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Cross-Sectional Geometry of Equine Metacarpal and Metatarsal Bones

[1]Gulsum Ozyigit and [2]Resat Ozcan
[1]Department of Anatomy, Faculty of Veterinary Medicine, Uludag University, 16059, Gorukle, Bursa, Turkey
[2]Department of Mechanical Engineering, Faculty of Engineering and Arch, Uludag University, 16059, Gorukle, Bursa, Turkey

Abstract: Fractures of metacarpal and metatarsal bones are very common in horses. The purpose of this study was to evaluate the cross-sections and the cross-sectional moment of inertia and to determine the resistance to bending moments from proximal to distal on diaphyseal regions of Mc_3 and Mt_3 bones. Computed tomography images were taken from 10 mm apart cross sections of the diaphyses of bones. Cross sectional surface area and moment of inertia were estimated and variations were observed from proximal to the distal of the diaphyses. The results indicate that Mt_3 has more strong construct than Mc_3 especially in dorsal and plantar bendings but has more resistance to mediolateral bendings than Mc_3.

Key words: Metacarpal bones, metatarsal bones, cross sectional study, moment of inertia, equine

INTRODUCTION

Bone Fractures, particularly the limb fractures, in horses usually occur either as a result of direct trauma from a fall, kick or knock or during strenuous exercise. Diaphyseal fractures of the third metacarpal bone (Mc_3) compose 22% of all horse limb fractures. This ratio increases 33% when the diaphyseal fractures of the third Metatarsal bone (Mt_3) are included (Nunamaker *et al*., 1989). Pain and inflammation on the dorsal surface of the Mc_3 referred to as shin soreness is most common in racehorses. Shin soreness develops as a result of increased strain on the Mc_3 from training in high speed of young horses, concussions and contusions (McIlwraith, 1987; Nunamaker, 2000) 12% of those racehorses develop stress fractures at the dorsal or dorsolateral aspect of Mc_3 during the racing (Nunamaker, 1996).

Fractures of the condyles are the most common long bone fractures of the Mc_3 and Mt_3 in horses in training (Ellis, 1994; Ferraro, 1990). For these reasons Mc_3 and Mt_3 bones of the horse is the most studied bone for its structural characteristics (Nunamaker *et al*., 1989; Stover *et al*., 1992), mechanical features (Les *et al*., 1997; Biewener *et al*., 1983; Nunamaker *et al*., 1990; Turner *et al*., 1975) and stiffness (Gibson *et al*., 1995; Nunamaker *et al*., 1991).

In the study, we aimed to evaluate the cross-sections and the cross-sectional moment of inertia and to determine the resistance to bending moments from proximal to distal on diaphyseal regions of Mc_3 and Mt_3 bones.

MATERIALS AND METHODS

In the study, Mc_3 and Mt_3 which were obtained from a native horse of with the weight of 300 kg that were brought to the Department of Anatomy as a course cadaver and having no problem related to locomotor system were used. The bones were removed from the body and metacarpal II and IV and metatarsal II and IV were also removed. The specimens were stored in 0.9% saline solution at -20°C until required (Les *et al*., 2002).

At first, computed tomography images were taken from Mc_3 and Mt_3. For this purpose computed tomography scans were taken 10 mm apart sections from the diaphyses of bones. The images obtained were transferred to the computer with the aid of a scanner. The edge contours were determined in Photo Editor 3.0 (Microsoft, Redmond, WA, USA) in all images. After that all images were converted to vector graphics and saved as a dxf file using with Kvec software (KK-Software, Weiden, Germany) and igs file using with DesignCad97 software. Transferring images to the ANSYS 5.5 finite element program (ANSYS Inc., Canonsburg, PA, USA) software were used for generating cross section areas from cross section images. Cross sectional surface area and moment of inertia were estimated and variations were observed from proximal to the distal of the diaphyses (Fig. 1-3).

