

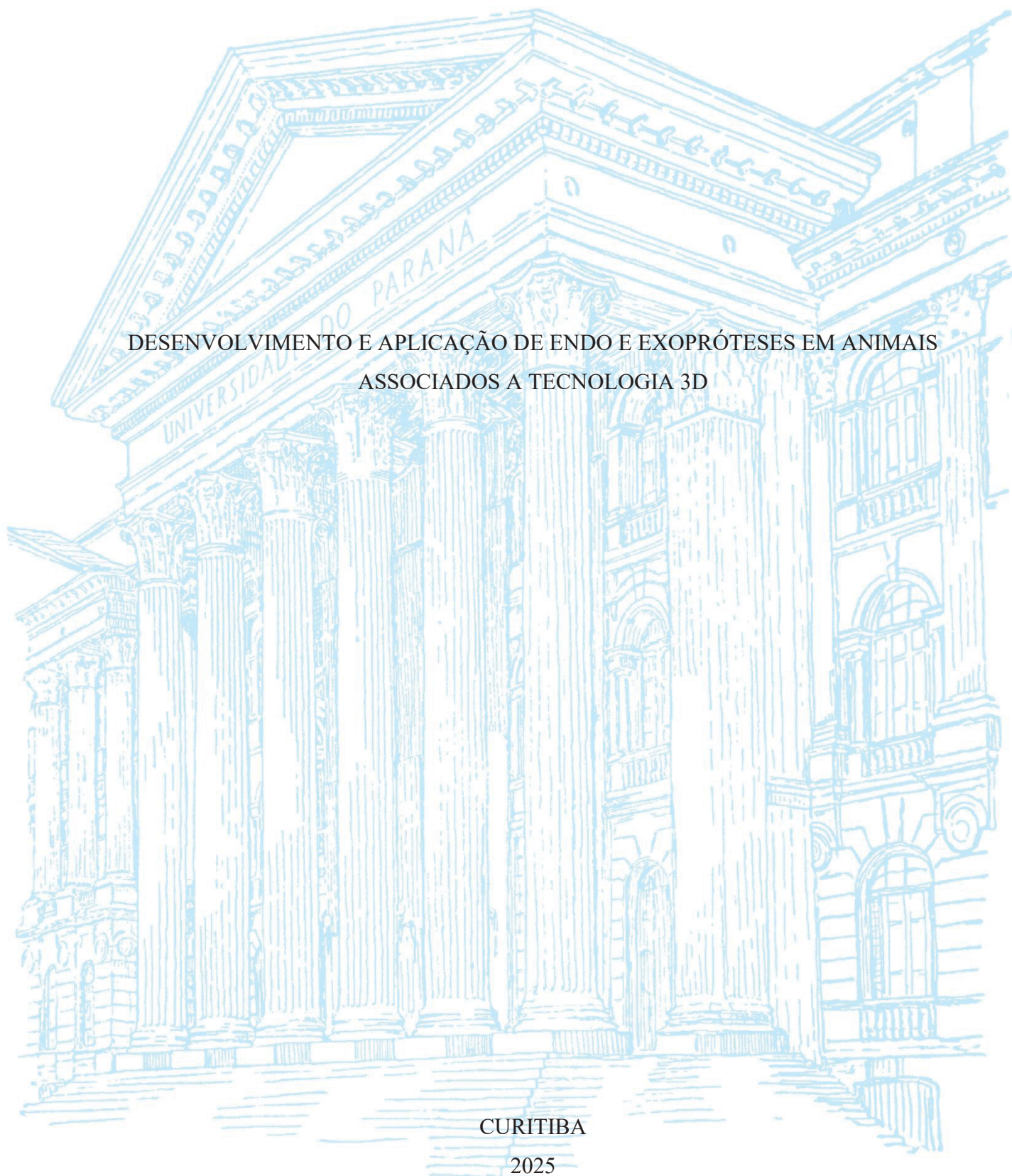
UNIVERSIDADE FEDERAL DE PARANÁ

ÍTALLO BARROS DE FREITAS

DESENVOLVIMENTO E APLICAÇÃO DE ENDO E EXOPRÓTESES EM ANIMAIS
ASSOCIADOS A TECNOLOGIA 3D

CURITIBA

2025



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Tese submetida ao Curso de Pós-Graduação em Ciências Veterinárias, Setor de Ciências Agrícolas, Universidade Federal do Paraná, como requisito parcial para obter o título de Doutor.

Orientador: Prof. Dr. Peterson Triches Dornbusch

CURITIBA

2025

DADOS INTERNACIONAIS DE CATALOGAÇÃO NA PUBLICAÇÃO (CIP)
UNIVERSIDADE FEDERAL DO PARANÁ
SISTEMA DE BIBLIOTECAS – BIBLIOTECA DE CIÊNCIAS AGRÁRIAS

Freitas, Ítallo Barros de

Desenvolvimento e aplicação de endo e exopróteses em animais associados a tecnologia 3D / Ítallo Barros de Freitas. – Curitiba, 2025.

1 recurso online: PDF.

Tese (Doutorado) – Universidade Federal do Paraná, Setor de Ciências Agrárias, Programa de Pós-Graduação em Ciências Veterinárias.

Orientador: Prof. Dr. Peterson Triches Dornbusch

1. Prótese. 2. Impressão tridimensional. 3. Ortopedia veterinária. I. Dornbusch, Peterson Triches. II. Universidade Federal do Paraná. Programa de Pós-Graduação em Ciências Veterinárias. III. Título.



MINISTÉRIO DA EDUCAÇÃO
SETOR DE CIÊNCIAS AGRÁRIAS
UNIVERSIDADE FEDERAL DO PARANÁ
PRÓ-REITORIA DE PÓS-GRADUAÇÃO
PROGRAMA DE PÓS-GRADUAÇÃO CIÊNCIAS
VETERINÁRIAS - 40001016023P3

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Os membros da Banca Examinadora designada pelo Colegiado do Programa de Pós-Graduação CIÊNCIAS VETERINÁRIAS da Universidade Federal do Paraná foram convocados para realizar a arguição da tese de Doutorado de **ITALLO BARROS DE FREITAS**, intitulada: **DESENVOLVIMENTO E APLICAÇÃO DE ENDO E EXOPRÓTESES EM ANIMAIS ASSOCIADOS A TECNOLOGIA 3D**, sob orientação do Prof. Dr. PETERSON TRICHES DORNBUSCH, que após terem inquirido o aluno e realizada a avaliação do trabalho, são de parecer pela sua APROVAÇÃO no rito de defesa.

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Assinatura Eletrônica

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21/10/2025 09:21:18.0

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*This work is dedicated to my
parents, Maria Agneide Barros de Freitas and
Marcos Antonio de Oliveira Barros.*

ACKNOWLEDGMENT

This work represents the fulfillment of a dream: to always strive to provide the best care for my patients. I am fully aware that I would never have reached this point alone, and I therefore extend my gratitude to all those who, in different ways, have inspired and supported me throughout this journey.

First and foremost, I thank **God**, the Author of Life, for granting me health, strength, and courage, which made it possible to bring this project to completion.

my parents, Marcos Antônio and Maria Agneide, who are my greatest role models in the school of life, for everything they have done to enable me to reach this stage. **To my wife, Adriana Marks**, my greatest source of encouragement throughout our life together and especially during the most challenging moments of this path. *I love you, “lovinho”*.

To my brother, Osmany, for his constant partnership and support.

To my friend, Milena Anfilo, for her daily support during difficult times and for taking responsibility at the clinic during my absences. You are incredible.

To my friends who have accompanied me in both academic and professional endeavors, my sincere thanks.

To my advisor, Professor Peterson Triches Dornbusch, for accepting this challenge and for the guidance that made this study possible.

To the esteemed members of the examination board, for graciously accepting the invitation and for the valuable insights that significantly enriched this work.

To the owners who believed in the purpose of this study—“saving paws”—and entrusted me with the care of their beloved companions.

To the company Bionostic[®] for performing patient CT scans, Engevet[®] Focus[®] and Cão Medica[®] for partnership in machined implant development, the Renato Archer Research Institute[®] and Cubobiomedical[®] for 3D-printed titanium implants, and 3Dlifelab[®], Bespokevet[®], Biofix3D[®], Crysthian Callegaro and Francisco Liebl for assistance in exoprosthesis development.

And finally, to **the animals**: my greatest source of inspiration and dedication. To all those who have been under my care, those who are with me now, and those who will come in the future, I extend my heartfelt gratitude. My commitment is to become better every day in order to care for you with all my heart and dedication.

Thank you so much!

*Our greatest weakness lies in giving up.
The surest way to succeed is to try one more time.*
— *Thomas Edison*

RESUMO

Com os avanços da tecnologia 3D na medicina veterinária, o uso de endoexoprótese tem se tornado uma importante alternativa na melhoria da qualidade de vida de pacientes amputados parcialmente. A amputação ainda possui algumas indicações, mas deve ser realizada somente quando todas as opções de tratamento já tiverem sido praticadas. A possibilidade de usar próteses em animais tem despertado o interesse dos tutores e médicos veterinários para promover qualidade de vida, por proporcionar correta distribuição de carga nos quatro membros e reduzir consequências de sobrecarga nos membros não amputados. Este trabalho relatou o processo de desenvolvimento e aplicação de endoexopróteses em seis gatos e cinco cães, desde a seleção dos pacientes até a recuperação pós-operatória. Foram realizadas tomografia ou radiografia em todos os pacientes para planejamento pré-operatório em softwares específicos. Na fase do planejamento cirúrgico foram feitas mensurações de tamanho, avaliação da morfologia do membro afetado e do antímero oposto para definição do melhor design, projetar a endoexoprótese e posterior fabricação. Os implantes foram usinados ou impressos em titânio 3D por *Selective Laser Melting* (SLM). As exopróteses foram impressas em Poliuretano Termoplastico (TPU) e implantadas nos pacientes. Ainda serão necessários estudos futuros para aperfeiçoar a técnica e minimizar as complicações pós-operatórias. A diversidade entre espécies e raças é um grande desafio para o sucesso dos casos. Os resultados do nosso estudo foram promissores e indicam que é possível utilizar as endoexopróteses na rotina veterinária. Onde 90% dos pacientes se beneficiaram com a implantação desta técnica, com apoio total do membro, retorno à função e satisfação dos responsáveis.

Palavras-chave: impressão 3D; implantes customizados; limb-sparing; ortopedia; osteointegração.

ABSTRACT

With advances in 3D technology in veterinary medicine, the use of endo-exoprostheses has emerged as an important alternative to improve the quality of life of partially amputated patients. Although amputation still has specific indications, it should only be performed when all other treatment options have been exhausted. The possibility of using prostheses in animals has attracted the interest of both owners and veterinarians, as it promotes quality of life by providing support on all four limbs and reducing the consequences of overload on non-amputated limbs. This study reports the development and application of endo-exoprostheses in six cats and five dogs, from patient selection to postoperative recovery. Computed tomography or radiography was performed in all patients for preoperative planning using dedicated software. During the surgical planning phase, limb measurements, morphological assessment, and implant design were carried out to optimize the endo-exoprosthesis before fabrication. The implants were either machined or 3D-printed in titanium using Selective Laser Melting (SLM), while the exoprostheses were printed in Thermoplastic Polyurethane (TPU) and subsequently implanted. Further studies are required to refine the technique and minimize postoperative complications. Species and breed diversity remain major challenges for clinical success. The results of this study were promising and demonstrate that endo-exoprostheses can be integrated into routine veterinary practice. Overall, 90% of patients benefited from the technique, achieving full limb support, return to normal activity, and high owner satisfaction.

Keywords: 3D printing; customized implants; limb-sparing; orthopedics; osseointegration

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INTRODUCTION

Veterinary orthopedic practice is constantly challenged by cases such as comminuted long bone fractures, bone neoplasms, malformations, in cases where bone repair is compromised, and iatrogenic injuries. Unfortunately, it is common for animals with fractures to receive inadequate treatment, and in many cases, amputation is performed even when several surgical alternatives are available (Mendonça & Fernandes, 2019). Advances in fracture management and soft tissue reconstruction have reduced the frequency of amputations; however, they remain necessary in certain circumstances, such as severe trauma with extensive skeletal muscle loss, necrosis, ischemia, intractable orthopedic infections, neoplasia, vascular disease, and arteriovenous fistulas (Drygas et al., 2008). Even when amputation is indicated, factors such as adaptability, potential future orthopedic complications, and the owner's acceptance of a disabled animal must be considered (Gorshkov et al., 2017; O'Neill et al., 2023). In general, amputated animals adapt and relearn to ambulate and survive; however, this adaptation is merely functional and does not necessarily reflect quality of life. In the long term, ligamentous, tendinous, and osseous disorders may arise in the remaining limbs due to overload. Therefore, amputation should not be considered a surgical alternative when there is still potential for limb salvage (Faria & Rocha, 2022).

The study of prosthetic applications in veterinary medicine is still in its early stages, but advances in surgical procedures and prosthetic design and manufacturing technologies show promise in developing devices capable of restoring near-normal limb function (Arauz et al., 2021). Many clinicians and researchers are exploring customized manufacturing approaches such as additive manufacturing, commonly known as 3D printing (Sarpong et al., 2025). Three-dimensional printed models have advanced in detail and applicability and are now widely used for complex surgical planning and training, medical education and research, tissue engineering, bone segment replacement, among other applications (Thomas et al., 2025).

