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Title page

Title: **Mathematical approximation of fibular malleolus curvature**

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ABSTRACT

While there are several manuscripts describing the articular surfaces of the ankle joint and the fibula itself, there is no study describing the outer surface and the degree of curvature of the fibular malleolus. This paper aims to approximate the sagital curvature of the outer surface of the lateral malleolus mathematically. Such data would facilitate the design of the anatomic plate that can be used for the ostheosynthesis of the fibular malleolus fracture.

30 males who were examined in the emergency department due to ankle sprains, where they underwent a standard anteroposterior x-ray of the ankle in the neutral position were recruited. The radiographs which revealed no bony injury were digitized and statistically processed.

A mathematical function for each separate fibula was obtained through the processing of the digitized x-rays. When all the functions were applied to one graph, common traits of all fibulas were noted. The mean value of all functions was obtained and it corresponds to the polynomial function of degree 6.

Mathematical approximation of the curvature is a simple and reliable method that can be applied to other ellipsoid human bone structures besides the ankle, thus being a valuable method in anthropometric, radiological and virtual geometric calculations.

Key words: fibular malleolus, curvature, mathematical model, morphometry, x-ray pictures

Introduction

The distal part of the fibula, lateral malleolus, forms the outer ankle joint, which is thickened and flattened in the transverse direction.[1] Articular surface for talus is found on the inner, medial, surface of the lateral malleolus. That surface is in slight valgus in relation to the vertical axis of the fibula.

A number of researchers established that even the slightest incongruence of articular surfaces leads to significant changes in the physiological intraarticular biomechanical relationship of the structures involved.[2-5] Unequally distributed strain occurs on articular surfaces leading to degenerative processes in articular cartilage causing arthrosis. This rule also applies to the ankle joint, being the most strained joint of the human body. The fibula takes approximately one fifth of all the forces straining the leg.[6]

In most instances plain radiographs determine operative or conservative treatment.[7] In cases where primary displacement or possible secondary displacement is anticipated operative intervention is carried out. The goals of operative treatment using with plating include anatomical reduction with stable fixation and early range of motion.[5]

Several papers have described the articular surfaces of the ankle joint and the fibula itself, but there are no studies describing the outer surface and the degree of curvature of the fibular malleolus.[8-15] The morphology of the ankle joint as well as its stability and natural mobility have to be kept in mind when designing stabilization plates.[8]

Considering that in the operative treatment of a lateral malleolar fracture a plate is placed on the outer lateral malleolar surface, topographical anatomical data could facilitate the development of an anatomic plate that can be used for the ostheosynthesis of the fibular malleolar fracture. This study therefore aims to mathematically approximate the sagital curvature of the outer surface of the lateral malleolus based on standard anteroposterior radiographs.

Materials and methods

Following local ethical approval (University of Zagreb School of Medicine Ethical Committee) 30 adult consecutive male patients presented in our emergency department due to ankle sprains, where they underwent a standard anteroposterior x-ray of the right ankle joint in the neutral position were recruited for the study.[12] The distance between the focus and the film was 100cm. There is a certain factor of magnification on such images, but this study ignored that magnification as it has no impact on the shape and curvature of the fibula.[8,9,12] The study included patients whose clinical examination and x-ray analysis established no fracture of the ankle joint,[7] were between 20 and 35 years of age and had BMI lower than 25 kg/m^2. Patients with current or previously known ankle joint fractures, neurological and neuromuscular diseases were excluded from the study. All patients provided written statements of consent.

All images were made by the Shimadzu© RADspeed safire (Shimadzu Corporation, Kyoto, Japan) digital x-ray machine used in our hospital. In order to isolate the edges i.e. the form of the fibula the images were processed in Adobe Photoshop® CS3 (Adobe Systems Incorporated, San Jose, California, USA) using Glowing edges, Grayscale and Invert modifications. The image was rotated by 90° on the right.

