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Radiographic parameters in gravity stress view of the ankle: Normative data

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ABSTRACT

Background: In rotational ankle injury with isolated fibular fracture, deltoid integrity is important for determining stability of ankle. Medial clear space and superior clear space in gravity stress view are parameters widely used to predict deltoid ligament tear. The purpose of this study is to report radiographic parameters in gravity stress view in normal population.

Methods: 120 persons were enrolled. Non weight-bearing ankle mortise and gravity stress view were obtained. Radiographic measurements were made by 2 investigators, including medial clear space (MCS), superior clear space (SCS), tibiofibular overlaps, tibiofibular clear space and talocrural angle. Statistical analysis included mean, mean difference, SD, 95%CI, paired T-test were calculated and subgroup analysis by foot length. Intraclass correlation coefficients were used to determine intra/interobserver reliability of measurement.

Results: Mean MCS in gravity stress view was 3.19 mm (95%CI 3.1–3.31). This compared to mean MCS of 3.01 mm (95%CI 2.9–3.12) in mortise view which was statistically significant ($P = 0.02$). Mean difference was 0.18 mm (95%CI 0.07–0.3). SCS in gravity stress view was 3.29 mm (95%CI 3.19–3.39) and when compared to MCS in gravity stress view, no statistical significance was found ($P = 0.158$). Mean difference was 0.1 mm (95%CI 0.03–0.21). In subgroup analysis by foot length, no significant difference was found in any parameters.

Conclusions: This study provides normative radiographic data for a gravity stress radiograph and supports that if measurable MCS >4 mm on gravity stress view, it should be aware of an unstable ankle in supination-external rotation injury.

1. Introduction

The most common type of indirect injury of ankle fracture, classified by Lauge and Hansen, is supination-external rotation (SER) [1,2]. Evaluation of deltoid stability is important in the management of supination-external rotation injury of ankle fractures. There is a need to clarify between stable and unstable ankle fracture in SER injury because the proper treatment of each type is different. Conservative means can be used in a stable group as in SER II and a favorable outcome obtained [3,4] but surgical intervention is mandatory in an unstable group as in SER IV [2,5–10]. The case of isolated lateral malleolus fracture with completely torn deltoid ligament is known as SER IV equivalent or bimalleolar equivalent [11]. The assessment of deltoid integrity in case of suspected bimalleolar equivalent may have some difficulty.

There are many methods to identify competency of deltoid ligament in SER injury such as clinical examination, manual stress view, weight-bearing stress view and gravity stress view. For the clinical assessment, recent study has shown that localized findings (medial tenderness, swelling, ecchymosis) are unreliable in the diagnosis of deltoid incompetence in SER injury [12–14]. Both manual stress [13–16] and weight bearing stress view [17–19] were proved to have a benefit in identifying deltoid status. In practical use, an uncomfortable test with unclarified amount of force to be applied in manual stress view and also the need to wait for about one week before study of weight-bearing radiograph, because of pain, could be drawbacks to these methods.

To make a decision on what to use for the diagnosis, we prioritize "no more harm technique". The gravity stress view has proved to be a useful tool for detecting deep deltoid ligament disruption [20] and equivalent to manual stress radiograph for

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detecting deltoid ligament injury in association with lateral malleolus fracture [21]. The other benefit of this test is no significant increase in VAS pain score [11].

In past studies, there are different cut-off parameters for diagnosis of deltoid ligament injury in gravity stress view, typically medial clear space (MCS) more than 4 mm or 5 mm [18,22]. Most studies are in cadaveric specimens so the property of the ligaments and muscle might be changed during post mortem period or after preservative agent was introduced causing clear space measurement to perhaps be different from a living person [20,22,23].

To our knowledge, there is no published normative data of MCS in gravity stress view of normal ankles. The purpose of the current study is to determine the normative data of gravity stress radiographs primarily in terms of medial clear space for determining the cut-off point in the diagnosis of deltoid ligament disruption in bimalleolar equivalent fracture. A secondary outcome is to report the normative data of superior clear space, tibiofibular overlap, tibiofibular clear space, talocrural angle and also to determine the effect of foot length on all measured parameters.

