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Computed Tomographic Assessment of surgical plans and fracture healing using bio fabricated rapid prototype 3D Printable Bone Models

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Abstract

Computed Tomography (CT) is the currently emerging diagnostic tool in the field of Veterinary Orthopaedic and soft tissue surgeries. CT images provide detailed information on the axis, morphometry and contour of the long bones in small animals. Accurate identification of the fracture site and its surgical methods paves the way to minimize the post-operative complications. With the help of 3D printed prototype bone models the selection of most appropriate surgical method and its implants required for the surgery could be identified. The objective of this study is to 1) To reconstruct three dimensional prototype models from the computed tomographic scan images using 3D slicer software 2) to develop an appropriate surgical strategies and plan to intervene the long bone fractures in dogs 3) to evaluate fracture healing by comparing the angle of alignment between the post fixation of bone fragments on the 60th and 90th days. A total of twelve dogs (8 female and 4 male) were used for this study. Multiplanar reconstructed images of the long bones were obtained from the computed tomographic images using 3D slicer software. The planimetry between the proximal and distal fragments were measured pre and post operatively. Appropriate surgical methods were identified and applied for the fracture fixation. Fracture healing at different interval were analysed. The Pre and post-operative planimetry measurements such LA, CA, CDA, TMA, PSL, DSL between the proximal and distal fragments on 60th and 90th days were statistically significant. Planimetric measurements obtained from pre and post-operative fractured fragments using 3D images were used to estimate the fracture healing between the 60th and 90th days. With the help of 3D printed biometric bone models the appropriate fracture plans were obtained and surgical fixation was done in accordance with the pre planned strategy. It is concluded that this study will contribute to the orthopaedic experimental studies of long bone fractures in dogs and which will serve as a modern perspective in veterinary orthopaedics.

Keywords: Fracture, CT images, 3D Prototype, planimetry, fracture healing

Introduction

The axial skeleton is composed of long bones, the majority of which are dense cortical bone. The diaphysis forms the shaft of the long bone and contains a core medullary cavity with vascular supply, lymphatics, fatty marrow and hematopoietic cells. Small animal practitioners will expect to see many long bone fractures over the course of their career. For those who are equipped to manage these surgically, the challenge is to select the appropriate fixation strategy and surgical technique. Fractures fixed with hard internal fixation undergoes a biological process called primary cortical healing, which involves remodelling of osteoclast and osteoblast cells. This process, to close the fracture space and join the fracture pieces involves the periosteum, external soft tissues and bone marrow to a lesser extent. Three dimensional (3D) printing has been applied extensively not only in human but also in veterinary medicine. Medical doctors require 3D visualisation from 2D pictures for improved tissue enhancement and therapy. Our study was aimed to obtain pre operative strategy by using the 3D printed biofabricate prototype bone models obtained from the computed tomographic images. Computed tomographic images provides a well differentiated bone and soft tissue images to estimate the morphological and anatomical the bone by making use of the 3D printed biofabricate prototype bone models.

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Materials and methods

Four dogs presented to the Orthopaedic Small Animal Unit, Madras Veterinary College, Chennai, with fracture of long bones were selected, irrespective of breed, age, or sex (three females and one male) and were subjected to radiographic examination, orthogonal radiographs lateral- medial and dorso-palmar/dorso-plantar were obtained to assess and classify the fractures. Temporary immobilization of the affected limb was done using modified Robert Jones bandaging technique which were then subjected to CT scan. Fasting protocols were strictly followed prior to surgery. Premedication was administered using Inj. Butorphanol and Inj. Diazepam @ 0.2 mg/kg body weight intravenously, with a 10-minute interval between the two. Anaesthetic induction was achieved with Inj. Propofol at 2-4 mg/kg body weight intravenously, titrated to effect. Following intubation with an appropriately sized endotracheal tube, anaesthesia was maintained using a Boyles apparatus with Isoflurane (2.5%) delivered in 100% oxygen. The animals were positioned in ventrodorsal and dorsoventral recumbency based of the bones that are to be exposed. Cross sectional images of the long bones were acquired from the CT device (Toshiba) at a

