The position and orientation of the first metatarsal axis was described by Hicks in 1953. The axis is drawn between navicular and the base of the third metatarsal. In pronation, neutral and supination foot postures, the orientation of the metatarsal axis changes as a function of arch height and the hallux valgus may develop due to the changes from this axis orientation.[10] Inclination of the first metatarsal can change depending on the height of the medial longitudinal arch. According to the data of our study, inclination has no effect on the measurement of DMAA.

Talbot and Saltzman[11] determined that the standard method for measuring the sesamoidal subluxation on the anteroposterior weight-bearing radiographs is not valid because of the rotation in hallux valgus. Another study[12] suggested that the hallux valgus deformity is a three-dimensional clinical condition with axial and coronal rotations of the first metatarsophalangeal joint. The weight-bearing tangential (sesamoid views) radiographs were advised to calculate the sesamoid rotation. Saltzman et al. advocated in another study that there was no correlation between the first metatarsal rotation measured on the tangential standing (sesamoid view) radiographs and the first metatarsophalangeal angle or the intermetatarsal angle of the first and second metatarsals measured on anteroposterior standing radiographs.[13]

Table 1. Mean DMMA of the first metatarsals at different inclination and rotation angles with standard error of means retrieved from digital images.

Pronation angle degrees	Inclination angle degrees		
	Deg 15	Deg 30	Deg 45
Deg 0	4.54±1.33	4.55±1.04	5.60±0.84
Deg 10	6.95±1.1	9.43±1.1	10.19±1.06
Deg 20	9.1±1.32	14.24±1.09	15.31±0.81

Table 2. Mean DMMA of the first metatarsals at different inclination and rotation angles with standard error of means retrieved from radiographic images.

Pronation angle degrees	Inclination angle degrees		
	Deg 15	Deg 30	Deg 45
Deg 0	3.72±0.97	4.09±1.27	3.66±1.05
Deg 10	6.57±0.79	7.83±1.08	8.81±1.22
Deg 20	8.65±0.73	12.04±1.19	16.03±1.07

All of these studies emphasize the effect of rotation on the evaluation of the hallux valgus deformity. Besides, the data found in our study showed that the measurement of the DMAA from anteroposterior radiographs and digital images were variable and may be effected when the first metatarsal was rotated axially.

Amarnek et al. demonstrated that there was a significant difference between the DMAA measurements on the preoperative radiographs and the direct measurements intraoperatively.[14] Elsaid et al.[9] had a wider range of variation in the range of the DMAA from -14 degrees to 30 degrees, with a mean of 8.2 degrees. The authors proposed that the DMAA increases minimally with age and also concluded that it could be the result of gradual deformation of the DMAA from repeated stress exerted by the hallux valgus deformity.

Deenik et al. had evaluated the preoperative and postoperative hallux valgus angle, intermetatarsal angle and DMAA measurements of the hallux valgus patients and concluded that DMAA was not significant for prediction of the postoperative hallux valgus angle in logistic regression, but was significantly increased in patients with severe hallux valgus.[7] On the other hand, in another study by Brodsky et al., rotational proximal crescentic osteotomy performed metatarsals had a lower postoperative DMAA, rather than the expected higher measurements.[15] This is further evidence of the variability of the angle measurement.

Our study had some limitations. As it was an *in vitro* study, we had no information about the existence of metatarsus primus varus or the conditions of the soft tissues on the dry cadaveric bones which we studied. This study design cannot mimic such *in vivo* conditions, which can alter the radiographic appearances.

In this study, we determined that when the pronation increases, the radiological measurement of DMAA also increases. On the other hand, we also discovered that pronation is one of the important components of the deformity. It shows the variability in the measurement of the DMAA. According to the current data, the measurement of DMAA from anteroposterior radiographs may not be appropriate for making clinical and surgical decisions. During the hallux valgus surgery, we must be focused on using the correct articular surface of the first metatarsal. To achieve the 'correct' amount of the DMAA measurement, a three-dimensional imaging of the first metatarsal, such as a CT-scan, should be done; but it is not practical for clinical use.

In conclusion, DMAA is important for preoperative evaluation and making a decision about the surgical procedure. By performing this *in vitro* study, we did not exclude the importance of the DMAA in clinical use. Rather, we would like to emphasize that the measurement of DMAA from anteroposterior radiographs is expected to be dependent to the rotational deformity of the hallux. We are now better aware of the variability of the angle measurement and that the correction of the measurement may be applied at higher degrees of rotational deformities.

Conflicts of Interest: No conflicts declared.

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