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Finite Element Modeling and Analysis of Central Tarsal Bone in Horse

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Abstract: The analysis of bones through computer modeling has gained an increasing importance in biomechanical studies. The degree of reliability of the analysis is proportional to the concordance between the model and the simulation. The purpose of this study was to improve the three-dimensional computer model of central tarsal bone by using coordinate reading method and to utilize the model in stress analysis of this bone. The 3-dimensional coordinates of various marked points on the proximal and distal surfaces of the central tarsal bone were measured by a comparator with a specially designed mechanism in laboratory. These points' coordinates were used for creating a model of the bone. Modeling and analyses were realized in ANSYS 5.5 program. The model consisted of 2900 nodes and 11866 elements. The highest von mises stresses occurred in the lateral end of the dorsal border in the distal surface.

Key words: Coordinate measurement, finite element modeling, finite element analysis, central tarsal bone, horse

INTRODUCTION

Biomechanical modelling is a means of studying mechanical behavior of biological objects. Modelling obviates the need for experimentation, which is unwieldy, costly and difficult to apply in certain situations. Design and validation of prosthetic implants and fracture risk assessment are only two examples of possible applications of biomechanical modelling (Adam *et al*., 2003; Cegonino *et al*., 2004; Guess and Maletsky, 2005).

The Finite Element Method (FEM) is widely accepted as one of the most practical and reliable method for analyzing mechanical structures in the field of engineering. Recent advances in computer technology further promote its usage. A number of studies using FEM to analyze stress or strain distribution patterns of bones in various situations have been published (Chosa *et al*., 2004; Zhong *et al*., 2006).

Accurate modelling of the sample under investigation is one of the most important steps in FEM analysis. The model formed in virtual environment is desired to be as realistic as possible both in terms of anatomical structure and biomechanical properties in order to obtain reliable results. This becomes even more important when material has irregular geometrical shapes, as in the case of bones. Various methods were used for translating real bone shapes into the computer models (Adam *et al*., 2003; Asgaria *et al*., 2004; Templeton *et al*., 2004). In one of these methods coordinates of points selected on the surface of bone fragment are transferred to the computer (Haut *et al*., 1998; Panjabi *et al*., 1997; Samuel and Shunmugam, 2001). In this method, a solid 3-Dimensional (3D) model is obtained by rendering the surfaces based on the transferred surface point coordinates. Expensive digital coordinate-reading devices can be used for determining the coordinate points. However, this operation can also be realized with the aid of a simple mechanism built in the laboratory.

To the researcher's best knowledge, there haven't been any finite element method studies published investigating the mechanics of stress distribution in the CTB of horse. This bone could provide a good baseline model for the biomechanical modelling studies of bones due to its rather simple anatomy. The researchers hypothesize that a successful modelling of the tarsal bone of horse can provide a basis for further in depth studies of stress analysis, fracture risk analysis and prosthesis development of bones in the veterinary field.

MATERIALS AND METHODS

In the study, CTB which was obtained from a native horse of with the weight 217 kg that was brought to the Department of Anatomy as a course cadaver and having no problem related to locomotor system was used. The bone was removed from the body and stored in 0.9% saline solution at -20°C until required.

Coordinate-reading method was used for the modelling of the bone. In this method the 3-dimensional coordinates of various marked points on the surface of the object are measured. From these coordinates, linear dimensions, angulations and areas of surfaces and cross-sections of the objects are calculated (Lanovaz *et al*., 2002). In the study, a point to the center on the proximal surface of the bone was considered as the starting point [(x, y) = (0, 0)]. Other points to be used in the development of the model were determined by marking 5 mm distances from the starting point using electronic compass (Mitutoyo Corporation, Kawasaki, Japan). X and y values of these points relative to the starting point were determined.

The same procedure was followed also for the distal surface. We drew 196 landmarks for the proximal surface points and 201 landmarks for the distal surface points (Fig. 1). Since the model was three-dimensional, z axis values of points were also determined by the use of a comparator (Baty International, West Sussex, England). The comparator, height of which was adjusted relative to the starting point was moved on the surface and the heights of all points in z direction were determined. Surfaces were measured unilaterally.