thickness of 1mm and value of 110kv. Multiplanar reconstructed images were obtained by transferring the cross sectional image to a 3D slicer software programme (Melican *et al.*, 2001). With the help of multiplanar reconstructed images planimetry between the pre and post fixation of bone fragment with callus formation during the period of 60th and 90th days were measured as LA, MA, CA, CDA, TMA, PSL, DSL (Table 1). Segmentation of the bone and soft tissue were obtained and they are fed to the 3D printing machine to develop 3D printed biofabricate prototype bone models. Then they were used for the assessment of appropriate fracture fixation strategy and technique by precontouring the bone plate to the axis of the 3D printed biofabricate prototype bone models. Appropriate implant size (bone plate & screws) were predetermined with the help 3D printed biofabricate prototype bone models and then the surgical technique was carried out on the selected animals (Chen *et al.*, 2019). The results were statistically analysed using one way ANOVA. Descriptive statistics for each variables were represented as mean $\pm$ SE. SPSS version 14.0 was used for the statistical analysis

Table 1: Name, abbreviation and definition of the parameters studied

Name	Abbreviation	Definition
Lateral angle	LA	From the point of proximal extremity of the bone to the distal extremity to determine the lateral deviation of the bone fragments
Medial angle	MA	Measured from the proximal aspect of the bone to the distal aspect medially to determine the medial deviation of bone fragments
Cranial angle	CA	Measured in accordance with the cranial aspect of the bone to determine any craniocaudal or caudodorsal displacement of the fractured fragments.
Caudal angle	CDA	Measured in accordance with the caudal aspect of the bone to determine any craniocaudal or caudodorsal displacement of the fractured fragments.
Total medullary angle	TMA	Total Medullary angle in between the fractured fragments were measured in between the medullary canal.
Proximal segment length	PSL	Proximal segment length is measured in between pre fixation of fractured bone fragments and post fixation of bone fragments with callus.
Distal segment length	DSL	Distal segment length is measured in between pre fixation of fractured bone fragments and post fixation of bone fragments with callus.

Results

Three dimensional biofabricate prototype models were created with the help of multiplanar reconstructed images obtained from the computed tomographic scan. The geometry of fractured bone and 3D printed bio fabricate models were observed to be in symmetry. The deviation of the fractured

limb was identified with the help of ruler which is inbuilt in the software. With the help of multiplanar images the planimetric measures obtained between the pre and post fixation of bone fragment with callus formation during the period of 60th and 90th days were evaluated.

Table 2: Mean Statistical values for the planimetry between the pre and post fixation of bone fragment with callus formation during the period of 60th and 90th days

Parameters	N	Pre-Operative (0 day)	Post-Operative (60 days)	Post-Operative (90 days)	p Value
LA°	12	154.08 ^a ±1.5	170.52 ^b ±1.09	171.65 ^b ±0.92	.000
MA°	12	128.43 ^a ±2.55	168.69 ^b ±1.00	168.75 ^b ±1.00	.000
CA°	12	141.11 ^a ±2.28	170.34 ^b ±1.14	170.63 ^b ±1.18	.000
CDA°	12	34.43 ^a ±3.19	171.38 ^b ±1.23	171.4 ^b ±1.22	.000
TMA°	12	19.98 ^b ±1.8	3.37 ^a ±0.19	3.41 ^a ±0.19	.000
PSL°	12	52.31±2.11	51.08±2.08	51.16±2.1	0.898
DSL°	12	53.88±3.19	52.38±3.12	52.48±3.12	0.931

^{ab} superscript bearing mean values with in row differ significantly.

Planimetry between the pre and post fixation of bone fragments with callus formation during the post-operative period of 60th and 90th days

Lateral angle (LA)

The lateral angle between the pre fixation of fractured bone fragments ($154.08^a \pm 1.5$) and post fixation of bone fragments with callus on the post-operative 60th day ($170.52^b \pm 1.09$) were highly significant with p value less than 0.001 ($p < 0.001$). Also the lateral angle in between the post fixation of bone fragments with callus formation on 60th day ($170.52^b \pm 1.09$) and on 90th day ($171.65^b \pm 0.92$) were highly significant ($p < 0.001$).