Corresponding Author: Gulsum Ozyigit, Department of Anatomy, Faculty of Veterinary Medicine, Uludag University, 16059, Gorukle, Bursa, Turkey

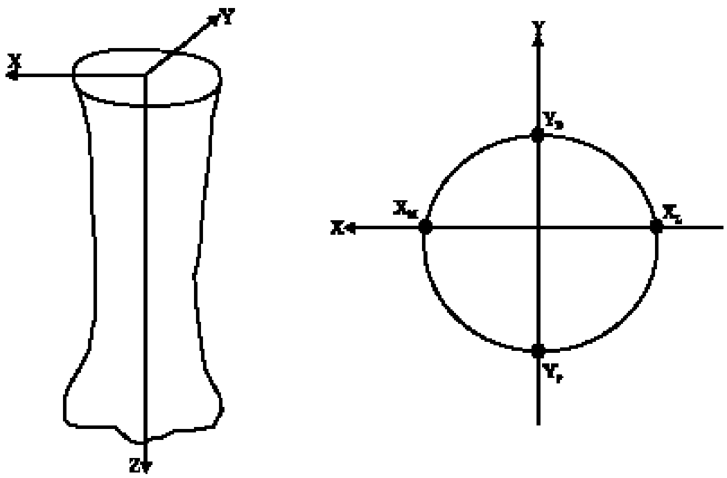

Fig. 1: Coordinate replacements of the bones X_L: Lateral radius of the cross sectional area; X_M: Medial radius of the cross sectional area; Y_D: Dorsal radius of the cross sectional area; Y_P: Palmar/Plantar radius of the cross sectional area

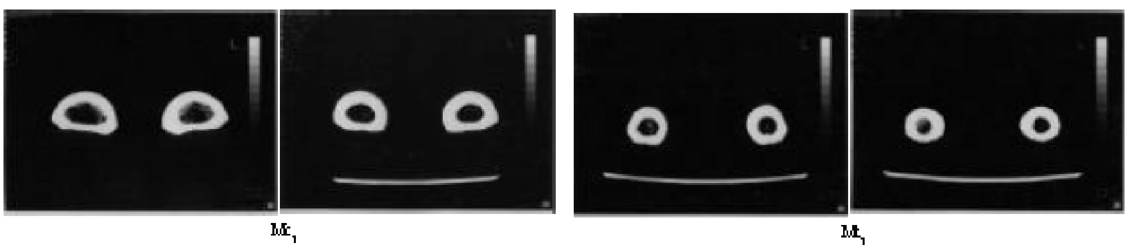

Fig. 2: Computed tomography images of Mc_3 and Mt_3

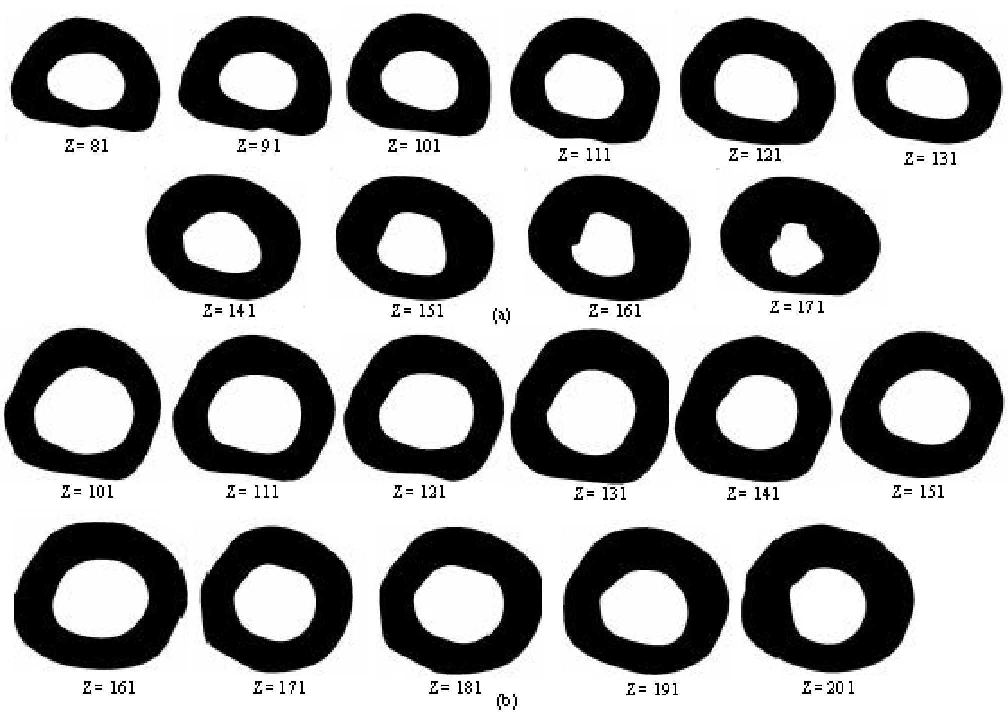

Fig. 3: (a) Cross sections of Mc_3 from proximal to distal (Z: Distance from proximal ends of the bone), (b) Cross sections of Mt_3 from proximal to distal (Z: Distance from proximal ends of the bone)