With this prosthetic technology, patients may benefit from partial amputations and the application of endo-exoprostheses, enabling rehabilitation and functional use of compromised limbs, including those affected by iatrogenic injury (Mendonça & Fernandes, 2019). Animals tend to adapt more readily than humans to prostheses, which is favorable given that amputated animals often experience reduced mobility, increased predisposition to obesity, greater metabolic demand, articular disorders in both ipsilateral and contralateral limbs, and chronic pain due to joint overload within a newly redistributed biomechanical system (Kirpensteijn et al., 2000; Mendonça et al., 2023). Successful surgical outcomes with endo-exoprostheses provide improved quality of life for amputee patients by allowing proper weight distribution

and restoration of species-specific behaviors (Fitzpatrick et al., 2011; Gorshkov et al., 2017; Wagner et al., 2022).

Based on the above, this thesis consists of three chapters: Chapter 1 - *Bilateral Femoral Intraosseous Transcutaneous Amputation Prosthesis (ITAP) in a Cat*, published in the journal *Acta Scientiae Veterinarie*; Chapter 2 –*Intraosseous Transcutaneous Amputation Prosthesis (ITAPs) and External-Fixation Amputee Prosthesis for limb salvage in 6 cats*; Chapter 3 - *Custom-made Endoexoprostheses for limb salvage in 5 dogs*. Chapters 2 and 3 will be formatted and published in an international journal to be defined.

The aim of this study was to design and implant customized transcutaneous prostheses in six cats and five dogs, using 3D modeling and printing technologies, and to monitor the clinical outcomes of these patients while seeking solutions to problems previously reported in the literature regarding limb-sparing surgeries.

REFERENCES

- ARAUZ, P.G. et al. New technologies applied to canine limb prostheses: A review. **Veterinary World**, v. 14, n. 10, p. 2793, 2021. Doi: [10.14202/vetworld.2021.2793-2802](https://doi.org/10.14202/vetworld.2021.2793-2802).
- DRYGAS, K.A. et al. Transcutaneous tibial implants: a surgical procedure for restoring ambulation after amputation of the distal aspect of the tibia in a dog. **Veterinary Surgery**, v. 37, n. 4, p. 322-327, 2008.
- FARIA, L. G.& ROCHA, T.A.S.S. **Orthoses and Prostheses**. In: Minto, B. W. & Dias, L. G. G. G. (Eds). *Tratado de ortopedia de cães e gatos*. São Paulo: Medvet. 2022. pp 464-481.
- FITZPATRICK, N. et al. "Intraosseous transcutaneous amputation prosthesis (ITAP) for limb salvage in 4 dogs." **Veterinary surgery** 40.8 (2011): 909-925.
- GORSHKOV S.S. et al. Percutaneous osseointegrated prosthetics of limbs in dogs and cats after partial amputation based on a series of clinical cases. **VetPharma**, No. 4 (38), 2017, pp. 58-73.
- MENDONÇA, A. G. C. et al. Fixed bilateral endo-exo prostheses in feline femur-case report. **Arquivo Brasileiro de Medicina Veterinária e Zootecnia**, v. 75, n. 01, p. 107-112, 2023.
- MENDONÇA, A.; FERNANDES, T.H.T. Exoprótese fixa em rádio de cão: relato de caso. **Nosso clínico**, p. 12-16, 2019.
- O'NEILL, D. G. et al. Dog breeds and conformations predisposed to osteosarcoma in the UK: a VetCompass study. **Canine Medicine and Genetics**, 10(1), 8, 2023.

SARPONG, J. et al. 3D-Printed Prosthetic Solutions for Dogs: Integrating Computational Design and Additive Manufacturing. **Designs**, v. 9, n. 5, p. 107, 2025.

THOMAS, C. et al. Orthopedic applications of 3D printing in canine veterinary medicine. **Frontiers in Veterinary Science**, 12, 1582720, 2025.

WAGNER J.R. et al. Complications and owner satisfaction associated with limb amputation in cats: 59 cases (2007-2017). **BMC Vet Res.** 2022;18(1):147. doi:10.1186/s12917-022-03246-z

CHAPTER 1

Bilateral Femoral Intraosseous Transcutaneous Amputation Prosthesis (ITAP) in a Cat



Acta Scientiae Veterinariae, 2025, 53(Suppl 1): 0000.

CASE REPORT
Pub. 0000

ISSN 1679-9216

Bilateral Femoral Intraosseous Transcutaneous Amputation Prosthesis (ITAP) In a Cat

Itallo Barros de Freitas¹, Gilberto Serighelli Júnior¹, Adriana Marks², Milena Hauer Anfilo²,
Danielle Buch², Vanessa Wotkoski Benoni², Jéssica Gonçalves Clock² & Peterson Triches Dornbusch²

ABSTRACT

Background: Intraosseous transcutaneous amputation prosthesis (ITAP) is a limb-salvage technique that involves anchoring an implant to the bone, enabling external prosthetic attachment via osseointegration. This approach offers an alternative to traditional amputation by preserving skeletal support and functional integration. Despite its increasing use in human medicine, ITAPs have been scarcely studied in veterinary practice, and no standardized guidelines exist for implant selection, considering the anatomical variability among species and breeds. This case report describes the successful application of ITAP in a cat following severe complications from bilateral femoral osteosynthesis, with a 27-month follow-up.

Case: A 1-year-old male cat, missing for 54 days, returned home with bilateral Salter-Harris type I femoral fractures. The patient underwent multiple unsuccessful surgical attempts, leading to complications such as contamination, bacterial resistance, Rush pin migration, plate exposure, osteomyelitis, and the need for muscle and skin flap reconstruction. Given the failure of all limb-preserving options, ITAP placement in the bilateral femoral diaphysis was proposed as an alternative to total limb amputation, aiming to restore independence and mobility. Preoperative planning involved computed tomography (CT) imaging, with Radiant[®] software used for image segmentation, bone viability assessment, and osteotomy height determination. A custom-designed titanium intramedullary implant was developed using CAD software. The surgical procedure was uneventful, and the patient was hospitalized for 3 days for postoperative monitoring. Fifteen days postoperatively, skin dehiscence and implant exposure were observed in the left femur. A revision surgery was performed, including implant coverage, bacterial culture, copious Betadine[®] lavage, and wound closure with 2-0 nylon sutures for the musculature and 3-0 for the skin. *Enterococcus faecium* was identified, and a 3-week course of compounded marbofloxacin was prescribed, leading to complete wound healing without further complications.

Discussion: The failure of prior fracture management necessitated the use of ITAP as an alternative to bilateral femoral amputation, ultimately resulting in excellent adaptation and quality of life. This case highlights the potential of osseointegrated implants in veterinary patients, demonstrating that ITAP can provide a durable and functional limb-salvage solution. The implant was designed with a fully intramedullary titanium structure to promote osseointegration, ensuring long-term biomechanical stability. A key feature was the inclusion of an anti-rotational locking pin to counteract rotational forces that could compromise implant integrity and prosthetic function. One of the major challenges in ITAP application is dermal integration, which is crucial to preventing ascending infection and soft tissue breakdown. Poor skin adherence to the implant can lead to complications such as infection, retraction, implant exposure, and mechanical failure, as reported in similar cases. The necessity for surgical revision in this patient underscores the importance of meticulous implant design and strict postoperative wound management. Long-term implant success also relies heavily on owner compliance, as proactive care and infection monitoring are essential to maintaining functionality and preventing complications. ITAP offers a functional alternative to total limb amputation by preserving biomechanics, restoring mobility, and improving quality of life. After 27 months, the patient showed no signs of implant failure or mobility impairment. Continued advancements in implant technology and surgical techniques will be essential to optimizing ITAP outcomes and expanding its application in veterinary medicine.

Keywords: Osseointegration, limb sparing, orthopedics, endo-exo prosthesis, surgery.

DOI: 10.22456/1679-9216.145883

Received: 21 February 2025

Accepted: 2025

Published: 2025

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De Freitas I.B., Júnior GS, Marks A, Hauer Anfilo M, Buch D, Wotkoski Benoni V, et al. Bilateral Femoral Intraosseous Transcutaneous Amputation Prosthesis (ITAP) in a Cat. Acta Scientiae Vet. [Internet]. 2025 Sep. 7 [cited 2025 Sep. 28];53. Available from: <https://seer.ufpr.br/index.php/ActaScientiaeVeterinariae/article/view/145883>

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Case: A one-year-old male cat, missing for 54 days, returned home with bilateral Salter-Harris type I femoral fractures. The patient underwent multiple unsuccessful surgical attempts, leading to complications such as contamination, bacterial resistance, Rush pin migration, plate exposure, osteomyelitis, and the need for muscle and skin flap reconstruction. Given the failure of all limb-preserving options, ITAP placement in the bilateral femoral diaphysis was proposed as an alternative to total limb amputation, aiming to restore independence and mobility. Preoperative planning involved computed tomography (CT) imaging, with Radiant[®] software used for image segmentation, bone viability assessment, and osteotomy height determination. A custom-designed titanium intramedullary implant was developed using CAD software. The surgical procedure was uneventful, and the patient was hospitalized for three days for postoperative monitoring. Fifteen days postoperatively, skin dehiscence and implant exposure were observed in the left femur. A revision surgery was performed, including implant coverage,

bacterial culture, copious Betadine® lavage, and wound closure with 2-0 nylon sutures for the musculature and 3-0 for the skin. *Enterococcus faecium* was identified, and a three-week course of compounded marbofloxacin was prescribed, leading to complete wound healing without further complications. **Discussion:** The failure of prior fracture management necessitated the use of ITAP as an alternative to bilateral femoral amputation, ultimately resulting in excellent adaptation and quality of life. This case highlights the potential of osseointegrated implants in veterinary patients, demonstrating that ITAP can provide a durable and functional limb-salvage solution. The implant was designed with a fully intramedullary titanium structure to promote osseointegration, ensuring long-term biomechanical stability. A key feature was the inclusion of an anti-rotational locking pin to counteract rotational forces that could compromise implant integrity and prosthetic function. One of the major challenges in ITAP application is dermal integration, which is crucial to preventing ascending infection and soft tissue breakdown. Poor skin adherence to the implant can lead to complications such as infection, retraction, implant exposure, and mechanical failure, as reported in similar cases. The necessity for surgical revision in this patient underscores the importance of meticulous implant design and strict postoperative wound management. Long-term implant success also relies heavily on owner compliance, as proactive care and infection monitoring are essential to maintaining functionality and preventing complications. ITAP offers a functional alternative to total limb amputation by preserving biomechanics, restoring mobility, and improving quality of life. After 27 months, the patient showed no signs of implant failure or mobility impairment. Continued advancements in implant technology and surgical techniques will be essential to optimizing ITAP outcomes and expanding its application in veterinary medicine.

Keywords: Osseointegration, limb sparing, orthopedics, endo-exo prosthesis, surgery

INTRODUCTION

Limb amputation is indicated in cases of irreparable trauma, necrosis, ischemia, bone neoplasia, and iatrogenic neurological injury [27]. While most animals adapt well to limb loss, long-term consequences may include reduced quality of life and compensatory overload on the remaining limbs, leading to joint, ligamentous, tendinous, and osseous disorders [21]. Therefore, amputation should only be considered when limb preservation is not a viable option [6,7,14].

The intraosseous transcutaneous amputation prosthesis (ITAP) is a technique that utilizes a bone-anchored implant traversing the dermis, allowing direct prosthetic attachment

through osseointegration [7]. This concept was inspired by the structure of deer antlers, where the skin integrates with a rigid bone structure without infection or marsupialization [4,7,22,23].

The first documented veterinary application of ITAP was reported in 2008 [4], involving bilateral intramedullary implantation in a canine tibia. Since then, this approach has been explored as an alternative to total limb amputation and limb-sparing procedures, with ongoing advancements aimed at expanding its applications and minimizing complications [7,9,25].

This study describes the successful use of ITAP to manage complications following bilateral femoral osteosynthesis in a one-year-old cat, with a 27-month follow-up, demonstrating its feasibility as a limb-preserving strategy.

CASE REPORT

A one-year-old, 3.6 kg, mixed-breed domestic cat was missing for 54 days before being found and taken for veterinary evaluation due to severe hind limb dysfunction. Physical examination revealed significant ambulatory impairment, and radiographic assessment confirmed chronic bilateral Salter-Harris type I fractures of the distal femur.

Multiple prior surgical attempts for fracture stabilization resulted in complications, including contamination, bacterial resistance, Rush pin migration, implant exposure, osteomyelitis, and the need for soft tissue reconstruction with a cranial tibial muscle flap followed by a caudal mesenteric artery axial pattern skin flap. Given the failure of conventional limb-preserving approaches, bilateral femoral ITAP placement was proposed as an alternative to total limb amputation. The owner consented to the procedure, prioritizing the cat's mobility and quality of life.

Preoperative planning was conducted using computed tomography (CT), with image segmentation, bone viability assessment, and osteotomy level determination performed in Radiant[®] medical imaging software¹ [RadiAnt DICOM Viewer, Medixant[®]] (Figure 1). The internal and external prosthetic components were designed using CAD software² [CAD Computer-Aided Design; Autodesk[®]].