The z coordinates data read for the distal surface was transformed according to proximal surface data and the actual z coordinates of the distal surface were obtained. For this purpose, ten points were determined randomly in both surfaces. Thickness of the bone in these points was measured using the electronic compass. By using the Eq. 1:

$$z_p' + z_d' + t = z \tag{1}$$

average z constant was found where z_p' is the z coordinates of a point on the proximal surface, z_d' is the z coordinates of a point on the distal surface and t is the thickness of the bone (Fig. 2). By using the Eq. 2:

$$z_d = z_d' \text{ ve } z_p = z - z_p' \tag{2}$$

z coordinates of the points were found in the distal and proximal surfaces where z_d is the z coordinates of a point on the distal surface.

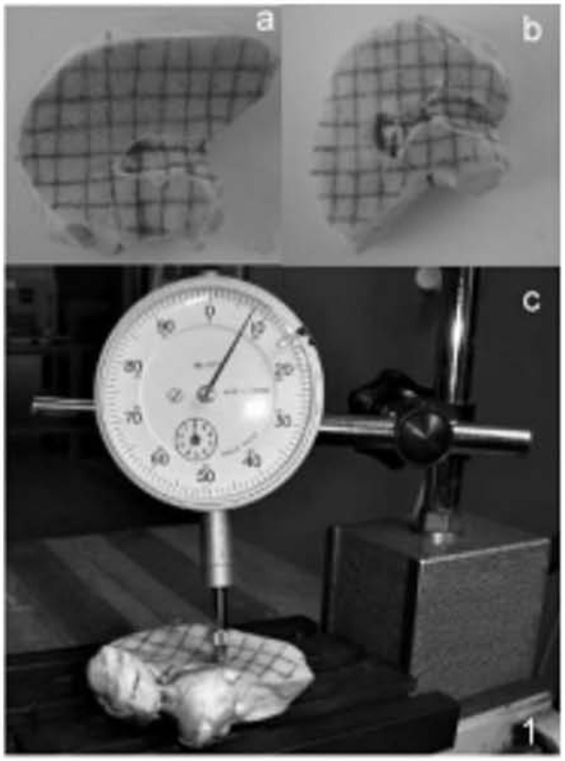

Fig. 1: Central tarsal bone and landmarks for the proximal (a) and distal (b) surface points and determining z axis values of points by the use of a comparator (c)

The numbered points were recorded as data file, as x, y, z values. Two records were formed separately for the proximal and distal surfaces and these files were transferred to ANSYS 5.5 finite element program (ANSYS Inc., Canonsburg, PA, USA) as input file. The points were attached through curves. Thereafter, areas surrounded by these curves were formed (Fig. 3) and a final volume was obtained (Fig. 4). Material characteristics for the bone model were determined by using E = 19.5 Gpa, ν = 0.307,

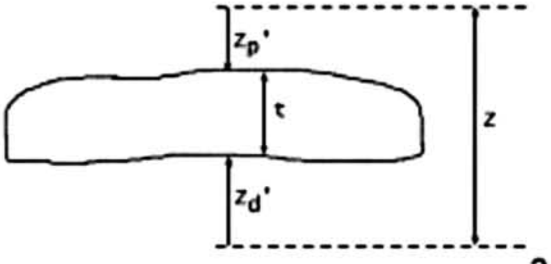

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Fig. 2: Transformation of the "z" coordinates data read for the distal surface. z_p': z coordinates of a point on the proximal surface, z_d': z coordinates of a point on the distal surface, t: thickness of the bone, z: Average z constant, e: Reference axis

