

Pelvic Fracture in a Cat - Precontouring of the Plate Based on Allogenic 3D Model and its Application

Kihoon Kim^{1,2}, Jaeho Shin³, Jaehwan Kim⁴ & Hwi-Yool Kim¹

ABSTRACT

Background: Pelvic fractures are commonly encountered in cats. The ilium is included in approximately 50% of pelvic fractures in cats. Although conservative management of the pelvic fracture is known to have good prognosis, surgical fixation is recommended for the pelvic fracture with ilial fractures. 3D printing is an accurate digital modeling method by converting two-dimensional (2D) images into 3D model. 3D printing in veterinary medicine has been described in the various orthopedic diseases such as angular limb deformities or fractures. The use of 3D model for presurgical planning is helpful to improve the results of complex surgical interventions. The objective of this study is to identify the usefulness of fabricating 3D models based on allogenic 2D data with aid of 3D printer program.

Case: A 4-year-old spayed female domestic shorthair cat presented with hindlimb lameness. Radiography revealed left ilial body fracture with multiple fractures including left tuber ischium, pubic symphysis, and bilateral cranial ramuses of pubis. Digital imaging and communication in medicine (DICOM) files of the complete ilium were extracted from a computed tomography (CT) scan of a healthy and castrated male cat of same breed. Volume rendering images were prepared by Slicer program based on DICOM files. After acquired 3D data were converted to STL (Standard Triangulation Language) file for the 3D printing machine, non-fracture involved area was removed except the left ilium using the Meshmixer® software and then data was stored as STL files again. The length of 3D model was adjusted to actual size using 3D printer firmware based on actual size of the ilial length. Subsequently, 3D modelling was performed using 3D printer. The plate was precontoured to conform to the lateral surface of the 3D model. Internal fixation using precontoured plate resulted in accurate bone alignment. The alignment of the ilium remained appropriate throughout the follow-up period. Complete union was identified 6 months after surgery.

Discussion: Although the most common method for the ilial fractures is the application of bone plates to the lateral side of the ilium, bone plate fixation is more challenging in cats owing to the small bone size and small surface area of the fracture sites compared to dogs. Therefore, it is important to make accurate presurgical planning for successful result of a surgery. 3D printing based on actual patient have several limitations including time for complete printing process and additional anesthetic episode to acquire CT images. However, in simple cases, a presurgical CT scan may not be necessary if the plate can be precisely precontoured based on the data from the other patient. In this way, the additional financial burden for CT examination also might be reduced. On the other hand, technical difficulty of utilizing hardware and software, and financial availability were another drawback. However, in this current study, most of limitations regarding conventional 3D printing based on actual patient were overcome by the application of the fused deposition modeling (FDM) technology with allogenic data. In the current study, total time for fabrication of 3D model based on FDM technology, was less than 3 h, which are much shorter than the time for conventional 3D printing. The difference of the ilial length between the actual patient and the 3D model was adjusted through the firmware program. Thus, differences of the conformation or size between the 3D model and the ilium of the patient was negligible during the surgery, although 2D images were not acquired from actual patient. Intraoperative contouring of the plate was not required. In conclusion, through presurgical plate contouring by the 3D bone template based on non-patient specific data, successful treatment of the ilial fracture was possible.

Keywords: allogenic, cats, ilial fracture, 3D printing.

DOI: 10.22456/1679-9216.124600

Received: 15 May 2022

Accepted: 30 July 2022

Published: 27 August 2022

¹Department of Veterinary Surgery & ⁴Department of Veterinary Imaging, College of Veterinary Medicine and Veterinary Teaching Hospital, Konkuk University, Seoul, South Korea. ²Department of Surgery, Dr. Dog Animal Medical Center (DAMC), Goyang, Gyeonggi-do, South Korea. ³Cheongna Gongam Animal Hospital, Incheon, South Korea. CORRESPONDENCE: H.-Y. Kim [hykim@konkuk.ac.kr]. Department of Veterinary Surgery, College of Veterinary Medicine and Veterinary Teaching Hospital, Konkuk University. 05029 Seoul, South Korea.