RESULTS AND DISCUSSION

The examination of the sections reveal that the cross section of Mc_3 is smaller in the proximal and larger in the distal regions when compared with Mt_3. (Fig. 4). Cross sectional areas in the proximal and distal regions were not shown differences in Mt_3. The mean diaphyseal area values were found as 493.141 mm^2, standart deviation were found as 53.40862 for Mc_3 whereas these values were found as 533.085 mm^2 and 18.67639, respectively for Mt_3 (Table 1 and 2). The mean cross sectional area values in the Mt_3 were greater and less variable than those in the Mc_3 (Fig. 4).

The cross sectional moment of inertia had smaller values on x-axis whereas showing greater values on y-axis in both bones (Fig. 4). In general, moment of inertia values were greater in Mt_3 compared to Mc_3. Moreover, moments of inertia on x-axis varied more for Mt_3 when compared with Mc_3 whereas a higher variation was observed for Mc_3 on y-axis.

In general, diaphyseal cross sectional area values were greater in Mt_3 compared to Mc_3 (Fig. 5). Cortical cross-sectional area affected to bone stiffness in long bones (Hanson *et al*., 1995). From this viewpoint Mt_3 has more strong construct than Mc_3 (Fig. 6).

Maximum tensile strains occurr on the palmar region of the proximal diaphysis in Mc_3 at dorsal bending. This region has lower fracture toughness (Les *et al*., 1997). Overtensile strains may cause fractures at this region. Tensile strains occuring on the dorsal region of the distal diaphysis in Mt_3 at palmar bending. Dorsal region indurable to tensile strain, overstrain may cause fractures at this region (Turner *et al*., 1975; Martin *et al*., 1996).

The compressive strains occur on the dorsal region greater than the tensile strains occuring on the plantar region of the Mt_3 at dorsal bending. The bone have a high resistance to dorsal bending (Banks, 1986). Dorsal and lateral regions have more tensile strain than other regions in Mt_3 (Turner *et al*., 1975). The tensile strains occuring on the dorsal region greater than the compressive strains occuring on the plantar region of the Mt_3 at plantar bending. Dorsal region indurable to tensile strain, overstrain may cause fractures at this region (Turner *et al*., 1975; Martin *et al*., 1996). This bending may cause fractures at dorsal regions of proximal diaphysis of Mt_3.

Feature of the strain in medial bending was compressive and tensile on medial and lateral regions, respectively. There was converse situation in lateral bending. The finding showed that Mt_3 has more resistance to mediolateral bendings than Mc_3 (Fig. 7) (Hanson *et al*., 1995).

Tensile strains on lateral regions was greater than compressive strains on medial regions of the palmar surface of the proximal diaphysis in Mc_3 at medial bending. This region is the critacal region for fractures

