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Anthropometric measurements of ankle mortise for evaluating mortise fracture reductions with an aim to develop contoured implants

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Abstract: *Background:* Ankle injuries are unique as they are not only intra-articular of weight bearing joint, but also caused by a variety of mechanism, each resulting in different pattern with ankle fractures. The primary concern is residual instability of the joint as malalignment or residual displacement can adversely affect the biomechanical behaviour of ankle and resulting loss of function, due to non restoration of normal anatomy. Therefore essential of proper anatomical parameters for assessment of reduction and improved designs of implants used to get good results. *Objectives:* Measuring various radiological and Anatomical normal parameters of the ankle mortise. *Material and Methods:* Cadaveric 20 fibula and 27 tibia. Anteroposterior and 15° internal rotation radiographs, of both Ankles in 20 adult individuals formed the material. Following parameters measured- a) Tibiofibular clearspace b) Tibiofibular overlap c) Talocrural angle d) Length of medial and lateral malleoli e) Angles sustained on medial surface of medial malleoli and lateral surface of lateral malleoli. *Results:* a) Tibiofibular clear space on Anteroposterior 2.4mm (±1.3mm) in 15° rotation 4.5mm (±1.2mm). b) Tibiofibular overlap in Anteroposterior 11.2mm (±4.4mm) in 15° rotation 4.2mm (±1.7mm). c) Talocrural angle in Anteroposterior 77.7mm (±3.2mm) in 15° rotation 79.9mm (±2.9mm). d) Length of medial malleolus in Anteroposterior 15.3mm (±1.01mm) in 15° rotation 15.3mm (±0.8mm). e) Length of lateral malleolus in Anteroposterior 27.35mm (±3.8mm) in 15° rotation 26.5mm (±5.1mm). Angles- Lateral bend of lateral malleolus was ranging 8°-21° average being 16.2°. Medial bend of medial malleolus was ranging 10°-34°, average 19.5°. *Conclusion:* The unique measurement of angles on both surface of malleoli and other parameters definitely contribute for assessment of reduction and prognostic evaluations of ankle fracture, Designing, moulding and manufacturing of prebent plates for use in distal ends of tibia and fibula.

Keywords: Ankle fractures, Medial malleolus, Lateral malleolus, Tibiofibular syndesmosis, Talar shift, Anthropometric measurements.

Introduction

Ankle fractures are amongst the commonest type of fractures treated by orthopaedic surgeons. The incidence of such fractures has increased since the last three decades in both the younger and elderly population, as well as due to increased vehicle accidents. Epidemological studies have estimated the incidence of malleolar fracture between 107 to 187 per 100,000 person year [1-2]. Due to advances made in classification, experimental projects on cadaver, radiologic evaluation and knowledge of bio-mechanics of ankle injuries. Clinical outcome of studies have formulated more effective strategies for management of ankle injuries. The goal of treatment is healed fracture and normal pain free ankle. Bonin [3] in 1940 gave an outstanding description of anatomical landmark of Ankle (i.e. Syndesmosis, clear space, etc.) which resulted in increased focus on the importance of the three components of the ankle. 1) Medial malleolus and medial ligaments. 2) Lateral malleolus and lateral ligaments. 3) Tibiofibular syndesmosis. All three components have to be addressed to keep the occupant of the ankle mortise, it means the talus, in a correct and stable state within normally aligned boundaries of former which is the aim of treatment. The main issue then is as to what is considered normal. The bony components can be radiologically assessed and have therefore been the focus of much research since the times of Bonin [3].