INTRODUCTION

Feline pelvic fractures are common fractures, accounting for 22-46% of feline fractures [5,6,9,13] and commonly caused by impact trauma [5]. The ilium is included in approximately 50% of pelvic fractures in cats and is commonly related to concurrent pelvic floor fractures, acetabulum, or contralateral sacroiliac luxation [1]. Conservative management of the pelvic fracture is known to have good prognosis [6]. However, surgical fixation is recommended for the pelvic fracture with ilial fractures. Because ilial body fractures with craniomedial displacement of the caudal fragment result in narrowing of the pelvic canal or lumbosacral plexus injury [6,9,13].

The 3D printing, also known as rapid prototyping, is an accurate digital modeling method creating a prototype through repetitive layered processing by converting two-dimensional (2D) image into 3D model [19]. The 3D printing in veterinary medicine have been described in the various orthopedic diseases such as angular limb deformities or fractures [3,4,7]. For the presurgical planning, 2D images for 3D modelling are acquired from mirrored computed tomography (CT) scans of the healthy contralateral bone [15,18]. The use of 3D model for presurgical planning is helpful to improve the results of complex surgical interventions [19]. However, time and cost required in fabrication of 3D models based on actual patient's information limits the wide application in veterinary medicine [18]. The aim of this study is to describe the usefulness of fabricating 3D models based on 2D images obtained from a healthy cat of same breed, but different sex and weight with aid of 3D printer program.

The use of 3D model for presurgical planning is helpful to improve the results of complex surgical interventions [19]. However, time and cost required in fabrication of 3D models based on actual patient's information limits the wide application in veterinary medicine [18]. The aim of this study is to describe the usefulness of fabricating 3D models based on 2D images obtained from a healthy cat of same breed, but different sex and weight with aid of 3D printer program.

CASE

A 4-year-old spayed female domestic shorthair cat weighing 2.5 kg presented with hindlimb lameness due to falling. Physical examination showed a weight-bearing lameness of left hindlimb. Complete blood

count revealed leukocytosis (26.23 K/uL; reference range [RR]: 2.87-17.02 K/uL). In serum biochemical analysis, increased alanine transaminase (295 U/L, RR: 12-130 U/L) was identified as well. Radiographic examination revealed left ilial body fracture with multiple fractures including the left tuber ischium, the left cranial ramus of the pubis and the pubic symphysis (Figure 1A). The length of the ilium from iliac crest to the ischiatic tuberosity was 7.36 cm (Figure 1B).

Volume-Rendering image (VR) acquisition from DICOM file

Digital imaging and communication in medicine (DICOM) files of the complete ilium were extracted from a CT scan (Figure 2A) of a healthy and castrated male cat of same breed, weighing 4.7 kg. VR images were created by Slicer¹ using DICOM files (Figure 2B).

Thresholding and segmentation

Isolation of the pelvic structures based on their specific density was performed by designating Hounsfield Unit (HU) from 500 to 3000 using threshold effect of Slicer (thresholding). Subsequently, the removal of any undesired or nonanatomic information was performed (segmentation).

Conversion of the data from volumetric to a 3D triangular mesh

Acquired 3D data were converted to STL (Standard Triangulation Language) file that can be used by the 3D printing machine. After this, using smoothing tool² (Meshmixer[®]), non-fracture involved area was eliminated except the left ilium (Figure 2C) and then data was stored as STL files again.

Printing 3D model and postprocessing

The length of 3D model was adjusted to actual size using 3D printer firmware. Subsequently, 3D model (Figure 3A) was fabricated by 3D printer³ (Flux delta[®]). The plate was contoured to conform to the lateral surface of the 3D model. Both of 3D model and the precontoured bone plate underwent gas plasma sterilization and were used during surgery to aid in gross planning (Figure 3B).

Anesthesia and premedication

After intravenous premedication with butorphanol⁴ [Butopahn[®] - 0.5 mg/kg] and ampicillin-sulbactam⁵ [Ubacilin[®] - 20 mg/kg], alfaxalone⁶ [4 mg/kg] was injected for induction. Subsequently, inhala-

tion anesthesia was maintained by administration of isoflurane⁷. Intraoperatively, the cat was given normal saline⁷ at a constant infusion rate of 5 mL/kg/h.