The selected implant was a threaded intramedullary titanium device featuring a proximal hole for locking with a 1.5 mm Kirschner wire (Figure 2). The external prosthesis was 3D-printed using polyethylene terephthalate glycol³ [PETG, Filament 1.75mm, alfa-chemistry[®]]

The patient underwent an 8-hour preoperative fasting period. Premedication included methadone⁴ [Mytedom[®] - 0.3 mg/kg,] and acepromazine⁵ [Acepran[®] - 0.03 mg/kg] intramuscularly (IM). Anesthesia was induced with esketamine⁴ [Ketamin[®] - 0.5 mg/kg],

midazolam⁴ [Dormire[®] - 0.4 mg/kg], and propofol⁴ [Propovan[®] - 4 mg/kg] intravenously (IV). Maintenance was achieved with isoflurane⁴ [Isoforine[®] -1 mL/mL] in 100% oxygen, combined with epidural bupivacaine⁴ [Neocaína[®] 0,5%] and a continuous infusion of esketamine⁴ [Ketamin[®] - 0.6 mg/kg/h] and fentanyl⁴ [Fentanest[®] - 5 mcg/kg/h]. Intraoperative medications included ceftriaxone⁶ [Ceftriaxona[®] - 30 mg/kg], dipyron⁵ [Analgex[®] - 25 mg/kg], and meloxicam⁷ [Maxicam[®] - 0.05 mg/kg].

Following appropriate limb preparation, the patient was positioned in lateral recumbency, and the surgical site was aseptically prepared with 0.5% alcoholic chlorhexidine and draped with a sterile field.

A craniolateral approach to the femur was performed, with an elliptical skin incision followed by fascia lata dissection and retraction of the biceps femoris and vastus lateralis muscles. Osteotomy was conducted at the mid-diaphyseal region to prepare the implant bed.

After pre-drilling the femoral canal with a 3.5 mm drill bit, the implant was inserted retrogradely using a Jacobs Chuck until seated at the osteotomy site. A custom 3D-printed guide was used for precise Kirschner wire placement, and excess pin length was trimmed with side-cutting pliers. Muscular closure was performed using 2-0 polydioxanone (PDS) with interrupted and Sultan sutures, and dead space was minimized with 3-0 PDS. The skin was closed with 3-0 nylon sutures (Figure 3). The same procedure was repeated for the contralateral limb. Intraoperative and postoperative radiographs were obtained (Figure 4).

Postoperative treatment included cefovecin⁸ [Convenia[®] - 8 mg/kg, SC every 15 days for two doses], meloxicam⁷ [Maxicam[®] - 0.1 mg/kg, SID, 3 days], and tramadol hydrochloride⁵ [Cronidor[®] - 2 mg/kg, BID, 5 days]. The patient remained hospitalized for three days for surgical site monitoring. Within 24 hours, he showed good adaptation to the prostheses, and by one week, ambulated normally.

After 15 days, skin dehiscence, retraction, and partial implant exposure were observed in the left femur, requiring revision surgery. The implant was covered using copious Betadine lavage, bacterial culture, and layered wound closure with 2-0 nylon for muscle and 3-0 nylon for the skin. Culture and antibiogram identified *Enterococcus faecium*, and compounded marbofloxacin was administered for three weeks, resulting in complete wound healing with no further dehiscence or stump contamination.

At the time of this report, 27 months postoperatively, the patient exhibits no signs of pain, lameness, or orthopedic complications (Figure 5).

DISCUSSION

Partial limb amputation is a standard approach in human medicine to facilitate prosthetic use, whether external or osseointegrated. In veterinary medicine, limb amputation has historically been the primary treatment for various conditions [4,5,13,24,26]. However, advancements in surgical techniques and implant technology have enabled limb preservation in selected cases, mitigating the long-term biomechanical consequences of total amputation [4,7]. In this case, the failure of previous fracture management led to the use of ITAP as an alternative to total femoral amputation, resulting in successful adaptation and restored mobility.

Veterinary applications of ITAP remain limited, and no standardized protocol exists for implant selection, considering anatomical variability across species, breeds, and patient adaptability [14]. Additionally, access to specialized surface treatment technologies and 3D-printed titanium implants remains a challenge for many veterinary surgeons [6,7]. Based on previous studies, the authors adapted a fully intramedullary titanium implant designed to promote osseointegration and ensure long-term functionality [9,10,18,20]. This approach incorporated CT imaging, CAD software, and 3D biomodel printing for surgical planning and implant optimization.

In human patients, a six-week osseointegration period is recommended before fitting an external prosthesis to allow stable bone integration. Some veterinary studies suggest using external fixation devices to protect the endoprosthesis during the immediate postoperative period, transitioning later to exoprosthesis use [7,10,12,26]. However, this approach was not feasible in this case due to the high and bilateral level of amputation, which prevented effective external stabilization. Consequently, the prostheses were attached intraoperatively, and rehabilitation commenced immediately after recovery from anesthesia.

Implant rotational stability is a key factor in ITAP success, requiring a locking component, such as a screw or pin, to counteract rotational forces at the implant-limb interface. 3D-printed guides improve pin placement accuracy, enhancing surgical precision and biomechanical stability [17,18,20]. In this case, customized guides were used for Kirschner wire positioning. However, intraoperative difficulties arose due to excessive proximal muscle mass, limiting guide placement and leading to failed pin locking in the right femur (Figure 5). Despite this, the patient demonstrated good adaptation, and the guide design was modified for future applications, allowing 180° rotational positioning for improved compatibility.

Prosthetic development has evolved significantly since the 1960s, beginning with dental and auditory implants, later progressing to osseointegrated limb prostheses [2,11,16]. The first

clinical report of ITAP in veterinary medicine was published in 2008, and since then, research has aimed to refine implant design and surgical techniques [4]. Current recommendations emphasize distal amputations whenever possible, as they facilitate ITAP placement and maximize limb function [1].

A major challenge in ITAP application is dermal integration, which ensures stable adhesion of soft tissue to the implant, preventing external contamination. Reported complications include infection, skin retraction, implant exposure, and mechanical failure [8,15,19]. Owner education is essential, as proactive management of these challenges facilitates long-term prosthetic function. In this case, skin retraction and implant exposure were observed in the left femur 15 days postoperatively, requiring revision surgery, bacterial culture, and targeted antibiotic therapy, resulting in complete wound closure with no further complications.

Limb prosthetic implantation is a viable option in veterinary practice, restoring natural biomechanics and functional mobility [7,10,18,19]. Only one prior case of bilateral distal femoral amputation was identified in the literature, reported by Mendonça [18]. In the present case, a more proximal (diaphyseal) amputation was successfully performed, demonstrating feasibility, good patient adaptation, and owner satisfaction after 27 months of follow-up.

The authors recognize ITAP's potential and encourage veterinarians to consider it as an alternative to high limb amputations. Further research will provide valuable insights to refine implant technology, improve surgical outcomes, and minimize complications for amputee patients.

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

REFERENCES

1. **Boylan MT, Boston SE, Townsend S, Cavalcanti JVJ. 2019.** Limb-shortening limb salvage (LSLS) in a cat with metatarsal osteosarcoma. *Canadian Veterinary Journal*. 60(7):757-761.
2. **Brånemark PI, Adell R, Breine U, Hansson BO, Lindström J, Ohlsson A. 1969.** Intraosseous anchorage of dental prostheses. I. Experimental studies. *Scandinavian Journal of Plastic and Reconstructive Surgery*. 3(2):81-100. doi: 10.3109/02844316909036699. PMID: 4924041.
3. **Dickerson VM, Coleman KD, Ogawa M, Saba CF, Cornell KK, Radlinsky MG, Schmiedt CW. 2015.** Outcomes of dogs undergoing limb amputation, owner satisfaction with limb amputation procedures, and owner perceptions regarding postsurgical adaptation: 64 cases (2005-2012). *Journal of the American Veterinary Medical Association*. 1;247(7):786-92. doi: 10.2460/javma.247.7.786.
4. **Drygas KA, Taylor R, Sidebotham CG, Hugate RR, McAlexander H. 2008.** Transcutaneous tibial implants: a surgical procedure for restoring ambulation after amputation of the distal aspect of the tibia in a dog. *Veterinary Surgery*. 2008 Jun;37(4):322-7. doi: 10.1111/j.1532-950X.2008.00384.x. PMID: 18564255.
5. **Ephraim PL, Dillingham TR, Sector M, Pezzin LE, Mackenzie EJ. 2003.** Epidemiology of limb loss and congenital limb deficiency: a review of the literature. *Archives of Physical Medicine and Rehabilitation*. 2003 May;84(5):747-61. doi: 10.1016/s0003-9993(02)04932-8.
6. **Faria, L. G.& Rocha, T.A.S.S.** Orthoses and Prostheses. In: Minto, B. W. & Dias, L. G. G. G. (Eds). *Treatise on orthopedics for dogs and cats*. São Paulo: Medvet. 2022. pp 464-481.
7. **Fitzpatrick N, Smith TJ, Pendegrass CJ, Yeadon R, Ring M, Goodship AE, Blunn GW. 2011.** Intraosseous transcutaneous amputation prosthesis (ITAP) for limb salvage in 4 dogs. *Veterinary Surgery*. 40(8):909-25. doi: 10.1111/j.1532-950X.2011.00891.x.
8. **Golachowski A, Al Ghabri MR, Golachowska B, Al Abri H, Lubak M, Sujeta M. 2019.** Implantation of an Intraosseous Transcutaneous Amputation Prosthesis Restoring Ambulation After Amputation of the Distal Aspect of the Left Tibia in an Arabian Tahr (*Arabitragus jayakari*). *Frontiers in Veterinary Science*. 11;6:182. doi: 10.3389/fvets.2019.00182.

- 9. Gorshkov S.S., Ulanova N.V., Manuilova V.V. 2017.** Percutaneous osseointegrated limb prosthetics in dogs and cats after partial amputation based on a series of clinical cases/Percutaneous osseointegrated limb prosthetics in dogs and cats after partial amputation based on a series of clinical cases . Veterinary Pharma Magazine, n. 4 (38). <https://vetpharma.org/articles/174/7157>.
- 10. Gorshkov, S. S.; Ulanova, N. V. 2019.** Interactive traumatology and orthopedics of children animals. Vol. 2. Moscou, Scientific Library, pp.438-508.
- 11. Hagberg K, Brånemark R. 2009.** One hundred patients treated with osseointegrated transfemoral amputation prostheses--rehabilitation perspective. Journal of Rehabilitation Research and Development. 2009;46(3):331-44.
- 12. Kang N.V., Pendegrass C., Marks L., Blunn G. 2010.** Osseocutaneous Integration of an Intraosseous Transcutaneous Amputation Prosthesis Implant Used for Reconstruction of a Transhumeral Amputee: Case Report. The Journal of Hand Surgery, 35(7), 1130–1134. doi:10.1016/j.jhssa.2010.03.037
- 13. Kirpensteijn J, van den Bos R, Endenburg N. 1999.** Adaptation of dogs to the amputation of a limb and their owners' satisfaction with the procedure. Veterinary Record. 30;144(5):115-8. doi: 10.1136/vr.144.5.115. PMID: 10070700.
- 14. Kneringer C, Schnabl-Feichter E. 2024.** Intraosseous Transcutaneous Amputation Prosthesis (ITAP) compared to Exoprosthesis in veterinary medicine - a literature review. Veterinary Practice Edition K: Small Animals / Pets. 52(6):359-366.doi: 10.1055/a-2453-6622.
- 15. Li Y, Felländer-Tsai L. 2021.** The bone anchored prostheses for amputees - Historical development, current status, and future aspects. Biomaterials. 273:120836. doi: 10.1016/j.biomaterials.2021.120836.
- 16. Lundborg G, Brånemark PI, Rosén B. 1996.** Osseointegrated thumb prostheses: a concept for fixation of digit prosthetic devices. Journal of Hand Surgery American Volume. 21(2):216-21. doi: 10.1016/s0363-5023(96)80103-1.

17. **Marcellin-Little D.J., Drum M.G., Levine D., McDonald S.S. 2015.** Orthoses and exoprostheses for companion animals *Veterinary Clinics of North America: Small Animal Practice*. 45(1):167-83. doi:[10.1016/j.cvsm.2014.09.009](https://doi.org/10.1016/j.cvsm.2014.09.009).
18. **Mendonça A.G.C; Braga V. A. A; Fernandes T. H. T; Oliveira G.C.R; Beraldo G.S. 2023.** Fixed bilateral endo-exo prostheses in feline femur - case report / Endo-exoprótese bilateral fixa em fêmur de felino - relato de caso. *Brazilian Archives of Veterinary Medicine and Animal Science (Online)*; 75(1): 107-112.
19. **Mendonça, A. G.; Fernandes, T.H.T. 2019.** Exoprótese fixa em rádio de cão: relato de caso. *Revista Nosso Clínico*, 22;127,12-16.
20. **Meng M, Wang J., Sun T., Zhang W., Zhang J., Shu L., Li Z. 2022.** Clinical applications and prospects of 3D printing guide templates in orthopaedics. *Journal of Orthopaedic Translation*, 13;34:22-41. May. <http://dx.doi.org/10.1016/j.jot.2022.03.001>.
21. **Mich PM. 2014.** The emerging role of veterinary orthotics and prosthetics (V-OP) in small animal rehabilitation and pain management. *Topics in Companion Animal Medicine* .29(1):10-9. doi: 10.1053/j.tcam.2014.04.002.
22. **Pendegrass CJ, Goodship AE, Blunn GW. 2006.** Development of a soft tissue seal around bone-anchored transcutaneous amputation prostheses. *Biomaterials*. 27(23):4183-91. doi: 10.1016/j.biomaterials.2006.03.041.
23. **Pendegrass CJ, Goodship AE, Price JS, Blunn GW. 2006.** Nature's answer to breaching the skin barrier: an innovative development for amputees. *Journal of Anatomy*. 209(1):59-67. doi: 10.1111/j.1469-7580.2006.00595.x.
24. **St Jean G.1996.** Amputation and prosthesis. *Veterinary Clinics of North America: Food Animal Practice*. 12(1):249-61. doi: 10.1016/s0749-0720(15)30446-1.
25. **Timercan A, Brailovski V, Petit Y, Lussier B, Séguin B. 2019.** Personalized 3D-printed endoprostheses for limb sparing in dogs: Modeling and in vitro testing. *Medical Engineering & Physics*. 71:17-29. doi: 10.1016/j.medengphy.2019.07.005. Epub 2019 Jul 18. PMID: 31327657.