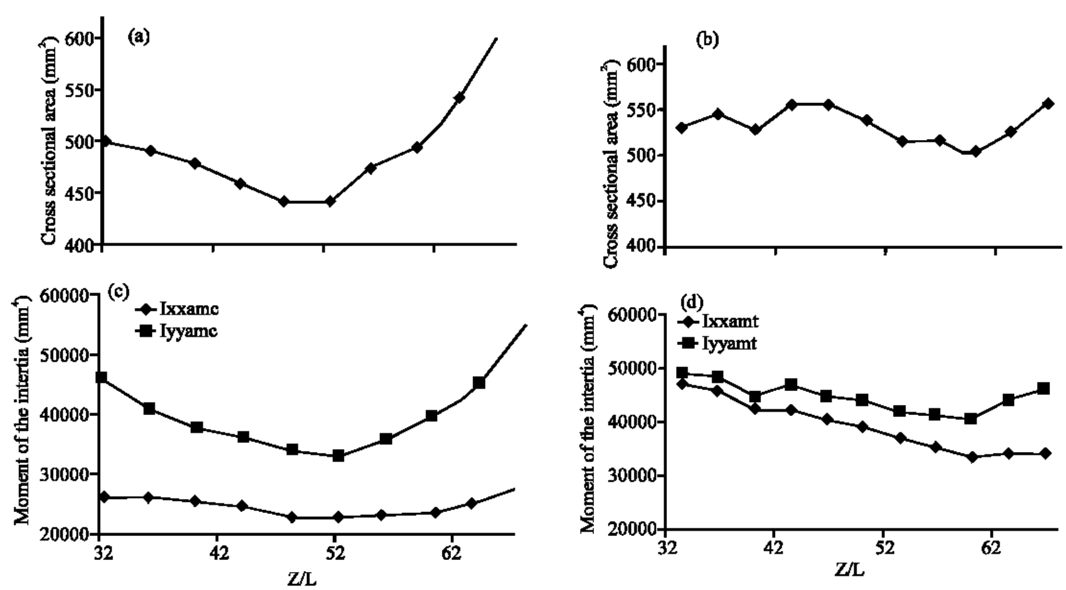

Fig. 4: Cross sectional area and moment of the inertia changes of the Mc_3 and Mt_3. Z: Distance of the cross section from proximal ends of the bone, L: Length of the bones. (a) Cross sectional area changes of the Mc_3, (b) Cross sectional area changes of the Mt_3, (c) Moment of the inertia changes of the Mc_3 and (d) Moment of the inertia changes of the Mt_3

Table 1: Moment of inertia and moment of inertia/cross sectional area ratio of the Mc_3

	Metacarpus III										
Z/L	Cross sectional area (mm^2)	Moment of inertia about X axis (mm^4)	Moment of inertia about Y axis (mm^4)	X_L	K_{XL}	X_M	K_{XM}	Y_D	K_{YD}	Y_P	K_{YP}
32	498	25987	45976	23.96	3.20	25.81	2.99	16.33	3.86	17.46	3.58
36	490	25999	40865	22.45	3.23	24.90	2.98	16.44	3.72	17.79	3.35
40	477	25504	37679	21.12	3.35	24.27	2.99	15.97	3.74	17.88	3.26
44	459	24521	35944	22.15	3.24	23.34	3.11	16.52	3.54	17.19	3.36
48	440	22976	33857	23.50	3.06	21.39	3.13	17.04	3.28	16.70	3.60
52	442	22821	32981	22.44	3.05	21.96	3.08	16.92	3.33	16.78	3.40
56	473	23077	35745	23.24	2.75	21.96	3.04	17.73	3.25	16.05	3.44
59	493	23467	39499	24.00	2.61	22.61	2.98	18.23	3.34	16.00	3.55
63	542	25470	45256	25.51	2.54	22.68	2.92	18.51	3.27	16.08	3.68
67	619	28046	54808	27.42	2.24	23.89	3.13	20.23	3.23	14.48	3.70

Table 2: Moment of inertia and moment of inertia/cross sectional area ratio of the Mt_3

	Metatarsus III										
Z/L	Cross sectional area (mm^2)	Moment of inertia about X axis (mm^4)	Moment of inertia about Y axis (mm^4)	X_L	K_{XL}	X_M	K_{XM}	Y_D	K_{YD}	Y_P	K_{YP}
34	530	47060	48661	16.84	4.73	16.44	6.83	18.75	5.45	13.00	5.58
37	544	45662	47977	10.39	4.50	15.72	6.77	18.64	5.17	12.39	5.61
40	528	42259	44574	10.55	4.62	15.82	6.27	17.31	5.17	12.76	5.33
44	553	42067	46672	15.77	4.34	15.77	5.93	17.53	5.35	12.83	5.35
47	554	40380	44395	14.75	4.25	17.10	5.40	17.15	5.44	13.52	4.69
50	537	38848	43731	14.21	4.23	17.24	5.38	17.12	5.73	13.44	4.73
53	516	36803	41875	14.95	4.31	16.62	5.49	16.56	5.43	12.99	4.89
57	515	34915	41160	15.40	4.28	15.82	5.02	15.85	5.19	13.50	5.05
60	502	33240	40435	14.66	4.27	17.16	4.88	15.49	5.49	13.57	4.69
63	526	33881	43709	16.03	4.19	16.44	4.75	15.37	5.18	13.57	5.05
67	556	34023	46019	15.37	3.91	17.16	4.76	15.67	5.39	12.87	4.82