Medial angle (MA)

Measurement of the medial angle in between the pre fixation of fractured bone fragments ($128.43^a \pm 2.55$) and the post fixation of bone fragments with callus ($168.69^b \pm 1.00$) on the 60th day were found to be statistically highly significant ($p < 0.001$). The medial angle in between the post fixation of bone fragments with callus at 60th day ($170.52^b \pm 1.09$) and 90th day ($170.63^b \pm 1.18$) were found to be statistically highly significant ($p < 0.001$).

Cranial angle (CA)

Cranial angle in between the pre fixation of fractured bone fragments ($141.11^a \pm 2.28$) and the post fixation of bone fragments with callus at 60th day ($170.34^b \pm 1.14$) were found to be highly significant ($p < 0.001$). The alignment of the cranial angle (CA) in between the post fixation of bone fragments with callus at 60th day ($170.34^b \pm 1.14$) and 90th day ($170.63^b \pm 1.18$) were found to be statistically highly significant ($p < 0.001$).

Caudal angle (CDA)

Caudal angle in between the pre fixation of fractured bone fragments ($34.43^a \pm 3.19$) and the post fixation of bone fragments with callus at 60th day ($171.38^b \pm 1.23$) were found to be highly significant ($p < 0.001$). The alignment of the caudal angle in between the post fixation of bone fragments with callus at 60th day ($171.38^b \pm 1.23$) and 90th day ($171.4^b \pm 1.22$) were found to be statistically highly significant ($p < 0.001$).

Total medullary length (TMA)

The total medullary angle between the pre fixation of fractured bone fragments ($19.98^b \pm 1.8$) and post fixation of bone fragments with callus at 60th day ($3.37^a \pm 0.19$) are highly significant with p value less than 0.001 ($p < 0.001$). Also the total medullary angle in between the post fixation of bone fragments with callus at 60th day ($3.37^a \pm 0.19$) and 90th day ($3.41^a \pm 0.19$) were highly significant ($p < 0.001$).

Proximal segment length (PSL)

Measurement of the proximal segment length in between pre fixation of fractured bone fragments (52.31 ± 2.11) and the post fixation of bone fragments with callus on the 60th day (51.08 ± 2.08) were found to be statistically not significant ($p > 0.005$). The proximal segment length in between the post fixation of bone fragments with callus at 60th day (51.08 ± 2.08) and 90th day (51.16 ± 2.1) were found to be statistically not significant ($p > 0.005$). This might be due to the resorption of bone in between the fragments.