26. Wendland, T. M., Seguin, B., & Duerr, F. M. (2023). Prospective evaluation of canine partial limb amputation with socket prostheses. *Veterinary Medicine and Science*. 9: 1521–1533. doi:10.1002/vms3.1146

27. Ziegler-Graham K., MacKenzie E.J., Ephraim P.L., Travison T.G., Brookmeyer R. 2008. Estimating the prevalence of limb loss in the United States: 2005 to 2050. *Archives of Physical Medicine and Rehabilitation*. 89(3):422-9. doi: 10.1016/j.apmr.2007.11.005.

FIGURE LEGENDS

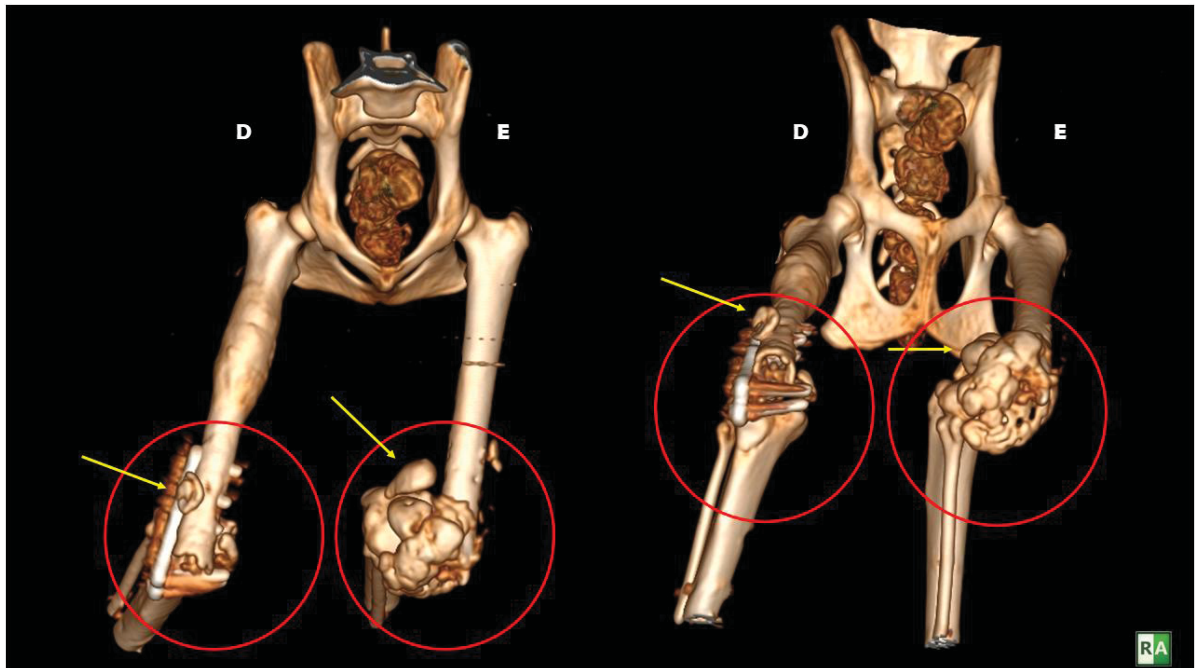


Figure 1. Three-dimensional (3D) reconstruction of the pelvic limbs for ITAP planning. The red circle highlights areas of articular damage in the stifle joints, while yellow arrows indicate luxated patellae and internal rotation of the left tibia.

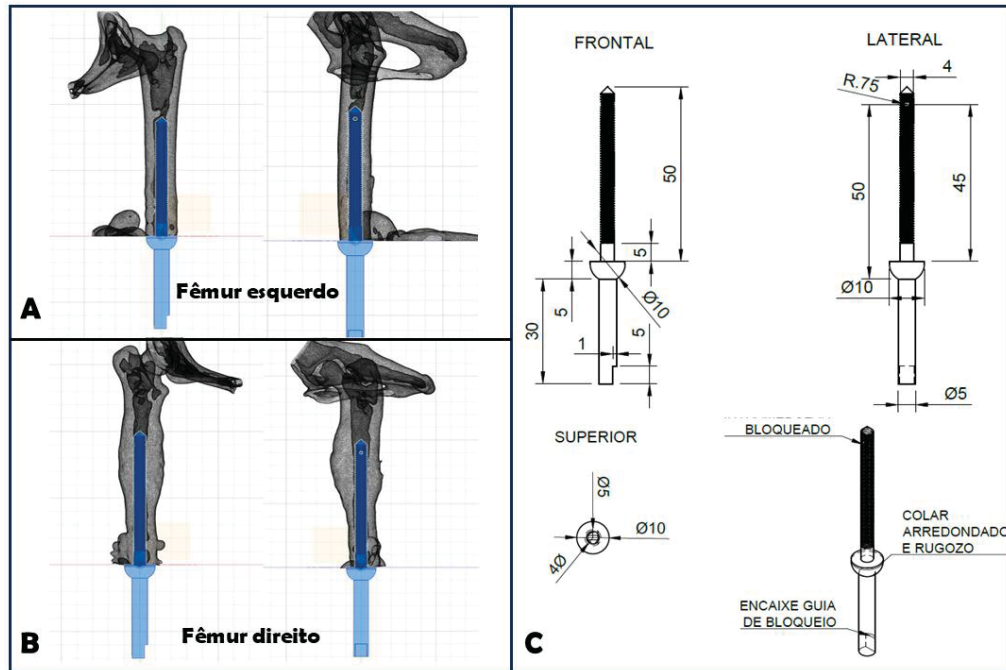


Figure 2. Technical and virtual planning of the femoral implant. (A) Segmentation of computed tomography images in craniocaudal and mediolateral views, with implant overlay. (B) Segmented left femur. (C) Technical drawing of the implant.

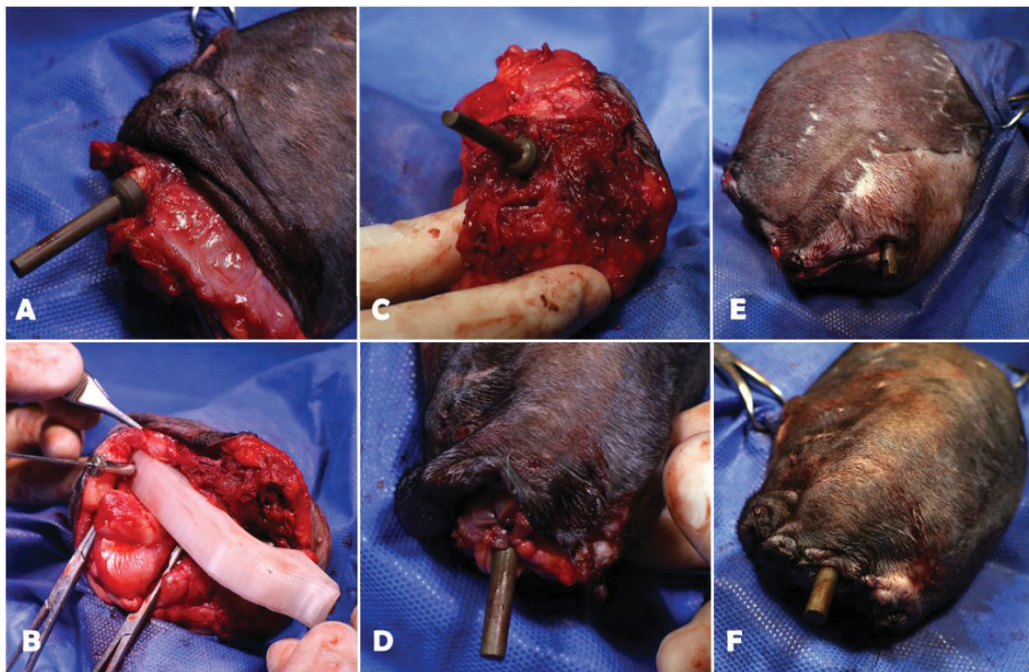


Figure 3. (A) Intraoperative image showing implant placement at the osteotomy site. (B) Application of a 3D-printed guide for implant stabilization using a 1.5 mm Kirschner wire. (C) Muscular approximation. (D) Myopexy with 2-0 PDS sutures. (E) Subcutaneous closure. (F) Skin closure with Sultan sutures using 3-0 nylon.

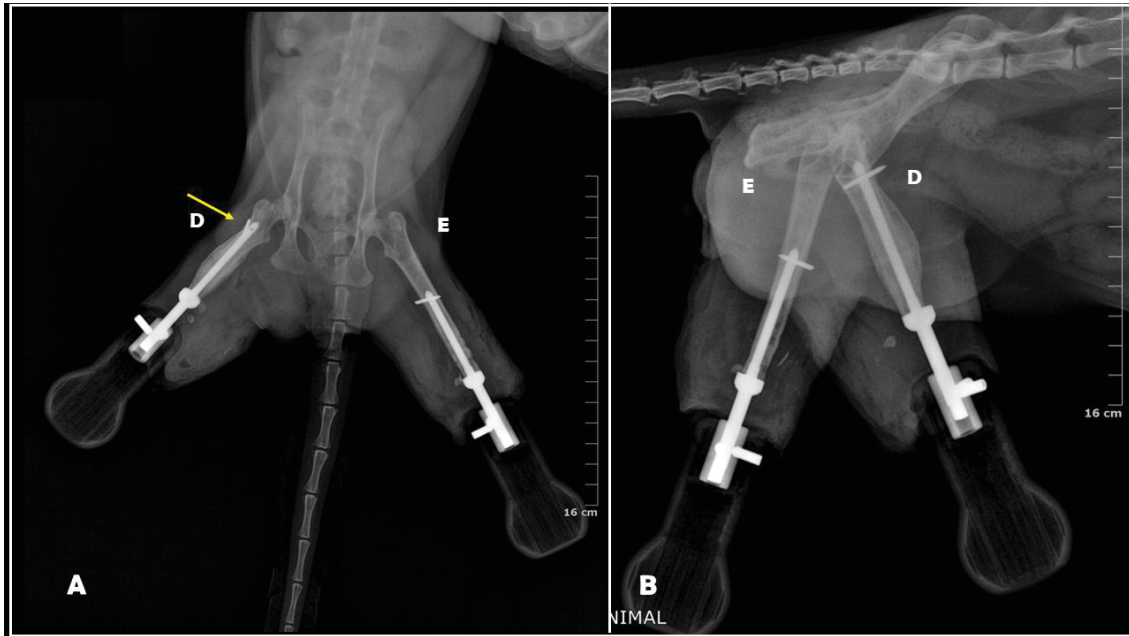


Figure 4. Immediate postoperative radiographs. (A) Craniodorsal projection. (B) Mediolateral projection. The correct positioning of the intramedullary implants and their intimate contact with the osteotomy site are observed. The yellow arrow indicates a failed 1.5 mm pin lock in the right femur.

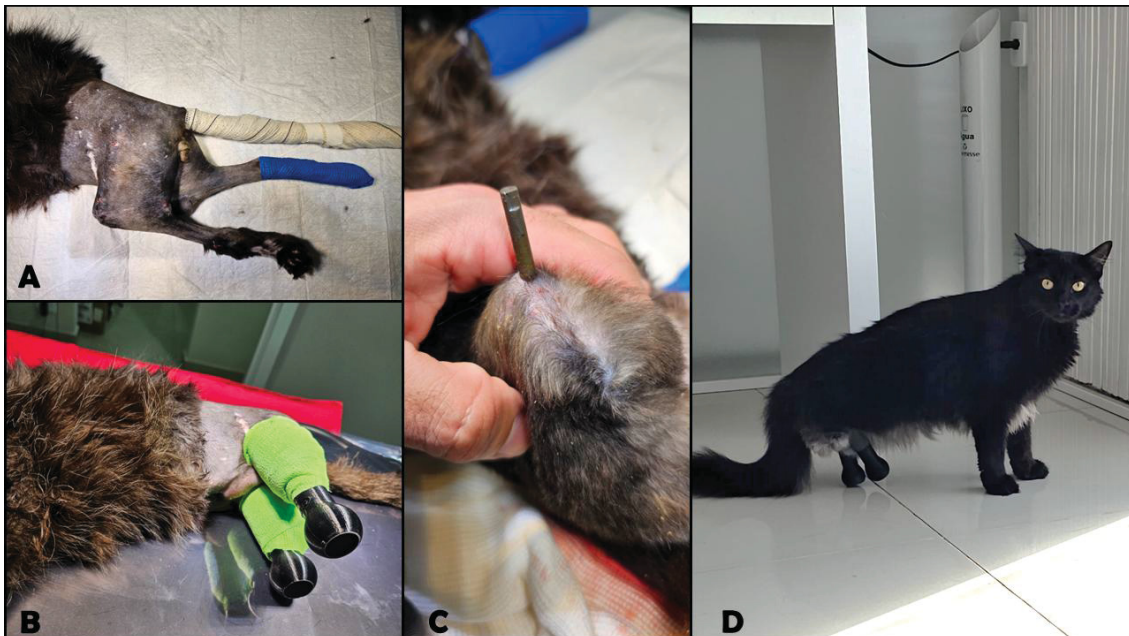


Figure 5. (A) Preoperative image showing severe orthopedic deformity with internal rotation of the left tibia. (B) Immediate postoperative image with prosthetic placement and bandaging. (C) Thirty-day postoperative image, demonstrating dermal integration of the right femur. (D) Image of the patient at 24 months postoperatively, fully adapted to the prostheses.