Following that a straight horizontal line through the middle of the bone was drawn. A line perpendicular to the horizontal line was positioned through the lowest point of the bone.[8-10,12,16-18] Then, a point on the vertical line and a point on the perpendicular line were marked, and their distances from the point of intersection between the two lines were measured. Such image was then loaded in Engauge Digitizer© v4.1 (Free Software Foundation, Inc., Boston, Massachusetts, USA). First, the coordinate origin was set in the point of intersection. Then, a point on the x axis and a point on the y axis that were previously measured were marked, and their distances from the origin were entered in the program. This served to place every fibula in the same position within the Cartesian coordinate system (first quadrant) enabling the comparison between them.[16,19,20] Each fibula was digitized and its edge marked by 60 – 70 points, each point defined by its position in the coordinate system, creating a couples of points representing the contour of the fibula (**Figure 1**). Digitized fibulas were then loaded into OriginPro© v7.5 (OriginLab Corporation, Northampton, Massachusetts, USA) in order to perform statistical analysis and their mutual relations could be established. Statistical analysis presented each fibula as a graph corresponding to a polynomial.[10,21,22] Fitting led to conclusion that the form of fibula corresponds to the polynomial function of degree 6 most closely.

Results

Each fibula is presented by a separate curve defined by coefficients a0, a1, a2, a3, a4, ..., a9 (**Figure 2; Table 1**), corresponding to the polynomial function of degree 6.

$$y = a_0 + a_1x^1 + a_2x^2 + ... + a_9x^9$$

Polynomial function of degree 6

Considering that all fibulas were analyzed in the same manner i.e. all were fitted by a polynomial function of degree 6, it was possible to obtain a mean value for all fibulas. We had 30 fibulas with 60-70 edge points per fibula and that enabled us to derive to a typical form of the fibula. Each curve represents a fibula (shown in dotted lines). By superpositioning all fibulas on one graph, the similarities between them become even more pronounced. In this manner, a mean value describing a typical form of the fibula was obtained (continuous line), (**Figure 3**). The graph shows all fibulas have similar traits. The curvature rises steeply (maximum being 0.75 to 1.5 cm) after which a less steep fall occurs. The overall length of the outer surface of fibular malleolus is approximately 3 cm. The continuous black curve represents the mean value of all fibulas which, is the polynomial function of degree 6.

Discussion

Malleolar fractures are among the most common lower limb injuries.[23,24] The majority of these require operative treatment. Anatomic reduction and stable fixation accompanied by soft tissue preservation can lead to an optimum outcome.[5]

In cases where both the distal tibia and fibula are fractured, except the tibial fixation by an external fixation device or intramedullary osteosynthesis, a growing number of authors supports the osteosynthesis of the fibula with a plate which facilitates reconstruction of the lateral column providing additional support to the ankle joint.[25,26]

The curvature of the bone to which a plate is being placed to, is a key factor determining the contact surface and the amount of stress the plate applies to the bone.[22]

In this study, using a mathematical modeling process we evaluated the surface topography of the fibula. Such information would provide important information for the appropriate design of anatomical contoured plating systems.

Limitations of the study include the relatively small sample of patients recruited, all patients being males (same sex) and only the right leg being examined. Furthermore, all the measurements were done by one assessor and only one time. An optimum of 10 repetitions is cited as a requirement for the margin of error to be as low as possible.[8] Moreover, our digitizing system, as all others, is subject to bias due to the operator who processes the reference points manually when digitizing the object.[10] It would be desirable in the future to make the biggest possible part of the process automatic in order to obtain results that are as precise as possible and to reduce the human factor influence[11].

The results show that there is certain margin of error for our mean polynomial coefficient values, which describe our fibulas. This is due to the significant differentiation between each fibula, and also due to the small variations in the individual coefficients that present themselves in different graphic displays. This is especially pronounced in cases of distances farther than 3cm, which represents in this case the end of the fibular malleolus i.e. the distal part of the fibular shaft.