Surgery

Positioned in lateral oblique recumbency with the left ilium uppermost and tilted toward the surgeon, a dorsolateral approach to the ilium was made rolling down the gluteal muscle from the lateral surface of the ilium [10]. The fracture fragments were identified and reduced temporarily. After fixation of the precontoured bone plate to the cranial fragment of the ilium, permanent stabilization was performed by fixation of the plate to the caudal fragment of ilium. Additional contouring of the plate was not required during the surgery. Closure of subcutaneous tissue and skin was performed in a routine manner. The recovery from anesthesia was uneventful. Postoperative radiographic image revealed accurate reduction of the ilium (Figure 4A). The patient discharged 7 days after surgery.

At the time of discharge, the patient no longer exhibited hindlimb lameness. Re-examination after 4 weeks, left hindlimb conformation appeared normal, and orthopedic examination of that limb was normal. Radiographs revealed only very slight mineralized callus and bone resorption at the fracture site but no evidence of implant failure or malalignment of the ilium (Figure 4B). On the owner's report, the patient revealed no signs of discomfort. After 8 weeks, progressive bridging of the fracture site with mineralized callus formation was identified and the pelvic alignment was appropriate (Figure 4C). 6 months after surgery, the complete union of the affected ilium was identified without any complication such as screw loosening or narrowing of the pelvic canal which can be observed in long-term follow-up in association with ilial fracture surgery (Figure 4D) [5].

DISCUSSION

Various fixation techniques have been reported in the veterinary literature for the internal fixation of ilial fractures using bone plate, lag screw, external fixation device, and pin [2]. Acetabular fracture with concurrent segmental ilial body fractures managed with the use of precontoured reconstruction plates has been also reported. The most commonly applied method for the ilial fractures is the application of bone plates to the lateral surface of the ilium [5]. However, in cats, bone plate fixation is more challenging owing to the small bone size and small surface area of the fracture sites compared to dogs [17] both were diagnosed with fractures of the ramus. The CT scans were used to print three-dimensional (3D). Screw loosening associated with lateral plating to the ilial fractures have been also reported [5]. Thus, it is important to make precise presurgical planning for successful outcome of a surgery [14].

In veterinary medicine, 3D printing have been used widely for presurgical planning of various surgeries including oral and maxillofacial surgery [18], mandibular surgery [17], angular deformity surgery [3],