CHAPTER 2

Intraosseous Transcutaneous Amputation Prosthesis (ITAPs) and External-Fixation Amputee Prosthesis for limb salvage in 6 cats

****The chapter will be formatted and submitted to a journal of the authors' choice.**

Intraosseous Transcutaneous Amputation Prosthesis (ITAPs) and External-Fixation Amputee Prosthesis for limb salvage in 6 cats

De Freitas I.B., Dornbusch, P. T.

Objective: To describe the clinical application of 5 intraosseous transcutaneous amputation prostheses (ITAPs) and 3 external-fixation amputee prostheses for limb salvage in 6 cats.

Study Design: Case series.

Sample Population: Client-owned cats with traumatic limb injuries.

Method: Limb amputation permitted the insertion of ITAPs into the calcaneus ($n = 3$) and femur ($n = 2$), and the application of external skeletal fixation into the tibia ($n = 3$). The remaining soft tissues, including skin, were secured around the ITAP. The implants were manufactured as single-piece components from titanium alloy, whereas the exoprostheses were individually customized using 3D printing with Polyethylene Terephthalate Glycol (PET-G). Outcome measures included subjective assessments of limb function by owners and veterinarians, in addition to radiographic evaluation.

Results: Three cats (1–3) received ITAPs, achieving dermal integration within 3 weeks and demonstrating pain-free ambulation within 1 week. Cats (4–6) underwent external fixation for tibial limb preservation, exhibiting comparable adaptation in locomotion. One cat (4) experienced complications with a calcaneal ITAP due to insufficient skin coverage over the implant; this was successfully managed with tibial external fixation (9-month follow-up). Two cats with calcaneal ITAPs died at 8 and 38 months postoperatively—one from complications related to Feline Leukemia Virus (FLV) and the other following a dog attack. External fixation was effectively employed to address ITAP-related complications (cats 4 and 6). The remaining patients were in good clinical condition and free of complications at the time of manuscript preparation.

Conclusion:

Implantation of ITAPs in the distal limb of cats is technically feasible and can result in favorable functional outcomes. Biological integration of osseous and dermal tissues with ITAPs appears reliable and durable. External-fixation amputee prostheses represent a versatile and valuable option for the management of amputated patients, providing satisfactory long-term functional results.

INTRODUCTION

In veterinary medicine, limb-preservation procedures have gained increasing attention, paralleling technological advances and a growing awareness among owners of the functional and quality-of-life impacts associated with amputation (Carr et al., 2018; Fitzpatrick et al., 2011; Arauz et al., 2021; Kvale et al., 2022).

The most common causes of amputation in cats include traumatic injuries, complications in fracture management, osteomyelitis, thromboembolism, and neoplasia (Wagner et al., 2022; Kimura, 2025). Although numerous studies have evaluated outcomes of limb amputation in dogs, far fewer have been reported in cats (Forster et al., 2010; Menchetti, 2022). Over time, compensatory overload may result in ligamentous, tendinous, and osseous disorders of the remaining limbs. For this reason, total amputation should not be considered the primary surgical option when limb-salvage procedures remain viable (Raske et al., 2015; Carr et al., 2018; Jarrel et al., 2018; Faria and Rocha, 2022).

Stump Socket Prostheses (SSPs) are the most frequently reported form of amputee prosthesis in the veterinary literature (Rosen et al., 2022). However, they are associated with substantial complications, including discomfort, infection, pressure sores, necrosis, poor adaptation, device failure, and limited patient acceptance (Marcellin-Little et al., 2015; Overmann & Forsberg, 2019; Kneringer & Schnabl-Feichter, 2024).

Osseointegrated prostheses provide a potential solution to the limitations of socket-based designs. Only a small number of such cases have been documented in veterinary medicine, including transcutaneous tibial implants in a dog (Drygas et al., 2008), intraosseous transcutaneous amputation prostheses (ITAPs) in four dogs (Fitzpatrick et al., 2011), bilateral femoral applications in two cats (Mendonza et al., 2023; De Freitas et al., 2025), and an innovative custom-made bilateral femoral fixation in a cat (Petazzoni & Maciejowski, 2025).

The major challenges associated with amputation prostheses remain the maintenance of healthy bone–implant and skin–implant interfaces, as well as the risks of implant exposure and stump infection. Numerous studies have sought to address these challenges through implant customization, material selection, and surface modifications, which continue to evolve (Pendegrass et al., 2006; Drygas et al., 2008; Fitzpatrick et al., 2011; Mendaza et al., 2022).

We hypothesized that the use of ITAPs and external skeletal fixation would be technically feasible, promote stable and long-lasting osseous and dermal integration, and enable functional limb use when combined with an appropriately designed exoprosthesis. The objective of this

study was to describe the development, clinical application, postoperative monitoring, and potential complications of four ITAPs and four external skeletal prostheses in 6 cats.

MATERIALS AND METHODS

This study was approved by the Ethics Committee on the Use of Animals (CEUA) of the Agricultural Sciences Sector at the Federal University of Paraná (UFPR), Brazil, under protocol number 051/2022, in accordance with the regulations issued by the National Council for the Control of Animal Experimentation (CONCEA). All owners signed an informed consent form prior to participation in the study.

The intrasosseous transcutaneous amputation prostheses (ITAPs) served two purposes: a mechanical function, enabling ambulation and attachment of the exoprosthesis (paw), and a biological function, facilitating osseointegration and dermal integration to seal the surgical site. Treatment planning was jointly determined by engineers and surgeons, after which the implants were machined from titanium alloy (Ti6Al4V) and received a surface treatment with sandblasting.

Commercially available linear external fixators were used in a 1A configuration and modified to allow direct attachment of the exoprosthesis to the connecting bar.

Preoperative assessment of the amputation site included measurement of the medullary canal diameter and cortical thickness based on orthogonal radiographic projections of the limb, using RadiAnt® DICOM Viewer medical imaging software.

The internal device was custom-fabricated for each cat by Cão Médica® and consisted of three components: (1) an intrasosseous threaded intramedullary stem, (2) an umbrella-shaped flange, and (3) a distal extracutaneous pin serving as the interface between the stump and the exoprosthesis fixation (Figure1).

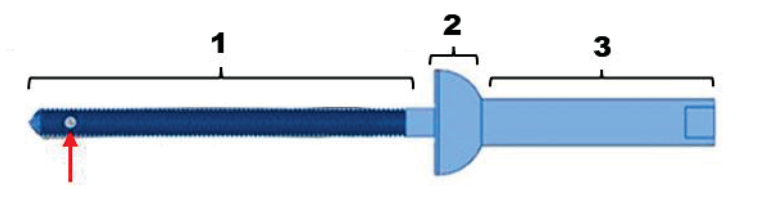


Figure 1. Illustrative image with the regions of the ITAP model (1): osseointegrated threaded intramedullary. (2): Necklace. (3): External exoprosthesis connection rod. Red arrow represents a proximal perforation for antirotational locking with Kirschner wire.

The implant dimensions allowed insertion of the stem into the femur or calcaneus using a manual Jacobs chuck introducer (Figure 2), by press-fitting the circular cross-section of the stem into the narrowest transverse diameter of the medullary canal, with the flange positioned within the subcutaneous tissue to relieve skin tension. The length and shape of the stem were determined by the maximum canal length and width that could be prepared using a milling drill. In cases in which an associated osteotomy is performed, it is important to emphasize the need for the osteotomy line to be parallel to the base of the implant in order to achieve a “perfect fit.” The average time required to manufacture the customized implant was approximately 8 days.

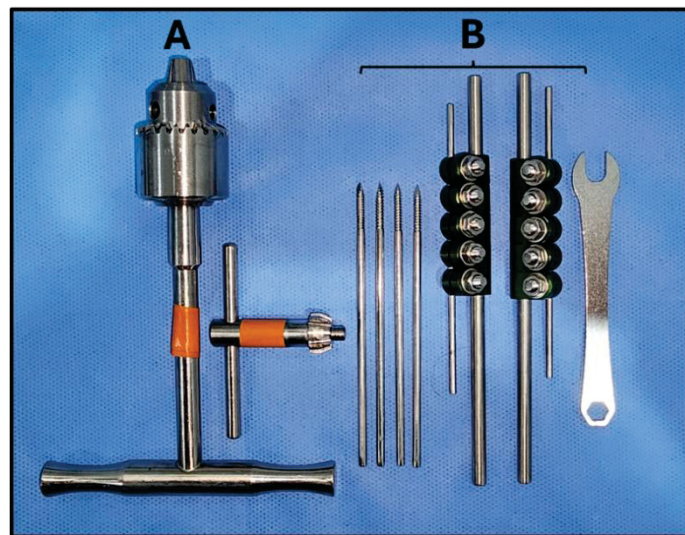


Figure 2. A: Photographic image of the surgical materials used for the implantation of endo-exoprostheses. B: Manual Jacobs chuck introducer; linear external fixator kit (Schanz pins, bars, clamps, and key). Used in cases of external prostheses.

Modified endo-exoprostheses with type 1A external fixators were assembled using commercially available devices. Percutaneous Schanz pins were placed trans-cortically (cis- and trans-cortices), and the exoprostheses were designed using CAD software and fabricated with Fused Deposition Modeling (FDM) 3D printing in Thermoplastic Polyurethane (TPU). They were secured directly to the fixation bar with Allen screws by press fit.

Inclusion criteria for this case series were cats presented to the orthopedic service with severe orthopedic injuries managed with ITAP or endo-exoprostheses following limb amputation.

RESULTS

CAT 1

A 2-year-old neutered male, 3.5 kg, mixed breed was admitted for evaluation of intermittent progressive right pelvic limb lameness after automobilist accident. The patient had an open fracture with great loss of muscle and nerve tissues of the left metatarsals. The cat underwent a distal amputation to stop the bleeding and close the wound. Subsequently, orthogonal

radiographs were performed with a spherical radiographic magnifier at the level of the calcaneus to plan the intraosseous transcutaneous amputation prosthesis.

Surgical Technique

The cat was positioned in right lateral recumbency to facilitate a craniomedial surgical approach to the calcaneal bone. Circumferential transverse incision of skin and musculature tissue at the level of metatarsus. The tarsal joint and vessel ligation was followed by retraction of the soft tissue envelope of the calcaneus.

Transverse osteotomy distal was performed to remove the articular surface of the calcaneus using a microsagittal saw blade with concurrent saline solution lavage of the saw blade and bone. A recipient tunnel in the medullary canal was created using a 2.0mm. At that point, we observed that the medullary canal was fragile and wider than anticipated based on the radiographic planning, the plan had to be modified.

We opted for a copious wash with Betadine solution, collection for culture and antibiogram after washing and there was no bacterial growth; We applied the threaded intramedullary implant and filled the gap with bone cement (Figure 3-1a). A 3d guide (TPU) for locking the pin was produced, but due to this looseness we were unsuccessful in locking (Figure 3-1b). Next, myopexy was performed with 3-0 nylon thread and skin suture with 4-0 sultan pattern. The exoprosthesis, 3D printed in PET-G, was inserted three days after the surgical procedure.