The medial, lateral and superior clear spaces, the tibiofibular clear space and overlap, the lateral tip of lateral malleolus, and the length of the lateral malleolus have all been subject for study. Pre-reduction and pre-operative radiological assessments, extrapolated on long term clinical results, have helped to improve the management of these fractures. For the ankle mortise to be well reconstructed, it is important to get the talus realigned to the tibial plafond, fibular length restored, and normal lateral and medial malleolar tilts and rotation re-established. For the management of lateral malleolus fractures, and pilon fractures precontoured plates are used. Without mentioning the nature of contouring to be done, restoration of proper tilts/rotation and malleolar lengths, especially in communited fractures can be very challenging. There seems to be lacuna in our understanding and literature of the contours of the medial surface of medial malleolus, lateral surface of lateral malleolus. The other parameters like tibiofibular clear space, overlap, the talocrural angle and lengths of both malleoli also need to be assessed in asian population. The correct anthropometric study of normal young adults and cadeveric tibia/fibula was therefore undertaken to provide insights into the above mentioned parameters. Inclusion criteria- a) Adult male. b) No history of ankle injury. c) Informed consent. B) Anteroposterior and 15° internal rotation radiographs of lower 1/3 of 27 cadaveric tibia (16 Right and 11 Left) and 20 cadaveric fibula (10 each Right and Left) obtained. Inclusion criteria- a) Adult cadaveric bone normal. b) Not deformed.

Material and Methods

Cadaveric 20 fibula and 27 tibia, anteroposterior and 15° internal rotation radiographs of both ankles in 20 adult volunteer formed the material. The study was done in two parts. A) Anteroposterior and 15° internal rotation radiograph of 20 volunteers obtained after informed consent. Inclusion criteria- a) Adult male. b) No history of ankle injury. c)Informed consent. B)Anteroposterior and 15° internal rotation radiographs of lower 1/3 of 27 cadaveric tibia (16 Right and 11 Left) and 20 cadaveric fibula (10 each Right and Left) obtained. Inclusion criteria- a) Adult cadaveric bone normal. b) Not deformed. Standard radiographs were used with self designed jig and measured at 0° rotation and 15° internal rotation position of plantigrade ankle. For standardization of radiographs we used a self designed jig to measure 0° rotation and 15° internal rotation position of the ankle. We also kept all the ankles in plantigrade position.

Figure-1: Showing angles

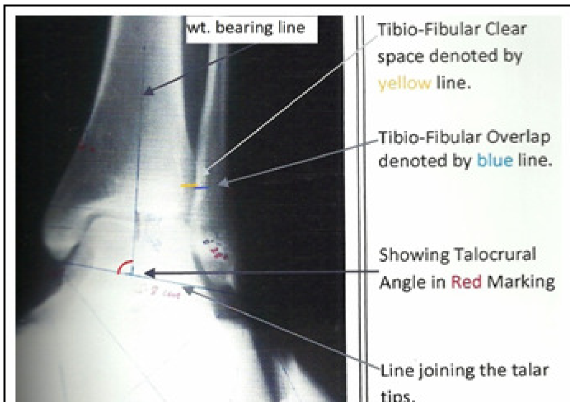

Figure 2- Showing tibiofbular clear space, Tibiofibular overlap, Talocrural angle

For proper anteroposterior radiographs of the fibula the talar facet on the lateral malleolus was used as a guide for proper rotational alignment of all fibula which were mounted on plastic in to avoid them rolling over and changing rotation. However, since this is based on naked eye observation, minor falacies may have crept in. All markings on the radiographs were done by fine marker pens to give as accurate a value as possible (figure 1 and 2). Fine plastic scales and goniometers were used to record lengths and angles on radiographs. A pair of Vernier Calipers was used to measure the lengths of the cadaveric malleoli (figure 3). The markings for study of angles A, B, C, A', B' and C' on radiographs of normal ankles and cadaveric bones was undertaken with a lot of care. However there were several occasions where there was no sharp bend in the border but a rounded concavity for angle A & A' and rounded convexity for angle B,B', C and C'. In such situations the middle point of the curve was used for selection of the point of bend. The average and range of all the parameters have been obtained and have been compiled as reference parameters of the ankle joint from this part of the world.

Figure-3: Technique for measuring length of malleolus.