2. Methods

This study was approved by our hospital's institutional review committee. We enrolled 120 patients, aged ≥18 years old who visited our foot and ankle outpatient clinic over a period of 12 months (January to December 2016). We excluded the patients who had history of ankle fracture and ankle instability, previous surgery on foot and ankle, ligamentous laxity, osteochondral lesion of talus, flatfoot stage IV, cavovarus deformity, ankle impingement and peroneal tendon problem. Non weight-bearing ankle mortise and gravity stress views with assisted device were obtained. The radiographic evidences of fracture, dislocation, degenerative disease, previous operative intervention or immature growth plate were excluded. Additionally, any radiographs which were taken with inadequate technique or absent magnification markers were also excluded. The patients' age and sex were noted. Informed consent was explained and accepted by all participants before proceeding with the study. For the remaining 120 radiographs, medial clear space (MCS), superior clear space (SCS), tibiofibular overlap (TFO), tibiofibular clear space (TFC), talocrural angle were measured on mortise view and gravity stress view using a digitally calibrated ruler and standardized technique [11,18,24–27].

2.1. Radiographic studies

All radiographs were taken by skillful technicians working in orthopaedic clinic and were trained in how to take radiographs in this study. The ankle mortise radiographs were taken at 15° internal rotation of the leg. For the gravity stress view, the patients were in a lateral decubitus position with their index ankle in neutral dorsiflexion and their ankle placed on a specially-designed table used for holding the leg and allowing the ankle to take a gravity-stress position. The X-ray cassette was held in a slot which rotated 15° from the vertical axis. The X-ray generator was tilted up 15° from the horizontal axis, making the beam perpendicular to the cassette (Fig. 1). The beam was centered at the level of the ankle. The source-to-film distance was 40 inch to get true-size radiographs [11]. All the radiographs were recorded and stored in digital format.

2.2. Outcome measurement

All radiographs were independently reviewed by two investigators; a fellowship-trained foot and ankle orthopaedist (A.P.) and a senior orthopaedic resident (S.K.). They were trained to measure all parameters by a senior foot and ankle orthopaedist (M. A.). Five parameters (MCS, SCS, TFO, TFC and talocrural angle) were measured on both mortise view and gravity stress view (Figs. 2–4). Foot length was measured from most distal to most proximal margin of soft tissue density in foot standing AP view. Measurements were obtained using the Picture Archiving and Communication System (PACS) imaging system (SYNAPSE, Fujifilm Medical Systems, USA) with digital calibration.

The investigators have randomly repeated their radiographic measurements in 60 cases (50% of cases) at 6 months after first

Fig. 1. Method of taking the gravity stress view with a specially designed table.