Aftercare and Follow-Up

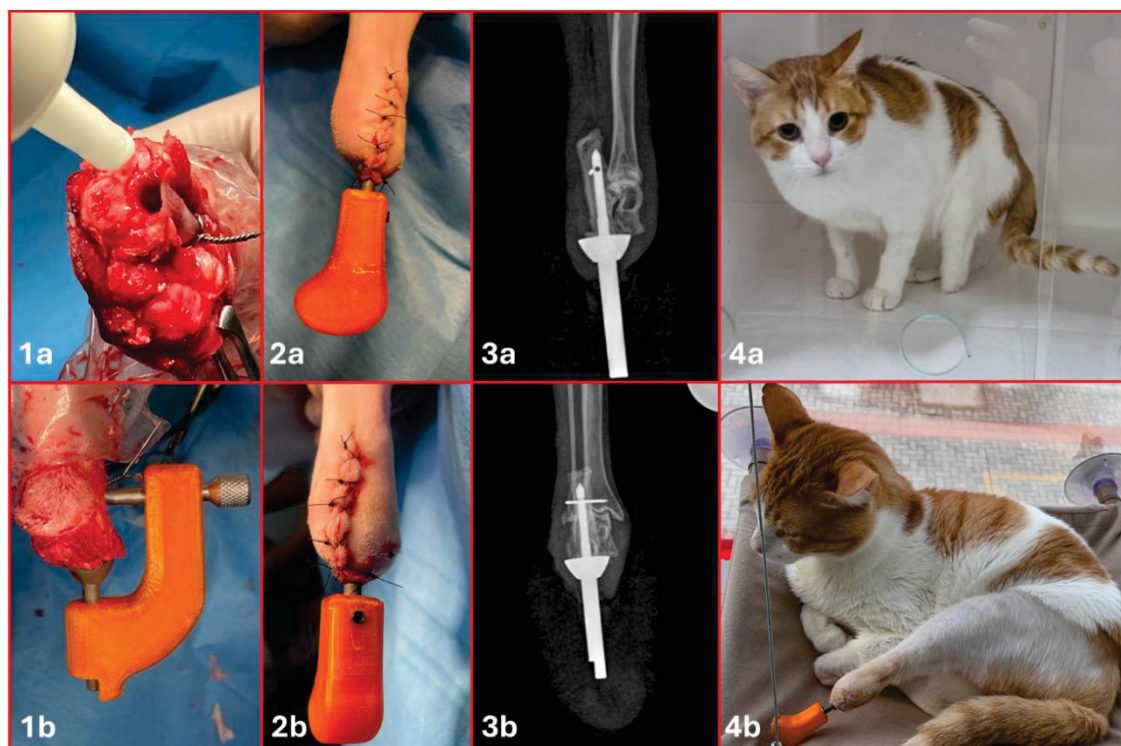


Figure 3. 1a: intraoperative photograph at the time of filling of the intramedullary canal of the calcaneus with bone cement; 1b: positioning of the 3D guide for locking with Kirschner wire; 2: lateral image (a) and caudal (b) of the surgical wound with the prosthesis placed; 3. Midlateral (a) and caudocranial radiograph of the calcaneus with ITAP applied; 4. Photograph of the patient before (a) and after (b) the surgery 28 days.

A bandage was applied immediately with gauze and chlorhexidine-based antiseptic spray and changed every day for 21 days. Cephalexin (22 mg/kg orally every 12 hours) was administered for 21 days; meloxicam (0,1 mg/kg orally every 24 hours) for 5 days; tramadol hydrochloride (1 mg/kg orally every 12 hours) for 5 days and neomycin ointment was applied to the skin-ITAP interface at the time of bandage change. The cat remained hospitalized for 3 days, presented early support of the prosthetic limb without pain and without signs of complications. The patient presented excellent limb support 7 days postoperatively. Resilient bone-implant and skin-implant interfaces were achieved based on physical findings and radiographic examination at 4 weeks. No prosthesis-related complications such as infection, implant exposure, or pin loosening were observed; however, 8 months after surgery, the cat developed systemic clinical complications associated with Feline Leukemia Virus (FLV).

CAT 2

A 2-year-old intact male, 4kg, mixed-breed was presented after automobilist accident with an open fracture of the right metatarsal bones, held together by a thin layer of skin (Figure 4). An

initial emergency surgery was performed, consisting of an amputation as distal as possible in order to preserve soft tissues for wound closure and to allow subsequent application of an ITAP at the calcaneus.

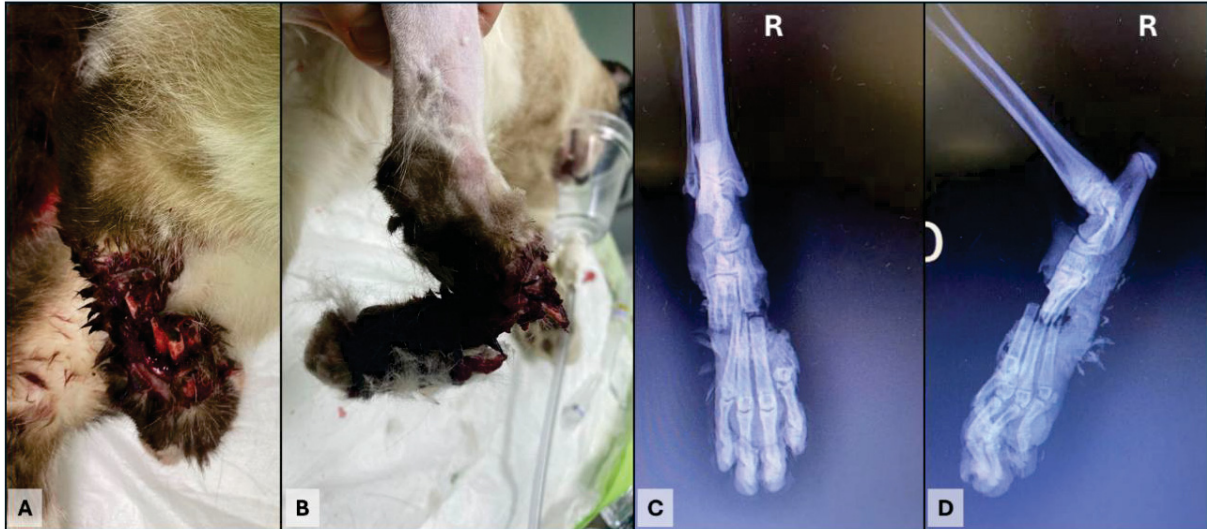


Figure 4 - Photograph of the paw lesion in the lateral (A) and caudal (B) views; C and D: craniocaudal and mediolateral radiography, respectively

The planning was carried out using orthogonal radiographs. A threaded intramedullary pin with a locking hole at its proximal end, machined in titanium, was selected. To enable implant locking, a guide was produced with the aid of 3D printing and 21 days after the first intervention, the patient underwent prosthesis implantation.

Surgical Technique

A semicircular incision was made at the stump, followed by dissection of the soft tissues, exposure, and removal of the tarsal bones. A transverse osteotomy using a Stryker oscillating saw was performed to remove the articular surface of the calcaneus, prepare the surgical bed, and prevent any gap between the flange and the cancellous bone. A 2-mm drill was then used to prepare the medullary canal, and the implant was inserted with a manual Jacobs introducer until fully seated within the bone. Myopexy was performed with 3-0 PGCL, and skin suture was achieved with 3-0 nylon in a Sultan pattern. A dressing with neomycin ointment was applied immediately to protect the pin–skin interface.



Figure 5. A: Radiographic image of the ITAP in the craniocaudal and mediolateral calcaneus (B); C: cranial and lateral photograph (D), of the skin-pin interface with 7 days. You can see a lot of crusts around the pin; E: patient with minutes after fitting his prosthesis (4 weeks post-surgery).

Aftercare and, Follow-Up

Cephalexin (22mg/kg orally every 12 hours) for 21 days; meloxicam (0,1 mg/kg orally every 24 hours) for 5 days; tramadol hydrochloride (1 mg/kg orally every 12 hours) for 5 days and daily cleaning with chlorhexidine-based antiseptic once daily, continuous use.

The implant was left in place for four weeks without limb support to facilitate osseointegration. The owner maintained the surgical wound cushioned with a soft dressing at all times. Subsequently, the exoprosthesis was fitted, allowing rapid adaptation of the patient's gait with the skin already dermo-integrated and without complications. Follow-up at 38 months showed no complications, with perfect dermal and osseointegration. Unfortunately, the patient had access to the street, jumped over the neighbor's wall, and was killed by a dog.

CAT 3

A 1-year-old intact male, 3.6kg, mixed-breed, was missing for 54 days before being found and taken for veterinary evaluation due to severe hind limb dysfunction. On examination revealed significant ambulatory impairment, and radiographic assessment confirmed chronic bilateral Salter-Harris type I fractures of the distal femur. Multiple prior surgical attempts for fracture stabilization resulted in complications, including contamination, bacterial resistance, Rush pin migration, implant exposure, osteomyelitis, and the need for soft tissue reconstruction with a cranial tibial muscle flap followed by a caudal mesenteric artery axial pattern skin flap. Given the failure of conventional limb-preserving approaches, bilateral femoral ITAP placement was proposed as an alternative to total limb amputation. The owner consented to the procedure, prioritizing the cat's mobility and quality of life.

The selected implant was a threaded intramedullary titanium device featuring a proximal hole for locking with a 1.5 mm Kirschner wire (Figure 1). The external prosthesis was 3D-printed using TPU.

Surgical Technique

Following appropriate limb preparation, the patient was positioned in lateral recumbency, and the surgical site was aseptically prepared with 0.5% alcoholic chlorhexidine and draped with a sterile field. A craniolateral approach to the femur was performed, with an elliptical skin incision followed by fascia lata dissection and retraction of the biceps femoris and vastus lateralis muscles. Osteotomy was conducted at the mid-diaphyseal region to prepare the implant bed.

After pre-drilling the femoral canal with a 3.5 mm drill bit, the implant was inserted retrogradely using a Jacobs Chuck until seated at the osteotomy site. A custom 3D-printed guide was used for precise Kirschner wire placement, and excess pin length was trimmed with side-cutting pliers. Muscular closure was performed using 2-0 polydioxanone (PDS) with interrupted and Sultan sutures, and dead space was minimized with 3-0 PDS. The skin was closed with 3-0 nylon sutures. The same procedure was repeated for the contralateral limb and the exoprostheses attached immediately. Intraoperative and postoperative radiographs were obtained (Figure 6).

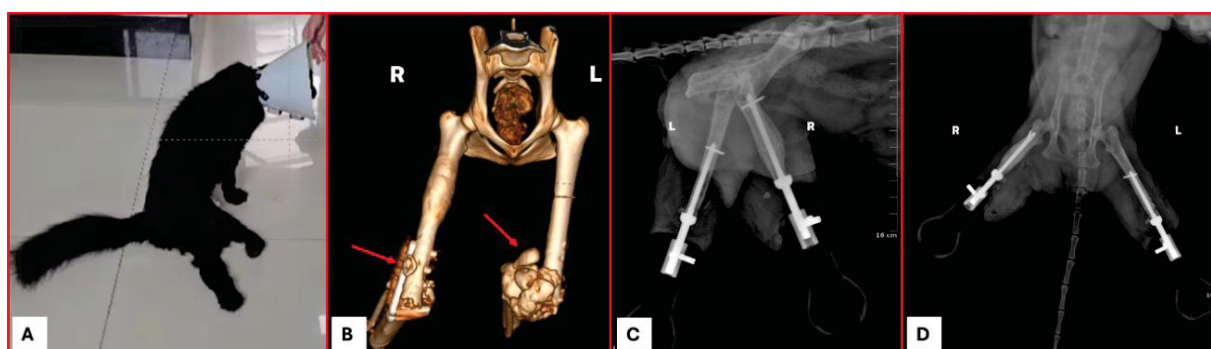


Figure 6. A: illustrative image of the patient in the preoperative period with injury to the pelvic limbs; B: 3d segmentation of the patient, red arrows show the dislocated patellas; C: radiographic lateral projection of the immediate postoperative period with the prostheses; D: ventrodorsal radiographic of the patient with ITAPs in the immediate postoperative period.

Aftercare and Follow-up

Postoperative treatment included Cefovecin Sodium (Convenia[®] - 8 mg/kg, subcutaneous every 15 days for 2 repetitions), meloxicam (Maxicam[®] - 0.05 mg/kg, orally every 24 hours for 5 days), and tramadol hydrochloride⁵ (Cronidor[®] - 2 mg/kg, orally every 12 hours, for 5 days).

The patient remained hospitalized for 3 days for surgical site monitoring. Within 24h showed good adaptation to the prostheses, and by one week, ambulated normally.

After 30 days, skin dehiscence, retraction, and partial implant exposure were observed in the left femur, requiring revision surgery. The implant was covered using copious Betadine lavage, bacterial culture, and layered wound closure with 2-0 nylon for muscle and 3-0 nylon for the skin. Culture identified *Enterococcus faecium*, and compounded marbofloxacin (following result of antibiogram) was administered for 3 weeks, resulting in complete wound healing with no further dehiscence or stump contamination. At the time of this report, 36 months postoperatively, the patient exhibits no signs of pain, lameness, or orthopedic complications.

CAT 4

A 1-year-old neutered female, 3kg, mixed-breed, rescued presented with an amputation lesion in the digits and granulomatous exposure of the entire metatarsal region. We chose to perform amputation at the level of the tarsals, preserve as much skin as possible for surgical closure with an ITAP in the calcaneus and a 3D printed exoprosthesis. The planning was carried out through radiography and CT scan with a threaded titanium implant of 2.8mm in diameter and the use of a locking guide

Surgical Technique

The surgical procedure was similar to the technique described in cats 1 and 2, We apply the improvements and corrections of possible failures that occurred in previous cases. We take care to preserve as much skin as possible for tension-free closure. Meticulous dissection, thinking about the preservation of the musculature and a pre-perforation with a 2.0mm drill in the calcaneus guided by trans surgical radiography. Every step by step went perfectly and uneventfully. We used a 2.8mm diameter titanium threaded pin, inserted with manual introducer and an anti-rotational pin lock guide was developed in aluminum (Figure 7H). It allowed the application of a 1 mm pin to block the implant in the intramedullary canal. Muscle closure (myopexy) was performed with 3-0 nylon and adequate implant coverage and skin suture with the same sultan suture. Unlike all of us, we apply a hybrid external fixator to protect the immediate support on the intramedullary implant to assist in osseointegration. Note that at the beginning of the procedure (Figure 7B) the skin was in excess and after the application of the ITAP the skin already showed intense retraction (Figure 7H). The initial skin injury hindered

proper closure over the implant, resulting in a tensioned suture (Figure 7J). Next, the External Skeletal Fixator was applied to protect the implant for 6 weeks.