Following parameters were studied for all radiographs obtained from volunteers- 1) Medial malleolus a) angle A;(angle drawn on medial bend seen over the medial surface). b) angle B;(angle drawn on downward bend seen over the medial surface). c) angle C;(angle drawn on lateral bend towards malleolar tip seen over medial surface) (figure 1). 2) Lateral malleolus. a) angleA' (angle drawn on lateral bend seen over lateral surface). b) angle B' (angle drawn on downward bend seen over the lateral surface). c) angle C'(angle drawn on medial bend towards malleolar tip seen over the lateral surface) (figure 1). 3) Talocrural angle- The talocrural angle is superior and medial angle formed by joining weight bearing line and the line joining the tip of two malleoli (figure 2). 4) Tibiofibular overlap- Maximum amount of overlap of the distal fibula and the anterior tibial tubercle. 5) Tibiofibular clear space- (distance between the medial border of the fibula and the lateral border of posterior tibia measured 1mm above the distal tibial articular surface (figure 2). 6) The length of medial and lateral malleoli were measured from the tibial plafond to the tips of malleoli respectively.

Similarly all the angles over medial surface of medial malleolus and lateral surface of lateral malleolus were measured on radiograph of cadaveric bone. Length of medial and lateral malleoli in cadavers were measured using vernier calipers. Meadial malleolus- from tibial plafond to tip. Lateral malleolus- from top of the facet for talus to tip.

Results

Table 1(a)

Parameters(both sides combined) AP	Minimum	Maximum	Average
1. Talocrural angle	73°	75°	74°
2. Tibiofibular overlap	6mm	23mm	11.2mm
3. Tibiofibular clear space	1mm	6mm	2.4mm
4. Angle A	10°	34°	19.5°
5. Angle B	15°	31°	23.6°
6. Angle C	31°	58°	41.075°
7. Angle A'	8°	21°	16.2°
8. Angle B'	12°	25°	18.7°
9. Angle C'	19°	45°	32.5°
10. Medial malleolar length	13mm	17mm	15.3 mm
11. Lateral malleolar length	22mm	36mm	27.35 mm

Table 1(b)		
Parameters (distance of various angles mentioned from malleolartips)	**Volunteer Ankle (AP Radiographs)**	**Cadaveric Bone**
Gross		
Medial malleolus length	15.3mm	15.7mm
Lateral malleolus length	27.2mm	23.7mm
In neutral AP view		
Angle A	19.7°	16.7°
Angle B	23.6°	27.1°
Angle C	41.0°	41°
Angle A'	16.2°	30.7°
Angle B'	18.6°	7.3°
Angle C'	32.4°	33.6°

Table 2			
Parameters(both sides combined) 15° rotation	**Minimum**	**Maximum**	**Average**
1. Talocrural angle	75°	85°	79.9°
2. Tibiofibular overlap	1mm	7mm	4.2mm
3. Tibiofibular clear space	3mm	8mm	4.5mm
4. Angle A	12°	32°	19.5°
5. Angle B	15°	35°	26.3°
6. Angle C	29°	62°	40.6°
7. Angle A'	10°	22°	16.6°
8. Angle B'	10°	26°	20.55°
9. Angle C'	22°	50°	32.65°
10. Medial malleolar length	13mm	16mm	15.3mm
11. Lateral malleolar length	21mm	34mm	26.5mm

Discussion

The ankle joint is an important weight bearing joint, being exposed and having no musculature to protect it. It is subjected to lot of stress with increase in automation and sporting activities, ankle fracture has shown rapid increase in incidence. The essential aim of management of fracture of ankle joint is to obtain union of fracture and provide a painless joint with normal function. To achieve the above aim, various normal anatomical and radiological parameters were studied like-

a)Tibiofibular clear space. b) Tibiofibular overlap. c) Talocrural angle. d) Length of both malleolus. e) Angle on surfaces of both malleoli.