Z: Distance of the cross section from proximal ends of the bone L: Length of the third metatarsal bone, X_L: Lateral radius of the cross sectional area; X_M: Medial radius of the cross sectional area; Y_D: Dorsal radius of the cross sectional area; Y_P: Palmar/Plantar radius of the cross sectional area; K_{XL}, K_{XM}, K_{YD}, K_{YP}: Moment of inertia/cross sectional area ratio of the X_L, X_M, Y_D, Y_P

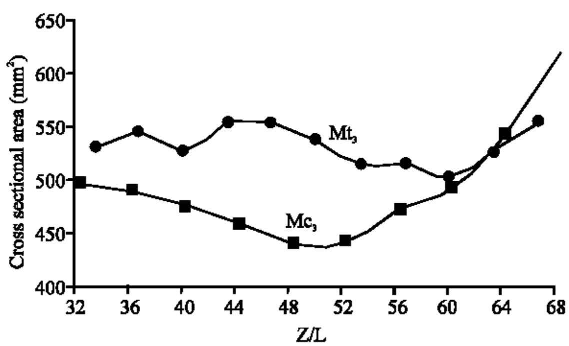

Fig. 5: Cross sectional area changes of the Mc_3 and Mt_3. Z: Distance of the cross section from proximal ends of the bone, L: Length of the bones

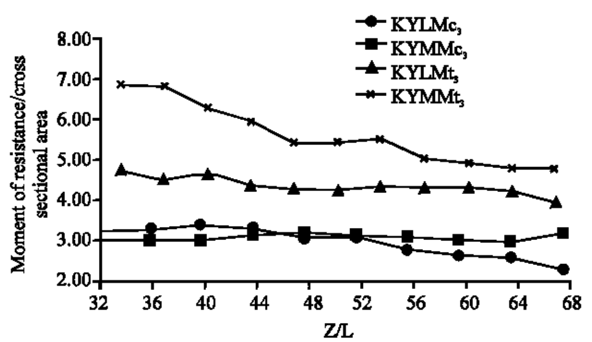

Fig. 6: Moment of resistance/cross sectional area ratio changes of the Mc_3 and Mt_3 with respect to x axis. Z: Distance of the cross section from proximal ends of the bone, L: Length of the bones

due to the bones had low resistance to tensile strain (Banks, 1986). Tensile strains on medial surface of the distal diaphysis had extreme value in Mc_3 at lateral bending.

The medial and dorsal regions have less tensile strain resistance than the other regions in Mc_3 (Turner *et al*., 1975). Resistance to lateral bending was greater than palmar bending of Mc_3 (Hanson *et al*., 1995).

Tensile strain at the lateral aspect of the bone, compressive and tensile strain dorsally and almost purely compressive strain at the medial and plantar sides (Turner *et al*., 1975). Tensile strains on lateral regions was greater than compressive strains on medial regions of the distal diaphysis in Mt_3 conversely Mc_3 at medial bending.

Tensile strains on medial surface was greater than compressive strains on lateral regions of the proximal diaphysis in Mt_3 at lateral bending.

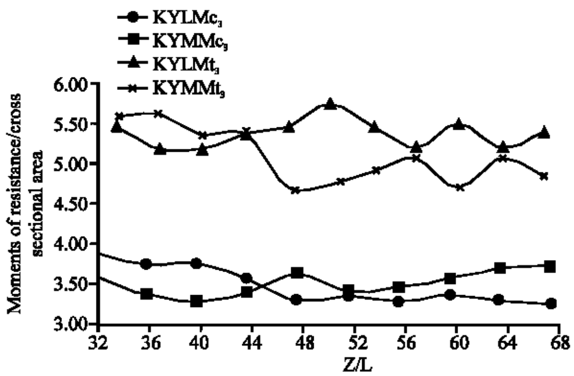

Fig. 7: Moment of resistance/cross sectional area ratio changes of the Mc_3 and Mt_3 with respect to y axis. Z: Distance of the cross section from proximal ends of the bone, L: Length of the bones

CONCLUSION

The finding showed that Mt_3 has more strong construct than Mc_3 especially in dorsal and plantar bendings but has more resistance to mediolateral bendings than Mc_3.

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