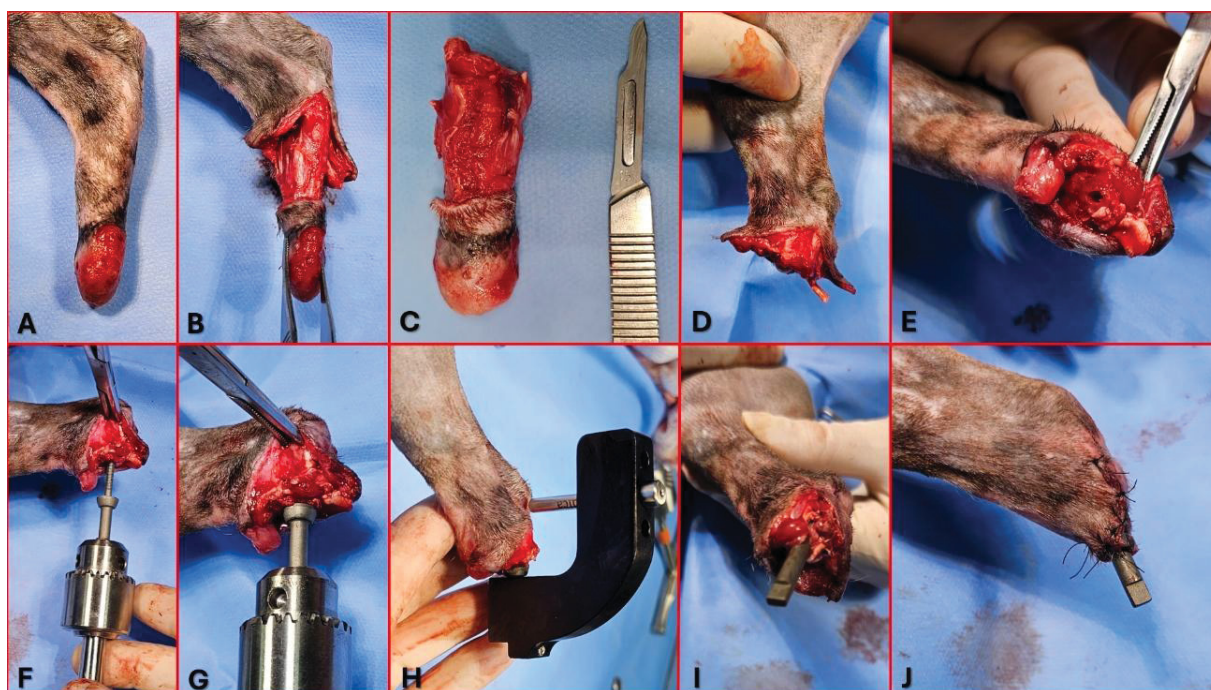


Figure 7 - Intraoperative photographs. A: paw with initial lateral view injury. B: dissection and preservation of skin and soft tissues. C: amputated portion at the level of the tarsal bones; D: appearance of the stump after amputation; E: pre-drilling with drill; F: ITAP application with manual introducer; G: ITAP inserted; H: application of the Guide for locking the threaded pin with 1mm locking guide; I: myopexy and beginning of subcutaneous closure and J: Skin suture and final appearance.

Aftercare and Follow-up

Cefovecin Sodium (Convenia[®] - 8 mg/kg, subcutaneous every 15 days for 2 repetitions), meloxicam (Maxicam[®]- 0.05 mg/kg, orally every 24 hours for 5 days), and tramadol hydrochloride⁵ (Cronidor[®]- 1 mg/kg, orally every 12 hours, for 3 days). The patient remained hospitalized for 24h for surgical site monitoring. Within 24h, showed good adaptation to the external prostheses, and by one week, ambulated normally. The patient started the support of the external fixator on the day after the procedure with adequate adaptation, without pain and without claudication.

After 6 weeks, the external fixator was removed and the exoprosthesis was fitted. The patient was reluctant to bear weight properly on the prosthetic limb, presenting with lameness and failing to adapt as expected. Pain was observed when attempting to support the limb, and at home, implant loosening occurred after the paw became caught on the stairs.

After 30 days, the patient was evaluated, and implant instability was noted. Surgical revision was decided upon, consisting of implant removal, irrigation with Betadine solution, and collection of material for culture and antibiotic susceptibility testing. Finally, a modified Type 1A external skeletal fixator was applied as an endo-exoprosthesis to manage periprosthetic

inflammation in preparation for future ITAP placement in the calcaneus or tibia. The procedure was minimally invasive, involving percutaneous insertion with a manual Jacobs introducer of two 2.0-mm Schanz pins, one placed proximally and the other more distally. This approach allowed treatment of the skin lesion while preserving limb support.

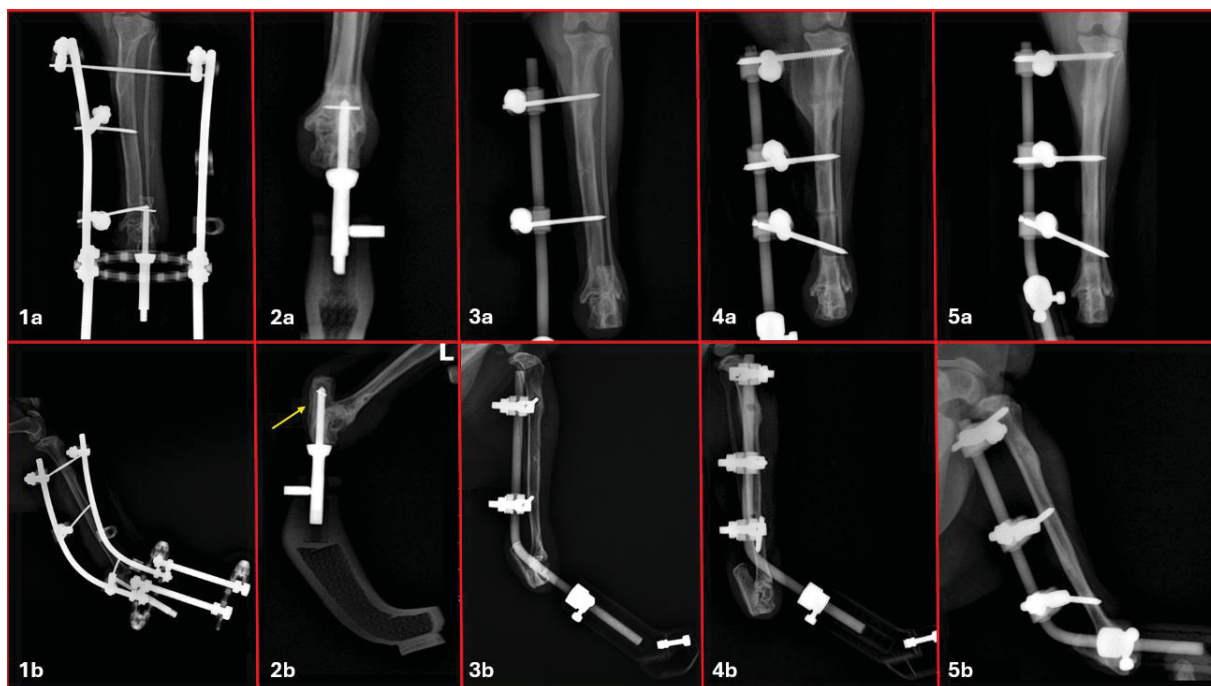


Figure 8 - a: craniocaudal projection and b: lateral median radiographic projection; numbers images of the same moments over time. 1. Immediate postoperative day 0; 2. ITAP after 30 days of limb use (45 days total P.O) with periosteal reaction (yellow arrow); 3. First ITAP revision with temporary external fixator (total 60 days); 4: External fixator overhaul with 30 days (total 90 days) and 5: most 5 months post fixator (total 8 months fixator)

Twenty-one days later, the cat returned with mild lameness. Radiographic evaluation revealed that one pin had fatigued. A minor surgical revision was performed, replacing all pins. This time, a 2.5mm diameter pin was placed proximal to the tibial plateau, along with two 2.0mm pins distributed along the diaphysis and distal epiphysis of the tibia. No postoperative complications were observed, and the patient rapidly adapted with early limb support. The response to limb uses with the external fixator was so pronounced that the owners decided to maintain the cat in this configuration. At 8 months postoperatively, follow-up showed no complications, with excellent adaptation, ambulation and owner satisfaction (Figure 8).

CAT 5

An 8-month-old intact female, 3.23 kg, mixed-breed, rescued with an unknown medical history, presented with absence of the distal third of the left tibia and absence of the phalanges of the right forelimb. The cat manifested limb-lift lameness of the left hind limb due to limb length discrepancy. Considering the young age, small tibial diameter, and ongoing bone growth, a modified type 1A external skeletal fixator (ESF) was selected to provide limb support and minimize overload on the remaining limbs during development. Preoperative planning was performed using radiographs.

Surgical Technique

The cat was positioned in left lateral recumbency to facilitate a medial surgical approach to the tibia and pin orientation. A small skin incision was made with a scalpel (number 11) blade to facilitate transcutaneous pin insertion. Three Schanz pins were inserted along the residual tibia, the first pin was 2.5 mm in diameter, and the remaining two pins were 2 mm in diameter. All pins were placed using a manual Jacobs pin introducer without predrilling and connected to an aluminum rod, to which the 3D-printed exoprosthesis in TPU was directly attached (Figure 9). The distance between the connecting bar and the skin was approximately 5 to 8 mm, depending on the local soft tissue thickness, to allow daily cleaning and optimize the fixator. The surgical procedure lasted 25 minutes. At the end, the patient underwent immediate postoperative radiography (Figure 10). The cat was hospitalized for 24 hours for postoperative observation and initial management.

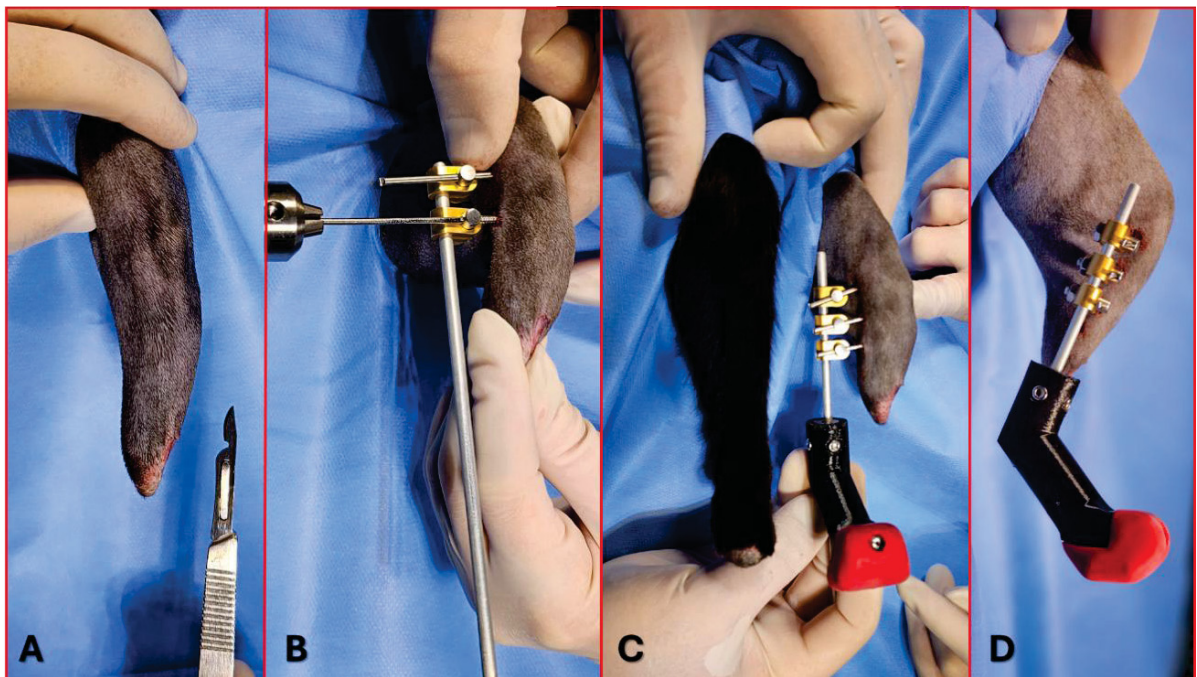


Figure 9 - Intraoperative photographic images. A: preparation of the patient's limb; B: Percutaneous application of Schanz pin with manual introducer; C: Adjustment of the exoprosthesis compared to the contralateral limb; D: lateral image of the limb after fixation of the exoprosthesis.