Tibiofibular clear space: Phillips et al (1977) [4] defined tibiofibular clear space as a horizontal distance from lateral border of the posterior tibial malleolus to the medial border of fibula measured on anteroposterior radiograph. Subsequent authors have used this criteria for the assessment of syndesmotic diastasis. Jenkinson et al (2005) [5] used a 1mm increase in tibiofibular clear space on external rotation stress radiograph as an indication for syndesmotic stabilisation. Leeds et al (1984) [6] suggested 2mm as an unacceptable increase in tibiofibular clear space. Stoffer et al (1996) [7] showed that syndesmotic injuries correlate with relatively small increase in the measurments on stress radiograph. In our study average tibiofibular clear space in anteroposterior radiograph was found to be 2.4mm(range 1-6 mm). In mortise view it was 4.5mm (range 3-8mm). The maximum normal range of clear space in our study was 6mm in Anteroposterior view and 8mm in 15° internal rotation view. Hence these may be taken as upper limit of normal. Conversely ankles with value beyond 5mm may be subjected to lateral stretch radiograph for confirmation of diastasis.

Tibiofibular overlap: The average tibiofibular overlap in anteroposterior view was found to be 11.2mm (range 6-23mm); in mortise view was found to be 4.2mm (range 1-7mm). In the anteroposterior radiograph the overlap in our study was found to have a range of 7mm to 19mm. Most of workers have commented that overlap of less than 10mm denotes diastasis. We recommend that there may be normal variations of less degree of tibiofibular overlap. In all such situation pre-operative lateral stress testing should be undertaken to confirm instability.

Talocrural angle: Isman and Inam(1977) [8] mentioned the talocrural angle as being important to indicate changes in fibular length. Sarkisian and Codi [9] defined the measurements of talocrural angle and proposed comparison of talocrural angle on injured with that on normal side. The normal talocrural angle in adults is 83°±4°. The difference in the angles of the two ankles of any individual is normally less than 2°. Phillips et al [4] took the difference of more than 5° to be abnormal. In their study of various criteria for predictions of results, the difference in talocrural angle was the only statistically significant radiograph, indication of good prognosis. In our study, the average talocrural angle was found to be 77.7°±5° in 0° antero-posterior radiograph. In 15° of internal rotation radiograph the values were 79.9° ±5°. We agree with Sarkisian and Codi [9] that the talocrural angle of two ankles of a given individual does not vary by more than 2°.

Length of both malleolus: Discussion of medial malleolar fractures in general, by workers have not taken into account the length of medial malleolus. There are no anthropometric studies of which we are aware on length of medial malleolus. The length is especially important to assess talocrural angle in bimalleolar fractures. The vertical displacement of medial malleolus especially in vertical fractures of medial malleolus or in communited medial malleolar fractures, may not only change the value of talocrural angle but may also be a factor for poor results. Phillips et al(1977) [4] accepted 2mm of maximum fibular shortening. Baird and Jackson(1987) [10] gave criteria for reduction for lateral malleolar fracture in which fibular shortening was not acceptable. In our study the average length of medial malleolus measured from tibial plafond to the tip in anteroposterior projection was found to be 15.3mm(range 13-17mm) (Table 1a,1b). In 15° internal rotation view the average 15.35mm(range 13-16mm)(Table 2). The average length of lateral malleolus measured from tibial plafond was found to be 27.35mm. Hence quantification of length of malleoli therefore is important. Individual measure-ments of malleoli therefore are significant and this study provides statistics for this part of the world.