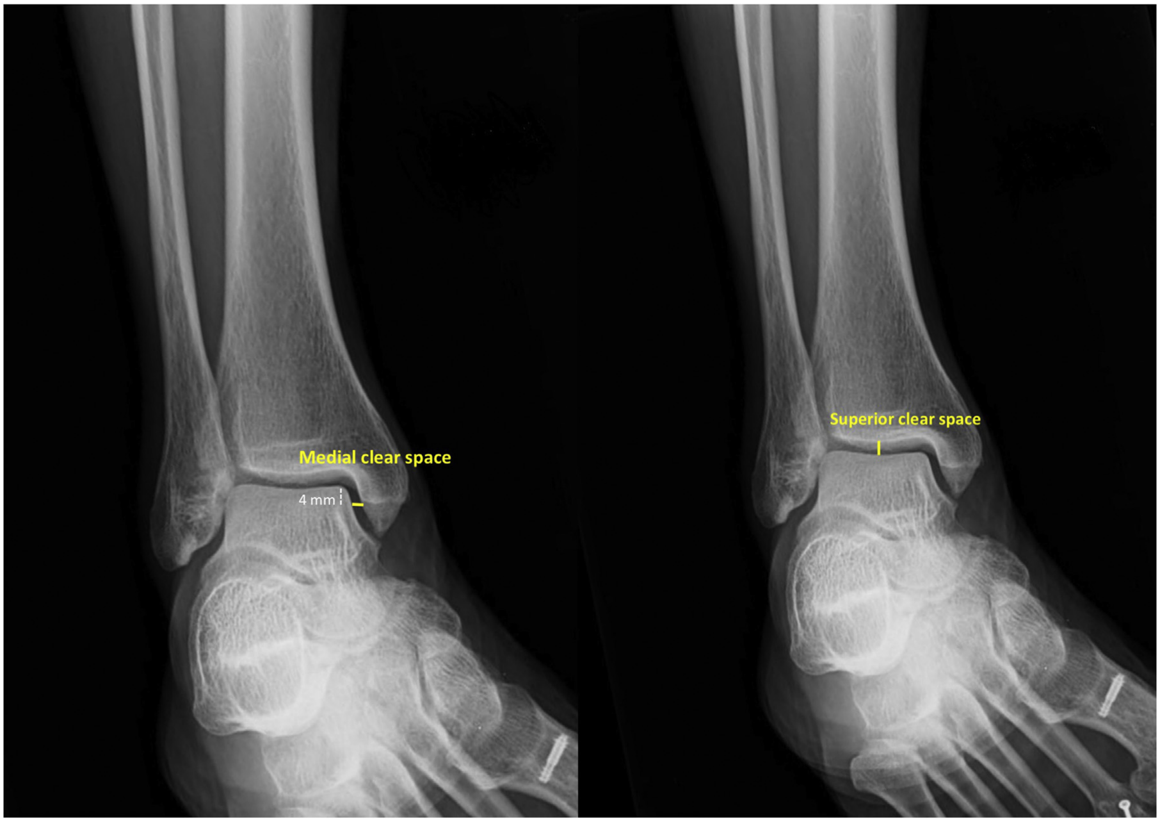

Fig. 2. Measurement technique for medial clear space (MCS) and superior clear space (SCS). MCS was measured as the distance from posteromedial border of the talus to posterolateral border of medial malleolus, parallel to ankle joint line and 4 mm below medial talar dome [27–29]. SCS was measured as the distance from inferior border of the articular surface of the distal tibia to the talar dome at midpoint of distal tibial articular surface [29].

measurement for assessment of intra-observer reliability. Inter-observer reliability was determined by comparing outcome of the measurement for 60 cases between two observers in a randomized mode.

2.3. Statistical analysis

The data analysis was performed using SPSS version 22.0 (SPSS: Chicago, IL) software. Kolmogorov–Smirnov test was used to calculate the distribution of mean, standard deviation (SD), 95% confidence interval (CI), mean difference, 95% CI of mean difference. The data analysis included the mean MCS and SCS, mean difference between MCS and SCS in gravity stress view, mean difference between MCS in gravity stress view and MCS in ankle mortise view, SD and a 95% CI. A paired *t* test was used to determine the difference between mean MCS measurement in gravity stress view and ankle mortise view. Subgroup analysis by foot length using independent non-parametric test. Intraclass correlation coefficients (ICCs) were calculated to determine intra-observer reliability and inter-observer reliability of all radiographic measurements. The following scheme was used for ICCs: less than 0.40 = poor; 0.40–0.59 = fair; 0.60–0.74 = good; greater than 0.74 = excellent. $P < 0.05$ was considered a statistically significant difference.

3. Results

Total included 120 participants, 42 male (35%) and 78 female (65%). Mean age was 51 ± 15 years (Table 1).

Medial clear space (MCS) in gravity stress view was 1.88–5.15 mm with mean MCS of 3.19 ± 0.62 mm (95%CI 3.1–3.31) compared to MCS in ankle mortise view that was 1.66–4.30 mm with mean MCS of 3.01 ± 0.61 mm (95%CI 2.9–3.12) (Table 2). The mean difference of MCS in both views was 0.18 ± 0.63 mm (95%CI 0.07–0.3), showing statistically significant difference ($P = 0.02$).