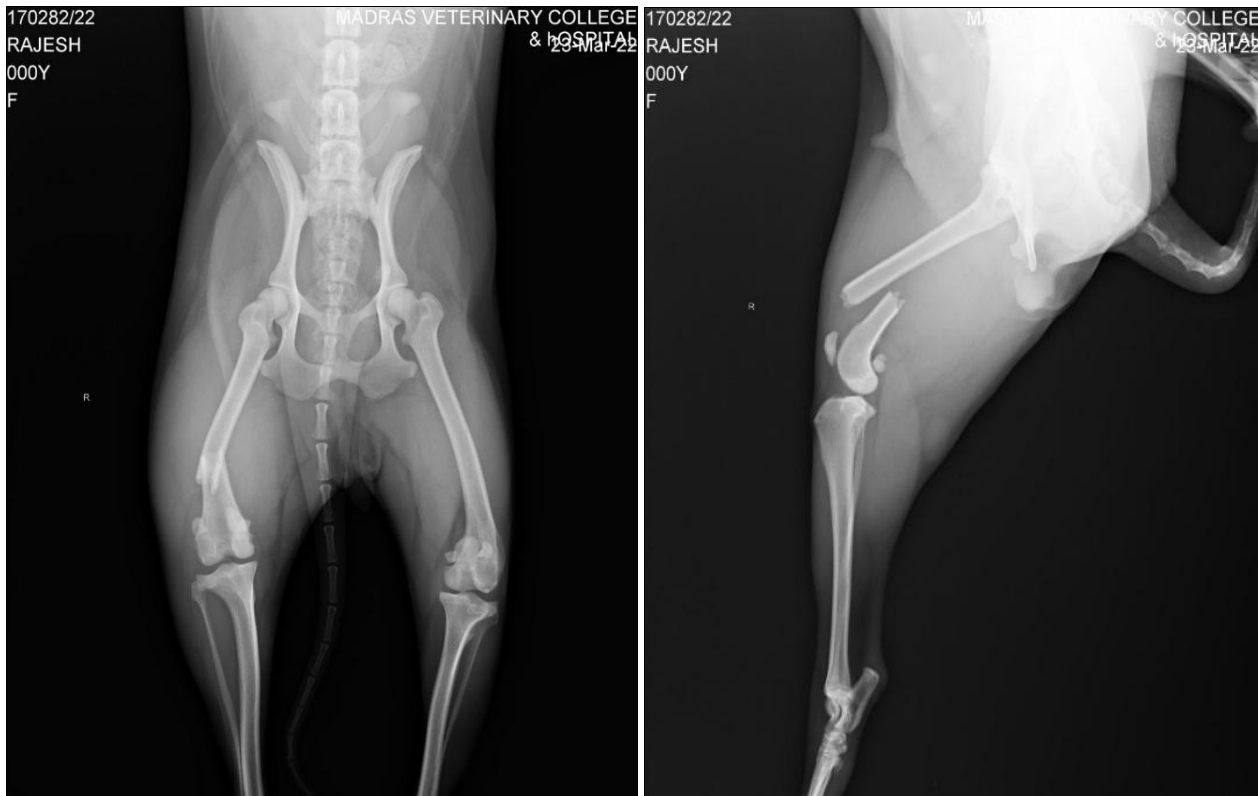
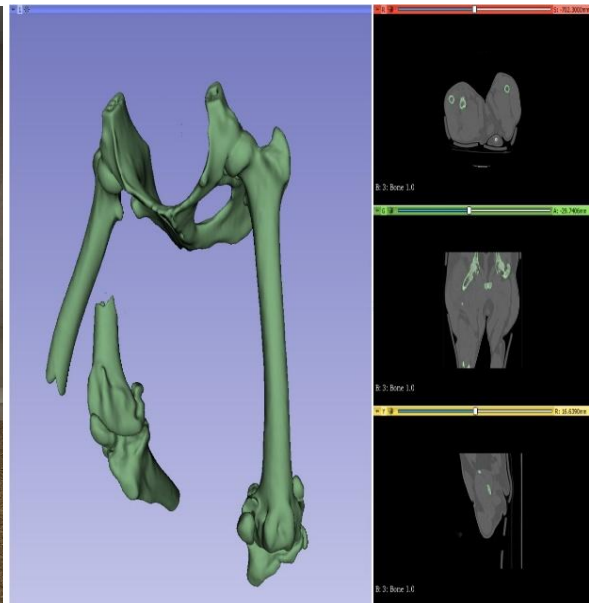
Distal segment length (DSL)

Measurement of the distal segment length in between the pre fixation of fractured bone fragments (53.88 ± 3.19) and the

post fixation of bone fragments with callus on the 60th day (52.38 ± 3.12) were found to be statistically not significant ($p > 0.005$). The proximal segment length in between the post fixation of bone fragments with callus at 60th day (52.38 ± 3.12) and 90th day (52.48 ± 3.12) were found to be statistically not significant ($p > 0.005$). This might be due to the resorption of bone in between the fragments during the fracture healing.