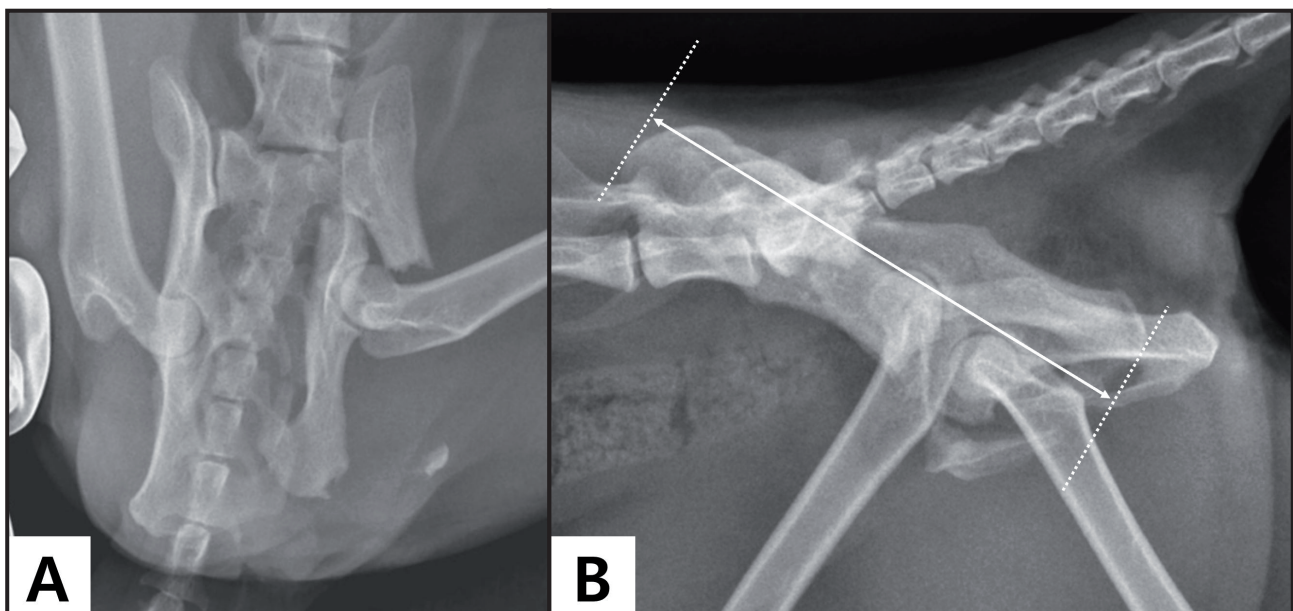


Figure 1. A- Multiple fractures including the ilial body, left tuber ischium, left cranial ramus of pubis and pubic symphysis. B- The length of the ilium from iliac crest to the ischiatic tuberosity was obtained from contralateral healthy ilium.