Curvature measurement in a large number of people would lead to a more precise assessment of lateral malleolus curvature in relation to age, sex, height, weight, etc. in a given population. The herein analysis shows that the values obtained in measuring the curvature of the fibular malleolus can be used in the designing process of a plate. From these data, a set of different curvature plates for the given population could be constructed. The plate that matches specific fibula could be selected based on the software, with minimal individual adjustment required. Current osteosynthetic plates are not adapted to the curvature of the fibular malleolus by default and this results in a decrease of contact area between the plate and the bone.

Despite the above mentioned limitations, the proposed method enables the analysis of the ankle morphology and ensures reliable results.[8,9] It can also be used in determining bone geometry when deciding on the appropriate implant or plate selection.[20] The method requires standard x-ray imaging, a personal computer and some software packages being all together cost effective.

Future comparisons of the same parameters in left and right leg, male and female patients, various age groups and an anthropologic comparison between present-day and archeological fibulas would be also of interest to the scientific world.

Conclusion

In conclusion, mathematical approximation of the curvature is a simple and reliable method that can be applied to other ellipsoid human bone structures besides the ankle such as olecranon of the ulna, proximal part of the humerus, mandibular condyle. According to preliminary results presented in this paper, this methodology can provide valuable method in anthropometric, radiological and virtual geometric calculations.

Conflict of interest

All authors declare no conflict of interest and no funding was used to carry out the project.

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Legends

Figure 1 Digitization of one fibula

Figure 1. Digitization of one fibula

Figure 2 Graphical representation of the function defining the fibula. The graph shows a fibula and the equation defining it. This is a polynomial function of degree 6 and the corresponding coefficients a_0, a_1, a_2, a_3, a_4, …, a_9.

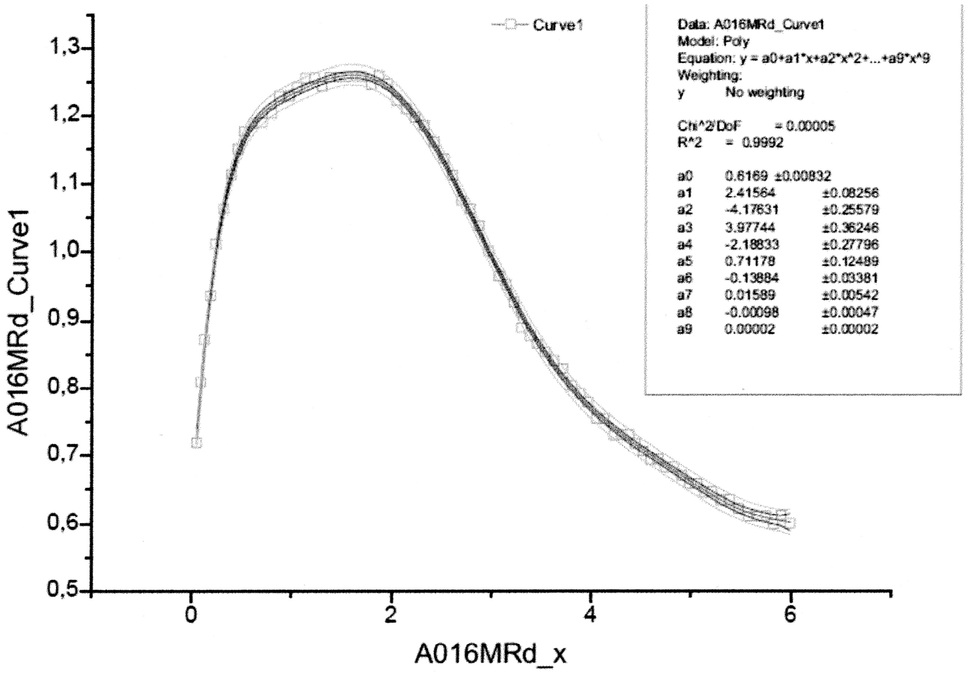

Figure 2. Graphical representation of the function defining the fibula. The graph shows a fibula and the equation defining it. This is a polynomial function of degree 6 and the corresponding coefficients a_0, a_2, a_3, a_4, ... , a_9.