Discussion

The axial skeleton is composed of long bones in which the majority are of dense cortical bone. The diaphysis forms the shaft of the long bone which consist of core medullary cavity with a vascularity, lymphatic supply, fatty marrow and hematopoietic cells. It is stated that the fracture healing is not constant. The four main zones are the medullary canal, the inter-cortical zones, the subperiosteal layer and the surrounding soft tissues. The "soft callus" that is produced by the medullary canal and inter-cortical zones is transformed into bone during endochondral ossification. The subperiosteal area and the soft tissues immediately surrounding the fracture produce a "hard callus" and builds bone by intramembranous ossification (Phillip, 2005). In our study the planimetry of LA, MA, CA, CDA and TMA were analysed between the pre fixation and the post fixation of bone fragments on 60th and 90th days post operatively. The analysed planimetric data and callus formation at different intervals were statistically significant to the study of Beale *et al.* (2020). Though there is minimal segmental bone loss during the intraoperative procedure, in different cases the length of the proximal and distal fractured fragment were found to be statistically not significant with p value more than 0.005. This study was found to be in correlation with (Meeson *et al.*, 2019) in which the change in the length of the proximal and distal segment during post fixation of the fracture fragments were due to segmental loss during the intraoperative procedures. Preoperative planning of surgical strategy of the fractured fragments were carried out with the help of 3D printed biofabric prototype bone models which was found to be in accordance with the study conducted by Chen *et al.* (2019) [2] in which the 3D printed prototype models were used for the planning of the case specific surgical strategies and techniques. The present study was conducted to determine the appropriate pre-operative size of the implants (bone plates and screws) that are required for the surgery. This study was in agreement with the study conducted by Chen *et al.* (2019) [2] in which the implant required for the internal fixation of fractures were predetermined with the help of the 3D printed solid replicas in 360 degree to the fracture site. The multiplanar reconstructed images were developed into 3D printable biofabric bone models, were found to be in accordance with study concluded by Pucci *et al.* (2017) in this the CT images which were available in DICOM format is converted into 3D printable format and then the prototype model is printed with the help of biomaterial such as polylactic acid. In this study the Rapid prototype 3D printable biofabric bone model was prepared with the help of Polylactic Acid (PLA) that was found to be in accordance with the study conducted by Fitzwater, K. L. (2010) [4] in this the 3D prototype bone models were developed using the fusion of the thermoplastic and polyacid materials. Similar kind of study was also conducted by the Harrysson *et al.* (2003) [5] in which the angular deformity of the fore limbs in dogs have been studied with the help of 3D prototype bone models printed with the help of Polylactic Acid (PLA).

**Fig 1: A)** Dorso Plantar radiographic view of the fractured limb**Fig 1: B)** Lateral radiographic view of the fractured limb**Fig 1: : C)** Computed tomography of the fractured limb**Fig 1: D)** Multiplanar Reformed Images obtained from computed tomography.

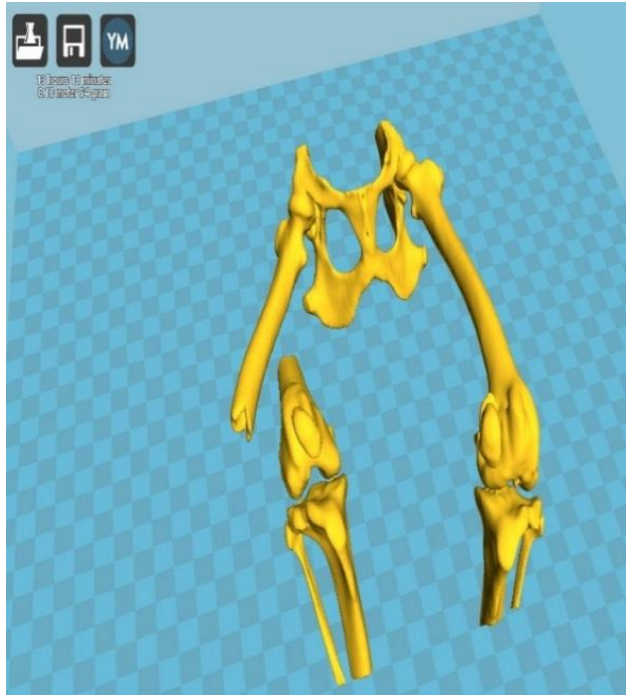


Fig 2: A) 3D prototype one model image reconstruction



Fig 2: B) Medial angle of the pre fracture fixation bone fragments (MA)(coronal)



Fig 2: C) distal segment length of the pre fracture fixation bone fragments (DSL)(sagittal)



Fig 2: H) proximal segment length (PSL)(sagittal) of the pre fracture fixation bone fragments



Fig 3 A) cranial angle of the Pre fracture fixation bone fragments(CA)(sagittal view)