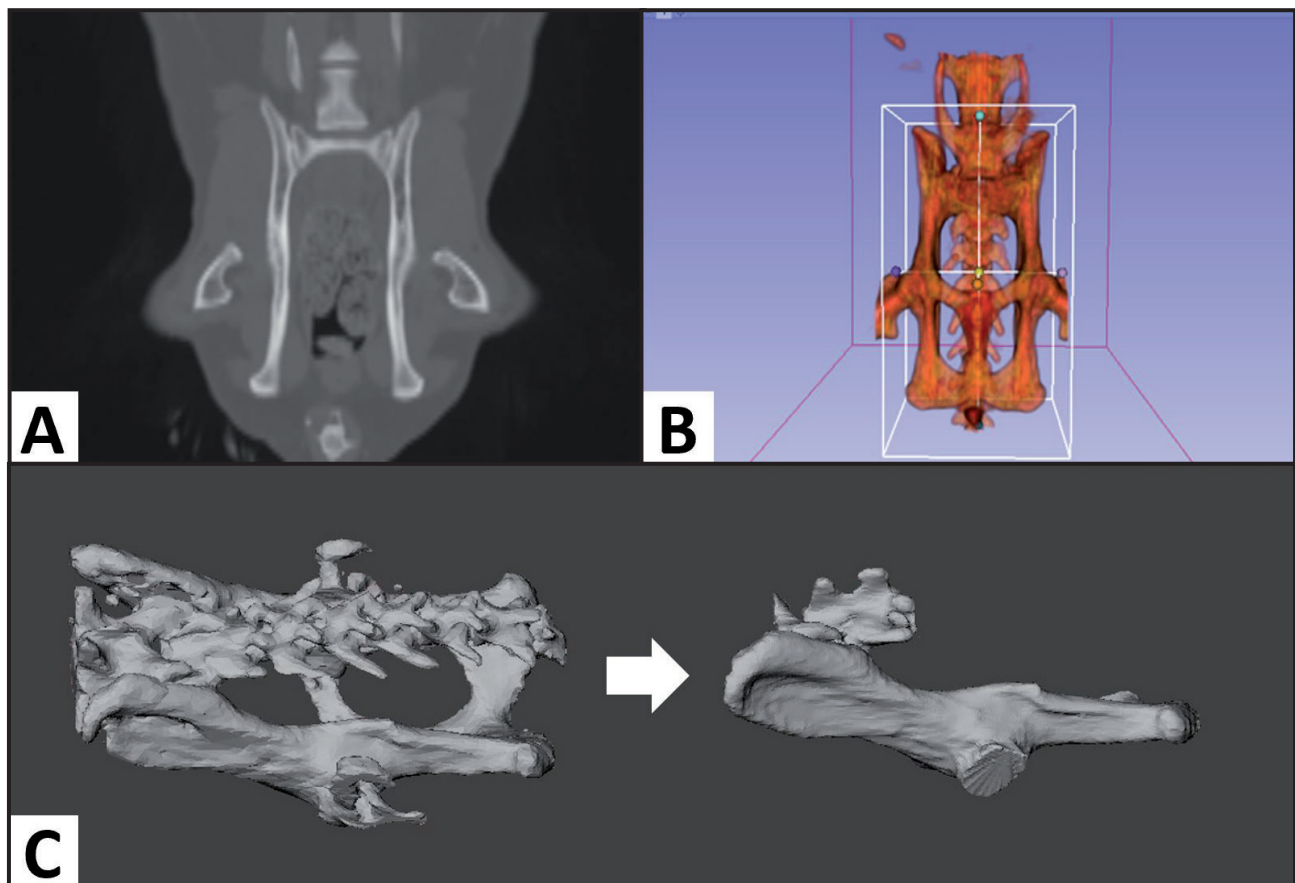


Figure 2. A- A CT images acquired from a cat of same breed but different sex and weight. B- Volume-rendering image obtained from DICOM files. C- Left hemipelvis acquired using the Meshmixer® software.

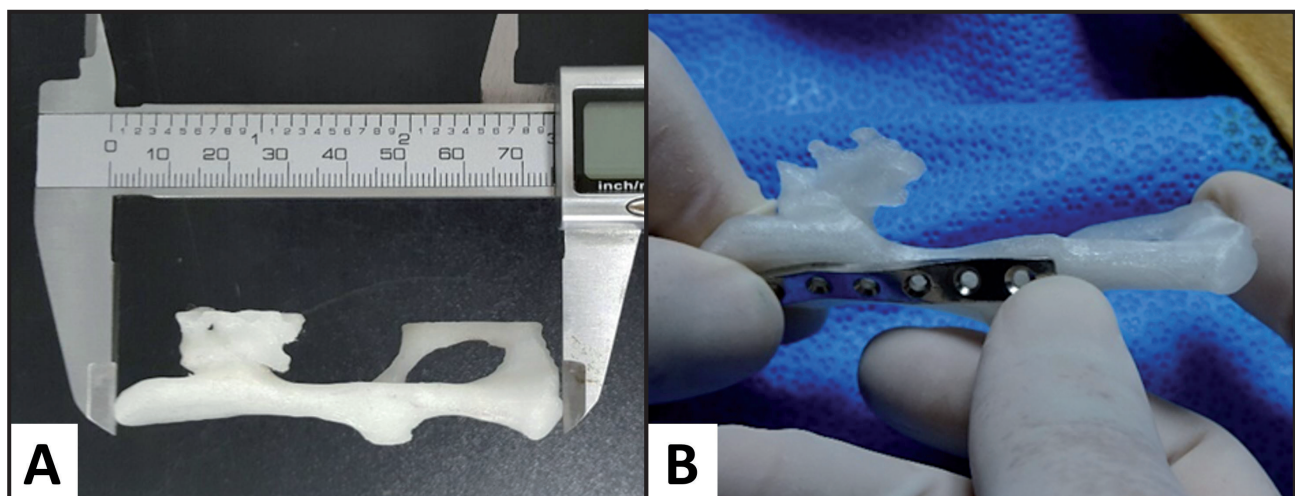


Figure 3. A- The length of the 3D model was 7.5 cm same as the actual length. B- Intraoperative utilization of the precontoured plate and the 3D model.

or humeral surgery [15]. 3D printing have improved the diagnosis and treatment of disease dramatically by allowing better and more precise presurgical planning. The 3D printing also decreased the actual operation time and the rate of potential postoperative compliations [8].