Superior clear space (SCS) in gravity stress view was 2.14–5.95 mm with mean SCS of 3.29 ± 0.56 mm (95%CI 3.19–3.40) (Table 1). The mean differrence of MCS and SCS in gravity stress view was 0.1 ± 0.7 mm (95%CI 0.03–0.21), showing no statistically significant difference between the two parameters ($P = 0.158$) (Table 3).

With reference to the foot length, most are in the group of 231–260 mm with 63 feet (52.5%). Mean foot length was 254 ± 19 mm with range from 206 to 295 mm (Table 4). Independent non-parametric test revealed that only the superior clear space in the gravity stress view had statistically significant difference between three groups of foot length ($P = 0.045$). From subgroup analysis by foot length, no statistically significant difference was found in all of the remaining parameters, implying no effect of foot length on all radiographic parameters of the ankle except for SCS in gravity stress view (Table 4).

Intraclass correlation coefficient (ICC) revealed that ICC of inter-observer was from 0.83 to 0.98 and ICC of intra-observer was from 0.89 to 0.99, excellent ICC result (Table 5).

4. Discussion

In a supination external rotation (SER) type of ankle fracture, there are a variety of methods to distinguish between SER II and SER IV equivalent ankle fracture. Michelson et al, in a cadaveric study, reported that gravity stress view has 100% sensitivity and specificity in identifying disruption of the deep deltoid ligament.