Figure 3 All fibulas superpositioned on one graph. Mean value of all fibulas is represented with continuous line.

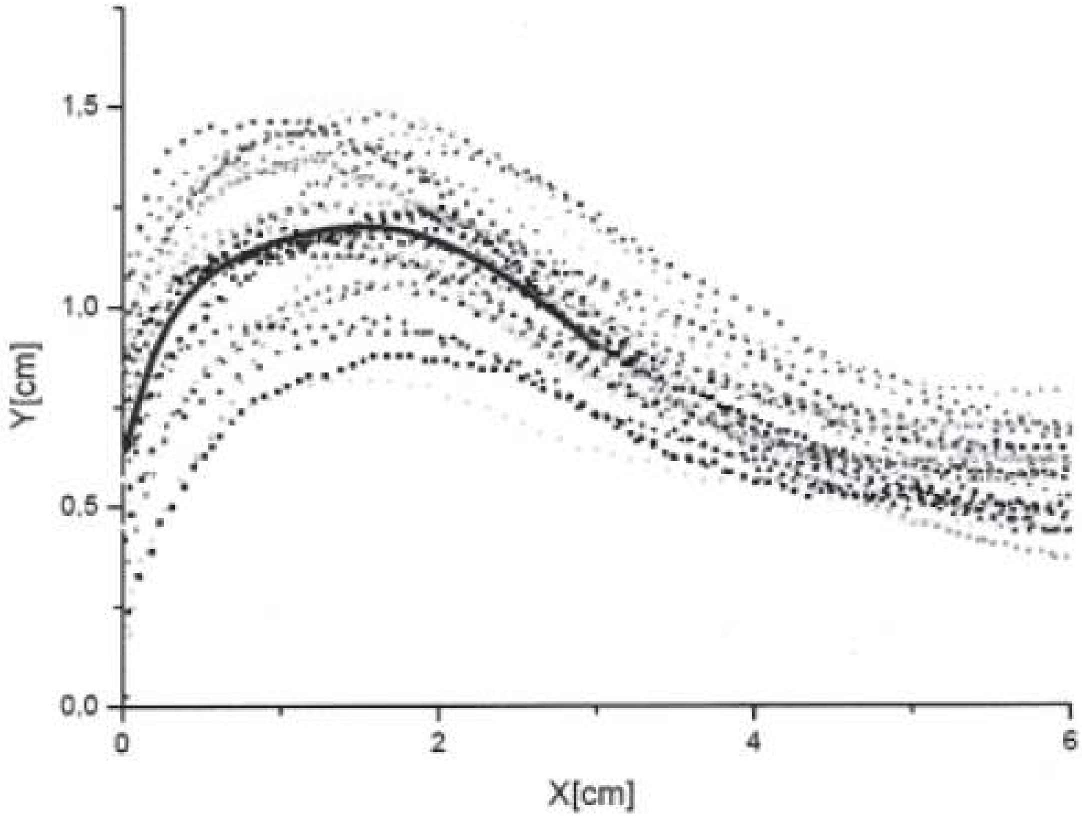

Table 1 All polynomial functions values and their margin of error for one randomly selected fibula

Coefficient	Value	Margin of error
a_0	0.59631	0.26113
a_1	2.0008	0.91111
a_2	−3.47245	2.55746
a_3	3.63172	3.36567
a_4	−2.28514	2.44839
a_5	0.87083	1.05921
a_6	−0.20382	0.27867
a_7	0.02874	0.04369
a_8	−0.00225	0.00375
a_9	7.47553E-5	1.35488E-4