However, conventional 3D printing based on actual patient have several limitations. Depending on the size of the bone, it typically takes almost 18 to

24 h (i.e. overnight) to complete the printing process [18]. This delay implies the patient should undergo at least 2 anesthetic episodes, to acquire CT images, and to perform surgery. In complicated cases, the need for 2 separate anesthetic process might be helpful for accurate diagnosis and presurgical planning [18]. However, in simple cases, a presurgical CT scan may not be required if accurate precontouring of the plate

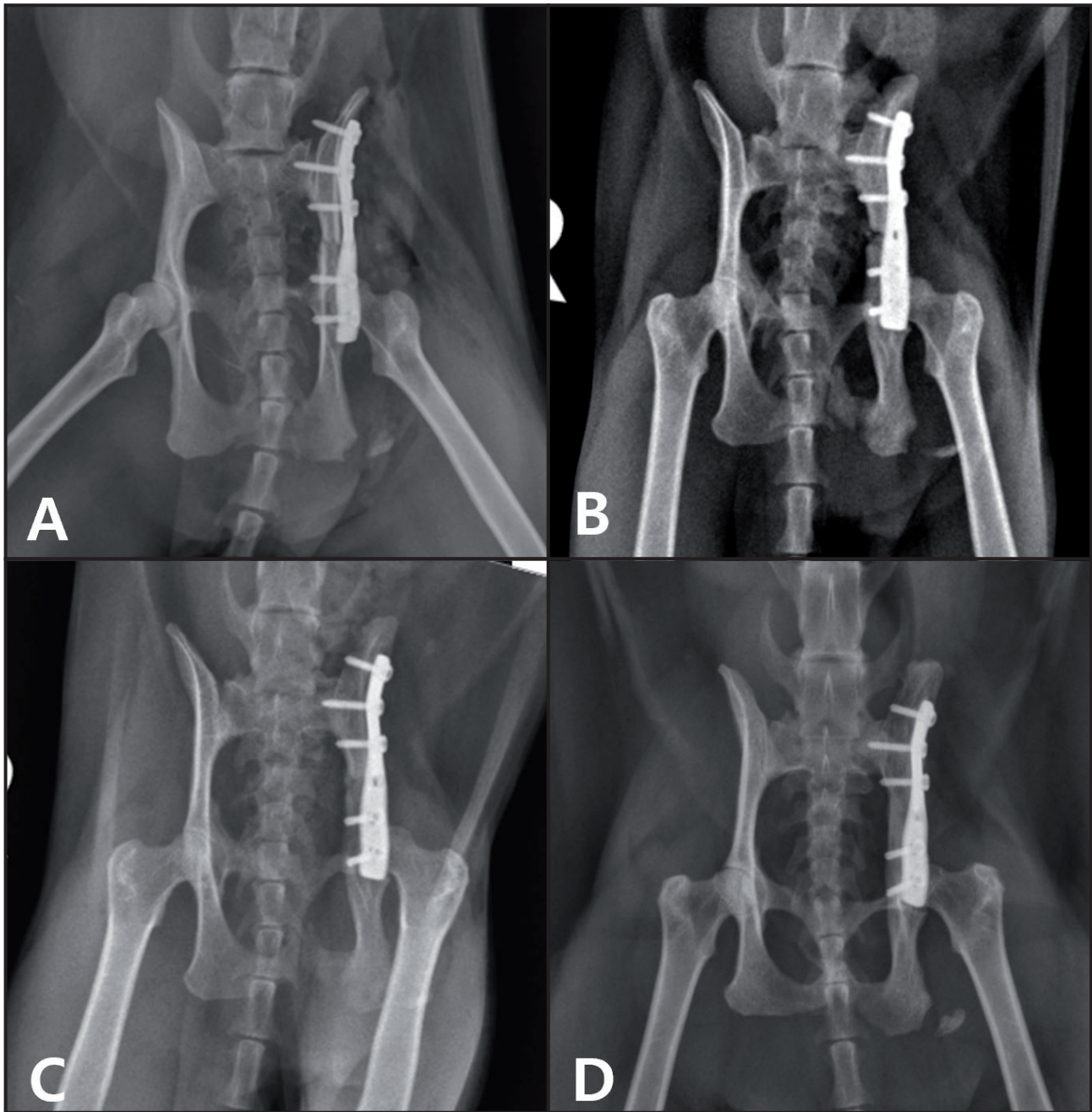


Figure 4. A- Postoperative radiographic image showing good alignment of the ilium. B- Radiograph taken 1 month after surgery showing slight mineralized callus formation. C- Radiograph taken 2 month after surgery showing advanced union. D- Radiograph taken 6 months after surgery showing complete bone union. The alignment of the ilium remained appropriate throughout the follow-up period.