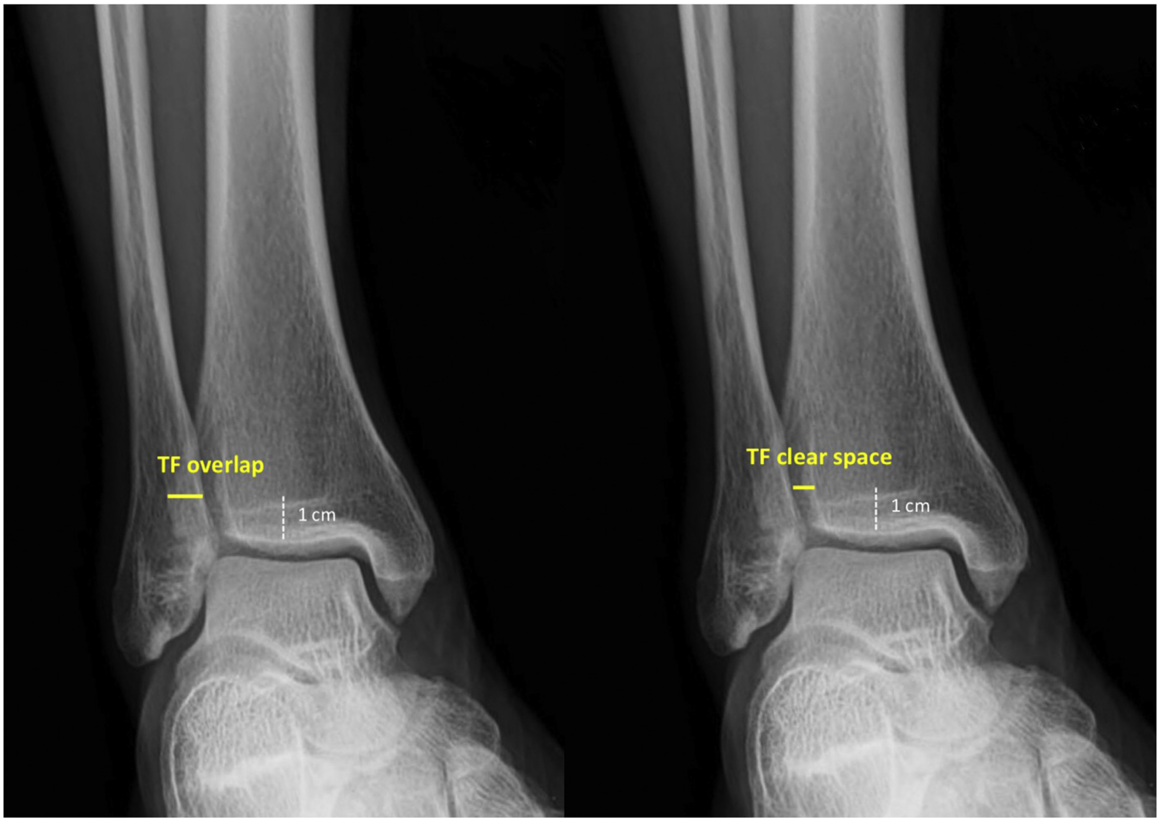

Fig. 3. Measurement technique for tibiofibular overlap and tibiofibular clear space. Tibiofibular overlap was measured as the distance of overlapping from medial border of lateral malleolus to lateral border of anterior tibial tubercle at 1 cm proximal to distal tibial articular surface [25]. Tibiofibular clear space was measured from medial border of distal fibular to medial border of incisura fibularis at 1 cm proximal to distal tibial articular surface [25].

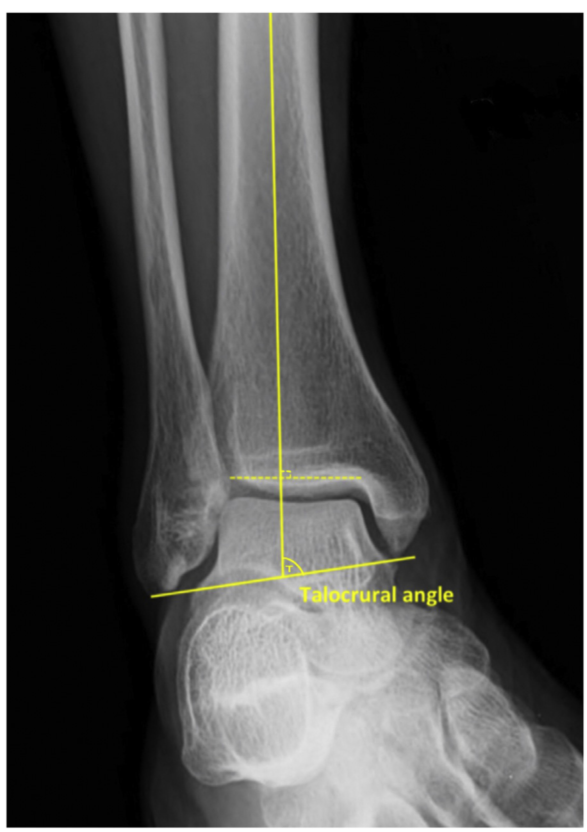

Fig. 4. Talocrural angle measurement (angle T). Talocrural angle was measured as the angle created from a line perpendicular to the distal tibial articular surface and a line connecting the tip of medial and lateral malleolus [27].

Table 1
Demographic data of patients (n = 120); SD = standard deviation, n = number of patients.

Variables	n	%
Age, mean (SD)	51 (15)	
Gender		
Female	78	65
Male	42	35
Diagnosis		
Achilles tendinopathy	38	32
Plantar fasciitis	30	25
Hallux rigidus	27	23
Hallux valgus	10	8
Morton neuroma	10	8
2nd MTP synovitis	5	4

Table 2
Measures of the ankle on mortise and gravity stress radiographs; m = mortise view, g = gravity stress view.

Radiographic parameters	Mean ± SD (mm)	95%CI	
		Lower	Upper
Medial clear space m	3.01 ± 0.6	2.9	3.12
Medial clear space g	3.19 ± 0.62	3.09	3.31
Superior clear space m	3.31 ± 0.6	3.21	3.42
Superior clear space g	3.29 ± 0.56	3.19	3.39
Tibiofibular overlaps m	5.45 ± 2.78	4.95	5.95
Tibiofibular overlaps g	5.02 ± 2.38	4.59	5.45
Tibiofibular clear space m	4.2 ± 1.14	3.99	4.41
Tibiofibular clear space g	4.18 ± 1.25	3.95	4.4
Talocrural angle m	78.09 ± 2.81	77.9	78.85
Talocrural angle g	78.18 ± 2.62	77.71	78.66

Table 3
Comparison of radiographic parameters and statistical analysis; m = mortise view, g = gravity stress view.