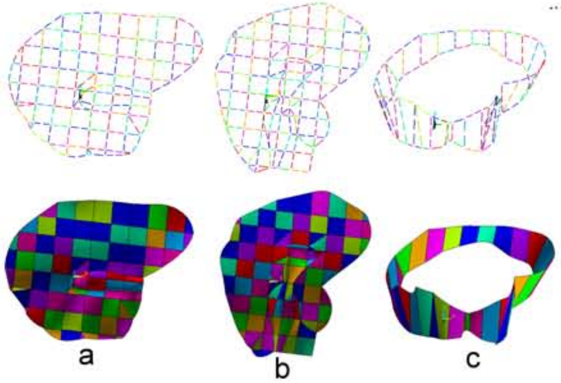

Fig. 3: Curves (top) and areas (bottom) of the model (a) Proximal surface (b) distal surface (c) lateral surface

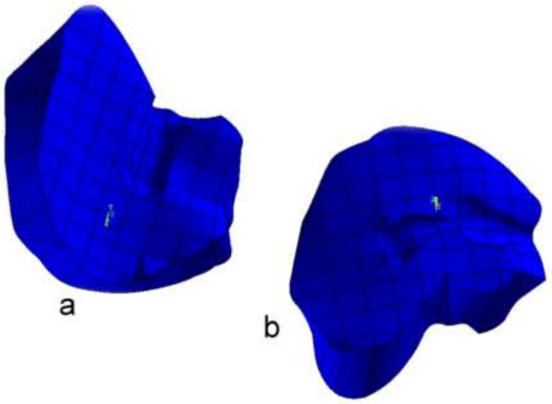

Fig. 4: Solid model of central tarsal bone (a) proximal view (b) distal view

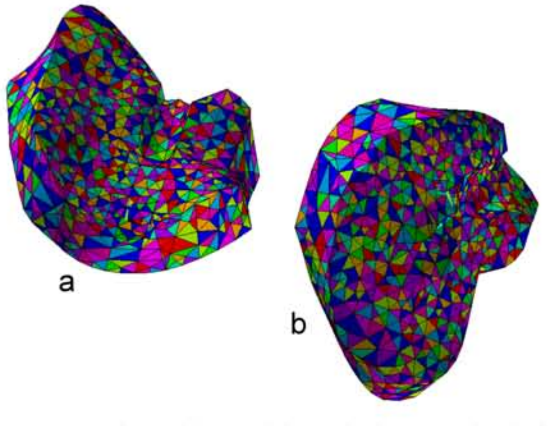

Fig. 5: Central tarsal bone with meshed (a) Proximal view (b) distal view

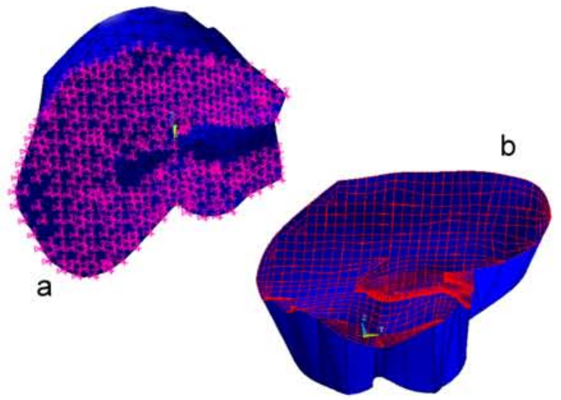

Fig. 6: Applied limit conditions (a) and pressures (b) to model

$d = 2000$ kg m^{-3} as previously reported (Wirtz *et al*., 2000). The model was separated into finite elements using three-dimensional volumetric elements as shown in Fig. 5. After this process, the limit conditions were determined by fixing a total of 1299 nodal points on the distal surface (Fig. 6a). The bone, through which the model was formed, belonged to a horse of 217 kg body weight. In horses, 45% of the body weight affects the hind legs (Nickel *et al*., 1986). Therefore, a pressure of 0.30913×10^6 N m^{-2} was applied to the proximal surface of the model, considering that the joint fluid dispersed the pressure evenly in all directions (Fig. 6b).

RESULTS AND DISCUSSION

Model consisted of 2900 nodes and 11866 elements on all surfaces. The models enable the observation of strains and deformations resulting from the application of force. Equivalent stresses (von Mises stresses) were shown in detail by perspective images and section images (Fig. 7 and 8). The stress distribution was decreased proximo distally but increased on the side surfaces. The highest values of von Mises stresses occurred in the lateral end of the dorsal border in the distal surface (Fig. 7).