is possible based on the data from the other patient. The additional cost for CT examination also might be financial burden for the client. Moreover, technical difficulty of utilizing hardware and software, and financial availability were another drawback [14]. However, in this current study, most of limitations concerning conventional 3D printing based on actual patient were overcome by the application of the fused deposition modeling (FDM) technology with the data from other patient of same breed.

The majority of commercial desktop printers are currently of the FDM type, which are affordable, and are relatively easy to use and provide excellent resolution. The 3D printers using FDM technology extrude a polymer filament through an extrusion nozzle that dissolves the polymer and controls the flow of material to fabricate a fine plastic structure [12]. The raw material includes polylactic acid (PLA) or acrylonitrile butadiene styrene or other thermoplastics. Fine lines of heated raw material are deposited successively in

numerous thin layers corresponding to a predetermined path for the object.

In the study reported here, total time required for fabrication of 3D model through 3D printer based on FDM technology, was less than 3 h, which are much shorter than the time required for conventional 3D printing. Every program used for 3D printing including 3D slicer® and Meshmixer® is open-source, which is released for free. Thus, excluding the investment of purchasing the printer, the total cost for manufacturing 3D model was less than 3 US dollars.

It is known that cats have less anatomical variance. According to the previous studies regarding sexual dimorphism of wild cats, negligible difference in the length of the ilium between male and female group has been reported [11,16]. Furthermore, in the current study, the difference of the ilial length between the actual patient and the 3D model was adjusted through the firmware program before 3D printing. Thus, differences of the conformation or size between the 3D model and the ilium of the patient was not identified during the surgery, although 2D images were not acquired from the patient. Additional intraoperative contouring of the plate was not required. Moreover, because the raw material used for 3D printing was PLA which can be sterilized, it was possible to utilize the 3D model as a guide before lateral plating of the real ilium during surgery. These factors reduced actual operation time. In addition to saving time, fabrication of 3D model base on non-patient specific data has advantage of reducing the anesthetic risk of the patient

and the financial burden for the client by reducing the number of CT scan to one.

The limitation of this study is that, although the software programs used for fabrication of 3D model in the current study were all open-source and relatively easy to manipulate compared to commercial programs, sufficient experience with, and access to, both of software and hardware is still required. Moreover, as a pilot study, only 1 case was included in this study. Thus, additional cases are required to further generalize effectiveness of the allogenic 3D model in actual patient.

In conclusion, through presurgical plate contouring by the 3D bone template based on non-patient specific data, successful treatment of the ilial fracture was possible. Simultaneously, the actual operation time, the anesthetic risk of the patient and the financial burden of the client were significantly decreased.

MANUFACTURERS

¹National Institutes of Health - NIH. Boston, MA, USA.

²Autodesk Inc. San Rafael, CA, USA.

³Flux Incorporation. Taipei, Taiwan.

⁴Myungmoon Pharmaceutical Co. Ltd. Seoul, South Korea.

⁵Whanin Pharmaceutical Co. Ltd. Seoul, South Korea.

⁶Jurox Pty Ltd. Rutherford, Australia.

⁷Choongwae Pharmaceutical Corporation. Seoul, South Korea.

Ethical approval. Since the surgery was performed in the local hospital, informed consent has been obtained from the owner instead of ethical approval from the institution.