Comparison of radiographic parameters	Mean difference ± SD (mm)	95% CI		Paired *t* test
		Lower	Upper	P value
Medial clear space g & medial clear space m	0.18 ± 0.63	0.07	0.3	0.02
Medial clear space g & superior clear space g	0.09 ± 0.7	0.04	0.22	0.158
Tibiofibular overlaps g & tibiofibular overlaps m	0.43 ± 2.72	0.06	0.92	0.086
Tibiofibular clear space g & tibiofibular clear space m	1.66 ± 1.38	1.41	1.91	0.739
Talocrural angle g & talocrural angle m	0.73 ± 2.28	−0.81	2.26	0.332

Regardless of the fibular status, when deep deltoid was intact, superficial deltoid release did not alter talar shift. Combined superficial and deep deltoid release with fibular osteotomy allowed lateral talar shift ≥2 mm and valgus tilt ≥15°. This work has shown how important the deep deltoid ligament is in providing medial ankle stability and usefulness of gravity stress view. However, they have assessed the MCS in cadaveric specimens, rather than the normal ankle [20].

Nonetheless, there is a problem with ankle position during stress view of the cadaveric study and the authors propose that dorsiflexion-external rotation position of ankle during manual stress radiograph has potential to give more width of medial clear space than other positions. On the other hand, if the ankle is in plantar-flexed position, less medial clear space could be detected causing an error of measurement due to ankle position [15]. In our work, we confirm the neutral position of the ankle by using a red arrow guide, perpendicular to the leg, on the floor of the examination room to ensure the ankle position of the patient, monitored by a technician. We control the fixed rotation of X-ray cassette and rotation of the leg by using a specially designed table for holding the leg with adjustable cassette slot.

Considering the measurement technique, previous literatures have varied definitions of medial clear space measurement. In our study, we have agreed with some measurement technique and adapted it for more friendly use through determining the measurement of MCS as the distance from posterolateral border of medial malleolus to posteromedial border of medial aspect of the talus [28] and parallel to ankle joint line [29] at point of 4 mm below medial talar dome [27]. We use a point landmark and a line parallel to ankle joint line because practically, it is easier.

Past research has recorded much MCS data in ankle mortise radiographs, manual stress or weight-bearing radiographs. The MCS data of gravity stress view were previously reported in cadaver [20] and injured ankle [11,21] with no normative data in normal population. Many reports published that deltoid ligament rupture is correlated with widening of MCS more than 4, 5 or 6 mm, with increasingly higher specificity but lower sensitivity with increasing cut point. Previous literatures have defined normal MCS as <4 mm and that MCS width ≥4 mm suggests deep deltoid incompetence [7,10,11,13,14,21]. Other studies propose that the MCS width ≥5 mm is a more reliable indicator [15,18,30]. Murphy et al. reveal that 16.7% of males and 1.1% of females had MCS ≥4 mm while 1.9% of males and zero females had MCS ≥5 mm [18].

McConnell et al. used a MCS of 4 mm on external rotation stress radiographs to indicate ankle instability after Weber type-B ankle fractures. In their series, MCS had to be ≥4 mm in width but also more than 1 mm greater than the SCS, in order to be classified as

Table 4
Radiographic parameters in gravity stress and mortise view classified by foot length; MCS = medial clear space, SCS = superior clear space, n = number of patients.

Foot length (mm)	n (%)	Mean MCS ± SD (mm)		Mean SCS ± SD (mm)	
		Mortise	Gravity	Mortise	Gravity
200–230	11 (9.2)	3.06 ± 0.79	3.41 ± 0.69	3.15 ± 0.54	3.13 ± 0.35
321–260	63 (52.5)	2.90 ± 0.58	3.13 ± 0.69	3.28 ± 0.65	3.23 ± 0.62
>260	46 (38.3)	3.15 ± 0.57	3.24 ± 0.49	3.40 ± 0.54	3.41 ± 0.50

Table 5
Intraobserver and interobserver intraclass correlation coefficient for radiographic parameters; m = mortise view, g = gravity stress view.