Angle on surfaces of both malleoli: There is a growing interest in use of small contured plates for fixation of pilon fractures by minimally invasive techniques [11-13]. These plates need to be well contured to conform to bony contour, especially on medial malleolus to prevent skin necrosis as it is subcutaneous. Raza 2009 [14]. There is a definite medial downward and lateral bends on medial malleolus. Plates need to conform to angle of this bend. The current study will prove to be extremely important as we have defined the three angles as well as their average values. The average angle A (medial bend) was 19.4° (range 10°-34°) in anteroposterior view. The same on 15° internal rotation was 19.25° (range 12°-32°)(Table 2). Thus minor rotation did not cause much change in angles. The second angle B (downward bend) was 23.65° (range 15°-31°) in anteroposterior view. In 15° internal rotation view average was 26.31° (range 15°-35°). This may be due to small tubercle causing this abberation. The third angle C (lateral bend) averaged 41.07° (range 31°-58°) in anteroposterior and 40.6°(range 29°-62°) in 15° internal rotation view. The values on two sides did show minor variations. However individuals did show similarities of the angles on both the sides and the measurements of especially angle A and B on uninjured side would be important for pre-contoured plates for use in this region. Colton [15] has mentioned the lateral tilt of lateral malleolus. DeSouza et al(1985) [16] in a classic publication mentioned lateral bend on lateral malleolus, was of an average of 13°. They also mentioned a small medial tilt of the distal end towards the tip. Raza and Rastogi [14,17] had pointed out four bends on lateral malleolus.

However we have found that there are infact three bends on lateral surface of lateral malleolus. It is therefore important to measure the three angles to enable proper pre-bending of laterally applied plates. The first lateral bend is most important. A larger than normal bend will result in valgus angulation; opening up of ankle mortise resulting in instability. On the other hand straight plate for lesser bends results in varus positioning of lateral malleolus leading to crowding of ankle mortise, dysfunction and early arthrosis. Our study addressed these problems by measuring each angle which will be important for designing of implants for lower end of fibula as well as for pre-bending of plates used for fixation. Following are statistics- a) The lateral bend A' average 16.35°(range 8°-22°). b) The downward bend B' average 19.6°(range 12°-26°). c) The medial bend C' average 32.6° (range 19°-50°). The average angle between the long axis of fibular diaphysis and the lateral malleolus in our study was found to be 16.35° which is more than that defined by Colton [15] 15°.This angle corresponds so closely to angle A', that measuring angle A' which is simpler may obviate the requirement of measuring the angle to find out lateral malleolar tilt. Is this increase a reflection of the Asian custom of squatting and sitting cross legged? It would be worthwhile to explore this possibility. The lateral malleolus has a remarkable lateral bend over the lateral border at a distance of approximately 34mm according to our study. It was more in DeSouza et al’s [16] study, may be due to the height of their patients being more. However, on overall picture of angles helps in designing pre-bent plates; finer adjustment being made pre-operatively, and evaluation of reduction for prognosis after closed/operative treatment.

Conclusion

From the study of the anthropometry of the malleoli the following conclusions can be drawn.

1. It is important to obtain 0° anteroposterior and 15° internal rotation views of not only the injured ankle but also the uninjured ankle. Comparison of parameters like the talocrural angle, and medial and lateral malleolar lengths on normal side is especially important for pre-operative assessment and planning, per-operative assessment of reduction, and for long term assessment of results.
2. The value for the talocrural angle (as measured by using the weight bearing line instead of a line along the tibial plafond) was significantly different 77.5°$\pm$ 5° as compared to that given by Sarkisian and Codi [9] 83°$\pm$ 4°.
3. The values for the tibiofibular overlap in our series was found to be 12.45mm with a range from 7.00mm to 19mm. Therefore values as low as 7.00 mm can be normal.
4. The upper value of tibiofibular clear space in our series was 6.00 mm in 0° anteroposterior views and 8.00mm in 15°internal rotaton views. Therefore these should be considered normal upper limits and not 5.00 mm as given by other authors.
5. We have, for the first time given gross cadaveric and radiological measurements of the lengths of the medial and lateral malleoli. These parameters may be of value for assessing quality of reduction especially in bilateral ankle fractures where comparison with normal ankle is not available.
6. Finally, we have described three bends of lateral border of lateral malleolus and medial border of medial malleolus. These values of these bends have been measured on radiographs of cadaveric bones, and 0° anteroposterior and 15^0 internal rotation radiographs of volunteers. These values will be of help in use of prebent plates for tibial plafond, and medial and lateral malleolar fractures.

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