The three dimensional FEM provides information to simulate the force systems and the resulting displacements in three dimensions. Moreover, stress and strain can be calculated. Recently FEM has become a frequently used technique in the field of medical and veterinary sciences (Anderson *et al*., 2003; Chosa *et al*., 2004; Lanovaz *et al*., 2002; Sweigart and Athanasiou, 2005; Zhong *et al*., 2006). In this study, we showed that the coordinate-reading method could also be used besides other methods (Adam *et al*., 2003; Asgaria *et al*., 2004; Templeton *et al*., 2004) in computer modelling with the aid of a simple mechanism established in the laboratory for non-complex biological objects.

The method also allows the observation of elastical behaviors under various forces on the model. The finite element model formed was compatible with the real bone, proving the usability of the method. It is possible to estimate the behavioral pattern of biological objects after a correct computer modelling without any need to generate actual experimental conditions. However, this method and simple mechanism can be used for small bones such as tarsal and carpal bones. In long bones anatomical details and landmark points on the surfaces are more than small bones and coordinate measuring takes time.

There are some experimental researches about equine hock joint (Eliashar *et al*., 2004; Khumsap *et al*., 2004; Lanovaz *et al*., 2002; Stock *et al*., 2005). However there are no finite element studies published about equine tarsal bones. This finite element model of central tarsal bone and the results of this model can be of benefit to further experimental studies on this bone. The limit conditions were used on the distal surface for rigid body

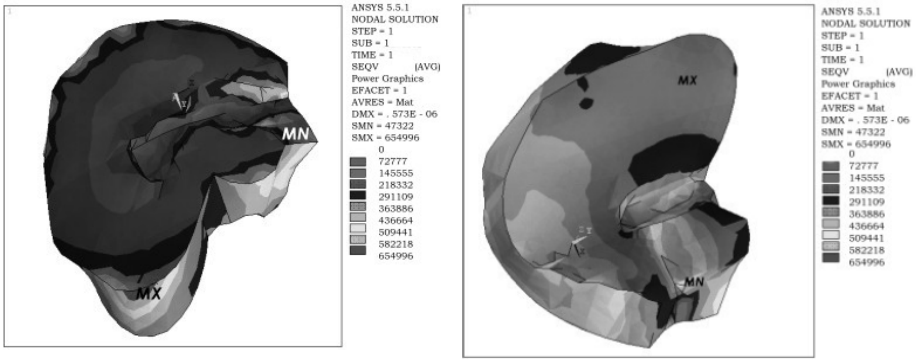

Fig. 7: Proximal (a) and distal (b) view of von Mises equivalent stresses

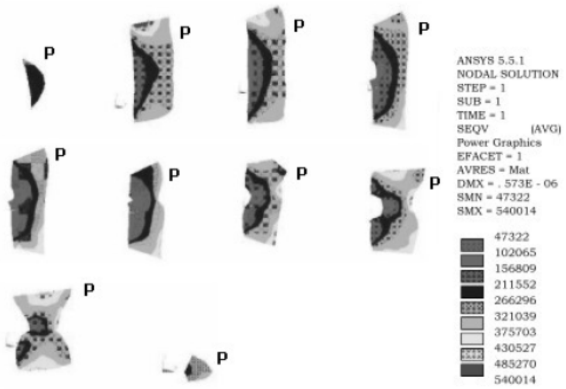

Fig. 8: von Mises equivalent stresses in sections from dorsal to plantar (P: Proximal surface)

displacement as there were no attached structures, where the force would be transferred to. This approach, although not reflecting a real situation, is verified as there is no stress intensity on distal surface.

CONCLUSION

Models of anatomical structures can be used for presurgical planning activities and to guide during surgical training (Berkley *et al*., 1999; Schwartz *et al*., 2005; Zhao *et al*., 2002). The finite element model and finite element analysis results can be used for fracture estimations and treatment methods with different stress conditions of central tarsal bone.

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