Declaration of interest. The author reports no conflicts of interest. The authors are responsible for the content and writing of paper

REFERENCES

- 1 Bookbinder P.F. & Flanders J.A. 1992. Characteristics of Pelvic Fracture in the Cat. *Veterinary and Comparative Orthopaedics and Traumatology*. 05(3): 122-127.
- 2 Burton N.J. 2011. Composite fixation of comminuted ilial wing fractures in cats: Three cases. *Journal of Feline Medicine and Surgery*. 13(5): 376-382.
- 3 Crosse K.R. & Worth A.J. 2010. Computer-assisted surgical correction of an antebrachial deformity in a dog. *Veterinary and Comparative Orthopaedics and Traumatology*. 23(5): 354-361.
- 4 Dismukes D.I., Fox D.B., Tomlinson J.L. & Essman S.C. 2008. Use of radiographic measures and three-dimensional computed tomographic imaging in surgical correction of an antebrachial deformity in a dog. *Journal of the American Veterinary Medical Association*. 232(1): 68-73.
- 5 Hamilton M.H., Evans D.A. & Langley-Hobbs S.J. 2009. Feline ilial fractures: Assessment of screw loosening and pelvic canal narrowing after lateral plating. *Veterinary Surgery*. 38(3): 326-333.
- 6 Harasen G. 2007. Pelvic fractures. *Canadian Veterinary Journal*. 48(4): 427-428.
- 7 Harrysson O.L.A., Cormier D.R., Marcellin-Little D.F. & Fajal K. 2003. Rapid prototyping for treatment of canine limb deformities. *Rapid Prototyping Journal*. 9(1): 37-42.

- 8 Hespel A.M., Wilhite R. & Hudson J. 2014. Invited review-applications for 3D printers in veterinary medicine. *Veterinary Radiology and Ultrasound*. 55(4): 347-358.
- 9 Krebs R.C., Roe S.C., Lascelles B.D.X., Marcellin-Little D.J., Trumpatori B.J. & Spodnick G. 2014. Biomechanical Evaluation of the Influence of an Intramedullary Pin on the Stability of a Feline Iliac Fracture Model Stabilized With a Bone Plate. *Veterinary Surgery*. 43(2): 114-119.
- 10 Langley-Hobbs S.J., Meeson R.L., Hamilton M.H., Radke H. & Lee K. 2009. Feline iliac fractures: A prospective study of dorsal plating and comparison with lateral plating. *Veterinary Surgery*. 38(3): 334-342.
- 11 Latimer H. 1936. Weights and linear measurements of the adult cat. *The American Journal of Anatomy*. 58(2): 329-347.
- 12 Marro A., Bandukwala T. & Mak W. 2016. Three-Dimensional Printing and Medical Imaging: A Review of the Methods and Applications. *Current Problems in Diagnostic Radiology*. 45(1): 2-9.
- 13 Meeson R.L. & Geddes A.T. 2017. Management and long-term outcome of pelvic fractures: a retrospective study of 43 cats. *Journal of Feline Medicine and Surgery*. 19(1): 36-41.
- 14 Oh W. 2014. Customized Model Manufacturing for Patients with Pelvic Fracture using FDM 3D Printer. *Journal of the Korea Contents Association*. 14(11): 370-377.
- 15 Oxley B. 2018. A 3-dimensional-printed patient-specific guide system for minimally invasive plate osteosynthesis of a comminuted mid-diaphyseal humeral fracture in a cat. *Veterinary Surgery*. 47(3): 445-453.
- 16 Petrov I. 1992. Metric characteristics and sexual dimorphism of the postcranial skeleton of wild cat *Felis silvestris* in Bulgaria. *Acta Theriologica*. 37(4): 397-401.
- 17 Southerden P. & Barnes D.M. 2018. Caudal mandibular fracture repair using three-dimensional printing, presurgical plate contouring and a preformed template to aid anatomical fracture reduction. *Journal of Feline Medicine and Surgery Open Reports*. 4(2): 1-6.
- 18 Winer J.N., Verstraete F.J.M., Cissell D.D., Lucero S., Athanasiou K.A. & Arzi B. 2017. The application of 3-dimensional printing for preoperative planning in oral and maxillofacial surgery in dogs and cats. *Veterinary Surgery*. 46(7): 942-951.
- 19 Xu J., Li D., Ma R.F., Barden B. & Ding Y. 2015. Application of Rapid Prototyping Pelvic Model for Patients with DDH to Facilitate Arthroplasty Planning: A Pilot Study. *Journal of Arthroplasty*. 30(11): 1963-1970.