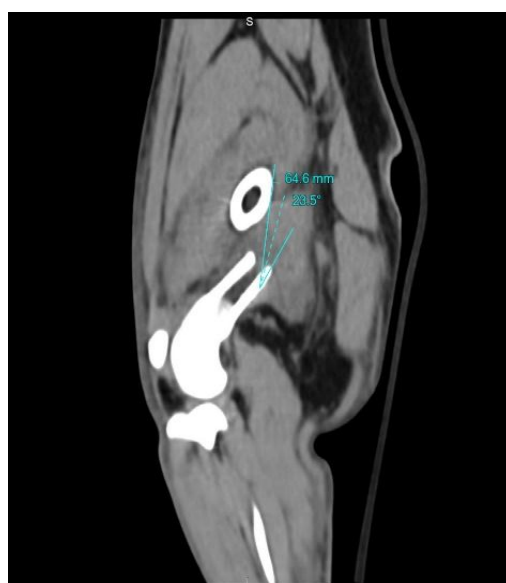


Fig 3: B) caudal angle of the pre fracture fixation bone fragments (CDA) (sagittal view)



Fig 3: C) Lateral Angle of the Pre fracture fixation bone fragments(LA)(coronal view)



Fig 3: D) Total Medullary Angle in between the Pre fracture fixation bone fragments (TMA)(sagittal view).



Fig 3: E) 3D Prototype bone model



Fig 3: F) Selection of Bone plate



Fig 3: G) Measuring the implant size on the Contralateral bone (10 hole Titanium LC-DCP)



Fig 3: H) Contouring the bone plate according to the axis of the 3D bone model



Fig 3: I) measuring the screw size



Fig 3: J) Selection of screws (mm) with the help of 3D bone model.



Fig 4: A) Preparation of the surgical patient



Fig 4: B) Fixing of assessed bone implant (10 hole Titanium LC DCP and 14mm Locking screw) to the bone



Fig 4: C) Distal Segment Length (DSL)

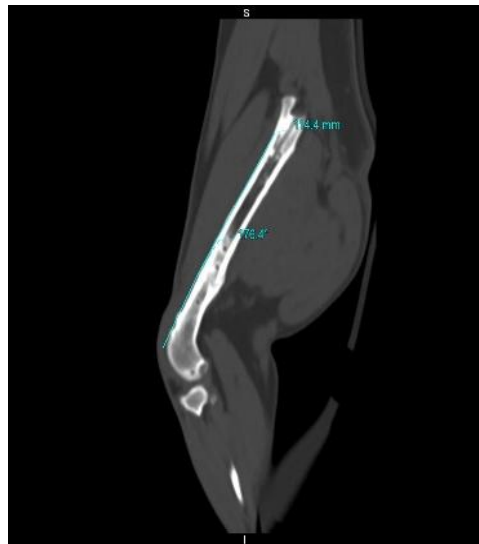


Fig 4: D) Cranial Angle (CA)(sagittal view) of the post-operative fragment with callus

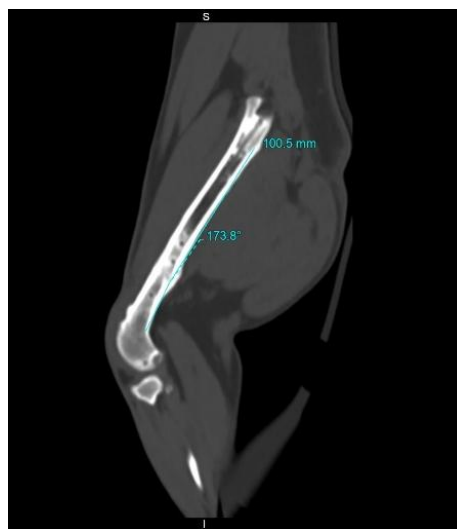


Fig 4: E) Caudal angle (CA)(sagittal view) of the post-operative fragment with callus



Fig 4: F) Medial angle (MA) of the post-operative fragment with callus (coronal view).

Conclusion

Application of CT over the preoperative assessment of implant size that is required for the fracture fixation of long bone fractures in dogs and also measuring the angle between the fractured and healed bone fragments will illustrate the advantages of the CT and the 3D printed prototype models

and its uses in the field of orthopaedic surgery. Proper implant selection and precised surgical planning was done with the help of CT and biofabricated bone models , indicating the importance of 3D bone models and CT in small animal orthopaedic surgery.

Conflict of Interest

Authors declare no conflict of interest

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