Radiographic parameters	Interobserver	Intraobserver
Medial clear space m	0.9	0.97
Medial clear space g	0.9	0.97
Superior clear space m	0.96	0.98
Superior clear space g	0.96	0.89
Tibiofibular overlaps m	0.98	0.99
Tibiofibular overlaps g	0.97	0.96
Tibiofibular clear space m	0.83	0.99
Tibiofibular clear space g	0.87	0.96
Talocrural angle m	0.84	0.89
Talocrural angle g	0.83	0.90

unstable ankle fracture. They reported the mean MCS on stress radiographs for stable ankles (SER II) was 3.63 mm, whereas that for unstable ankles (SER IV) was 5.69 mm [14].

Regarding the relationship between MCS and SCS, a report from DeAngelis et al. mentioned that, in the ankle mortise view of normal population, there is statistically significant difference ($P < 0.0001$) between an average MCS 2.7 mm and an average SCS 3.6 mm with average absolute difference being 0.9 mm [24]. Our study has also compared the MCS with SCS in gravity stress view, but we could not find significant difference between mean MCS and mean SCS ($P = 0.158$). In contrast to usual clinical event of patients with ruptured deltoid ligament, the medial clear space must be significantly wider than superior clear space.

According to our study, the mean MCS in gravity stress view was 3.19 ± 0.62 mm (95%CI 3.1–3.31). Taking the recent data of previous works – normal range of MCS less than 4 mm – we can conclude that the MCS width in our population with suspected ruptured deltoid ligament is more than 4 mm. The medial clear space could be wider in gravity stress view when compared to ankle mortise view. There is significant difference between medial clear space in mortise view and gravity stress view, which was 0.18 mm ($P = 0.02$) (95%CI 0.07–0.3). Interestingly, we can state that in a competent deltoid ligament, when we take a gravity stress view, medial clear space could be wider but the maximal widening is not more than 0.3 mm. Such widening magnitudes are very small and clinically meaningless.

As part of the secondary outcome, we hypothesized that different foot length could explain the different values in our measurements. Therefore, we classified the foot length into 3 groups. The results revealed that all parameters in both mortise and gravity stress view have no statistically significant difference between groups ($P > 0.05$) except only the SCS in the gravity stress view. Consequently, we can conclude that foot length has no significant effect on MCS in both views and SCS in mortise view.

The strength of this study, to our knowledge, lies in it being the first study in normal population regarding medial clear space of ankle joint in gravity stress view taken from a specialized tool where the patient is placed in a standard position creating the same view for every radiograph. Our measurement techniques were clearly defined in all parameters. We tested all parameters for the reliability of measurement, which was excellent. In addition, this work was performed in normal patients so there are physiologic conditions that cannot be found in a cadaver. For example, muscular contraction could apply a directed force on the talus, adding an element of stabilization to the ankle [6,28,29].

There are some weaknesses in the study. First, regarding selective bias of studied population, we did not include all normal healthy population into the study but we collected them from those who visited the foot and ankle outpatient clinic in our hospital because in this population, they actually have to take the foot and ankle radiograph for other conditions so we already had a foot AP view and ankle mortise view and only a gravity stress view was needed to complete the protocol. However, we excluded clinical and radiographic conditions that could affect the studied parameter as previously noted. We assume that our selected population could represent a normal population. Second, the PACS imaging system that was used for this study showed patients' name and age so the reviewers could know this information during the measurement. Although the reviewers only interacted with patient radiographs during the measurements, some patients may have been familiar to both of the reviewers in the outpatient clinic, leading to possible bias in their review.

5. Conclusion

This study provides many normative radiographic data for the gravity stress view and ankle mortise view with reliable method of measurement, importantly on the MCS in gravity stress view of 3.19 ± 0.62 mm. If the measurable MCS on gravity stress radiograph is more than the upper limit of this range, it should be aware of an unstable ankle injury. Foot length has no effect on MCS.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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