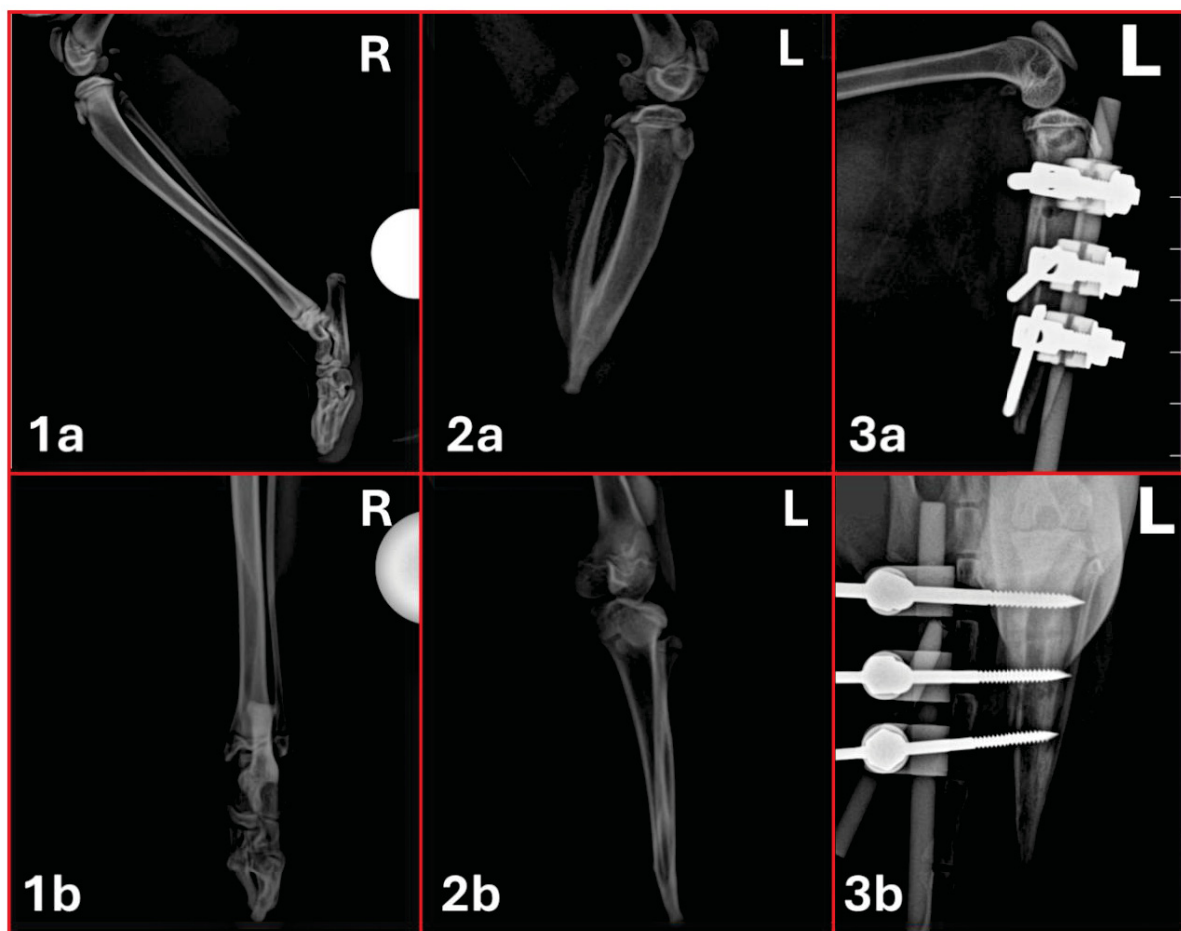


Figure 10. Letter a: midlateral radiographic projection and (b) craniocaudal. 1: radiography of the right limb with a possible malformation or chronic metatarsal injury; 2: Left limb, image for surgical planning; 3: Immediate postoperative radiographic imaging with external fixator applied to the left tibia.

Aftercare and Follow-up

Postoperative treatment included amoxicillin + potassium clavulanate (20mg.kg dose every 12 hours orally) for 7 days; meloxicam (0.05mg.kg once daily) for 5 days; tramadol hydrochloride (1mg.kg every 12 hours orally) for 3 days; in addition to daily cleaning of the external fixative with chlorhexidine-based antiseptic spray. The cat is adapting, physiotherapy twice a week, has satisfactory support of the limb, without complications so far 2 months postoperatively.

CAT 6

A 3-year-old intact female, 4kg, mixed-breed, rescued with an unknown medical history with open metatarsal fracture with irreversible vascular compromise. He first underwent damage containment surgery and after 60 days a hybrid endoexoprosthesis in the tibia (April 14, 2025). Presented immediate support and an ambulatory adaptation without claudication. However, after 4 months the skin began to retract, exposure of the implant and consequent skin contamination and osteomyelitis (Figure 11A). He was referred for care by our team to bring an alternative to the complication of endoexoprosthesis and amputation (August 2025). Clinically, the patient was well, with adequate support of the limb, but with significant discomfort and licking over the dressing. When evaluating blood tests, they showed

leukocytosis, anemia. A clinical treatment was then started and after 15 days we underwent surgical revision.

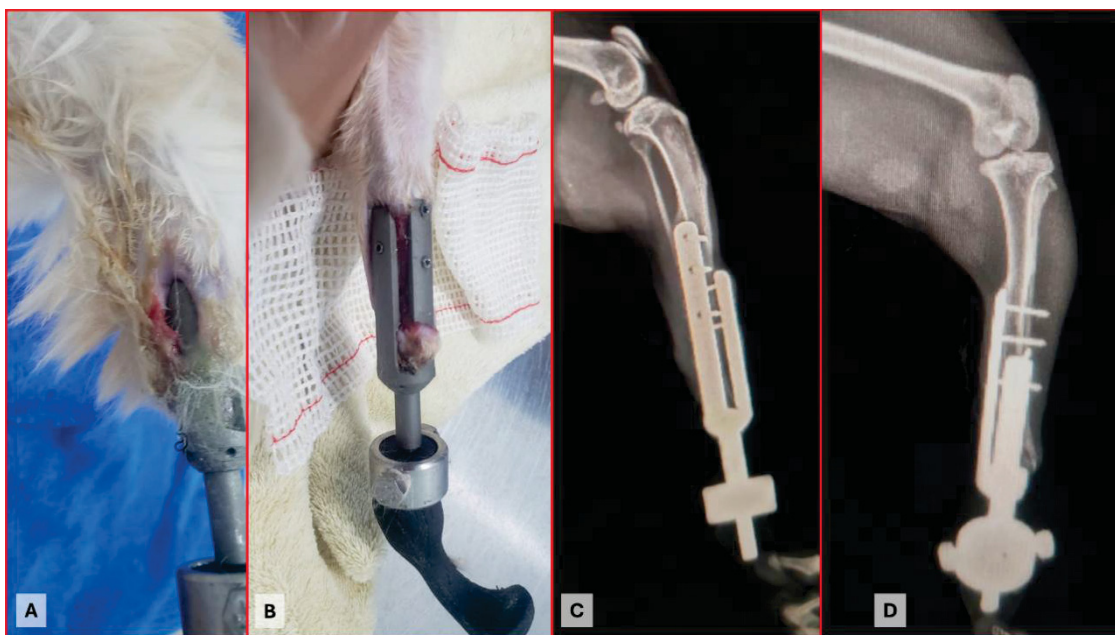


Figure 11. A: photographic image of the patient's care after the ITAP complication (August 2025); B: Photographic image after tricotomy, wound cleaning and washing with saline solution; C: Midlateral (C) and craniocaudal (D) radiograph of the left tibia.

Surgical Technique

The planning consisted of removal of the endoprosthesis, copious washing with betadine, culture and antibiogram, followed by wound debridement, ostectomy of the distal tibia region to allow skin closure (Figure 12). After the surgical approach to the soft tissues, the external fixator modified to preserve the support of the limb was applied with the application of three Schanz pins using the manual Jacobs introducer percutaneously without pre-perforation. The first pin was proximal to the tibial plateau was 2.5 mm and two were 2.0 mm in the sequence towards the tibial shaft, as the distal region was compromised by infection and previous perforations. The exoprosthesis was connected to the bar immediately after the end of the procedure and sent for radiography (Figure 13).

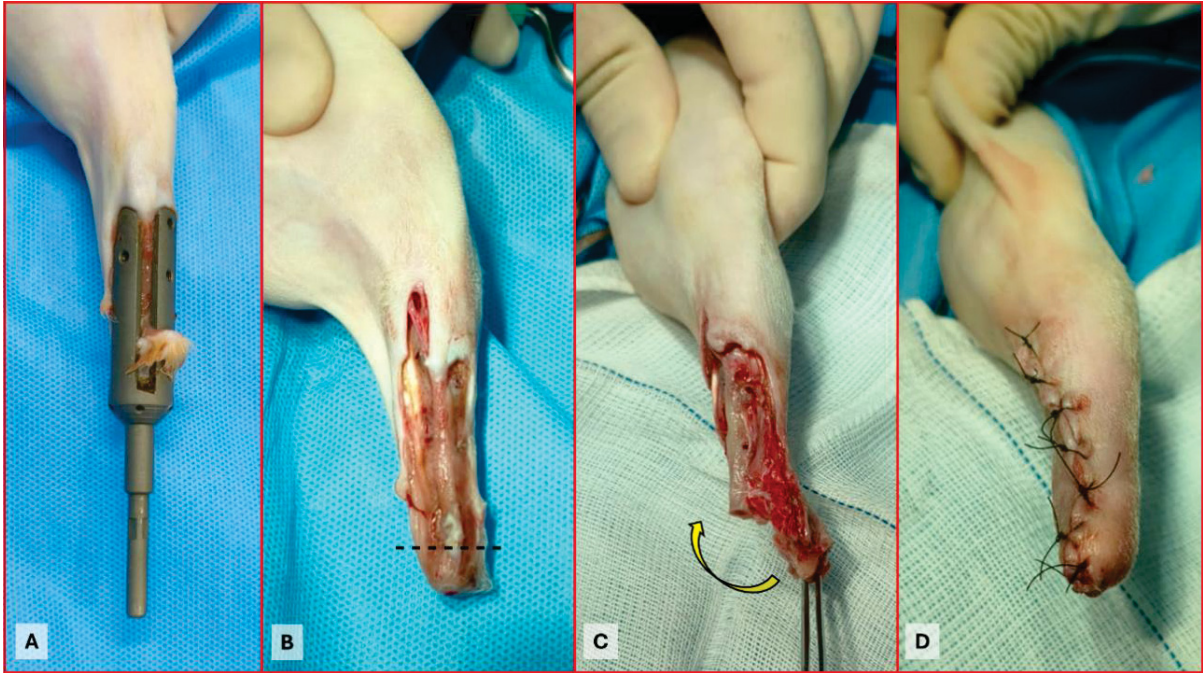


Figure 12. Intraoperative photographs, A: left tibia after trichotomy and antiseptic; B: tibia after ITAP removal, black dotted line represents the height of the osteotomy to facilitate wound closure; C: tibia after distal osteotomy, betadine lavage, and soft tissue debridement; D: final appearance after skin suture.

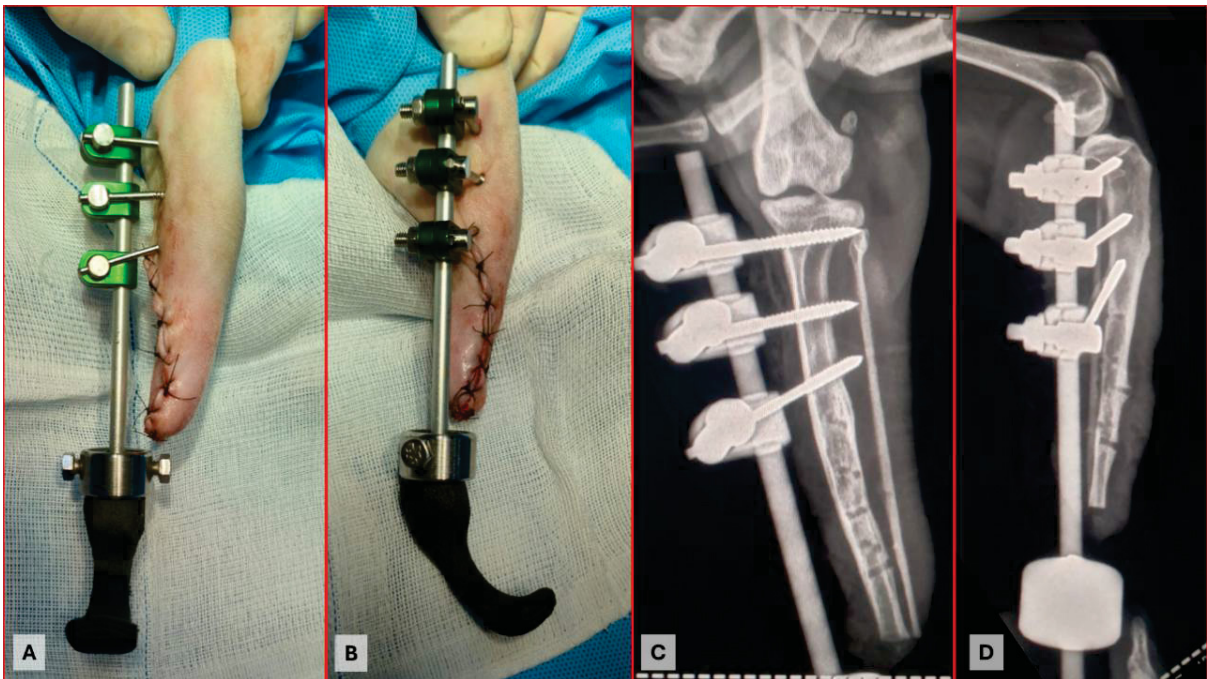


Figure 13. A: intraoperative photograph of the cranial and medial view (B) of the tibia with the application of the external fixator and exoprosthesis; C: craniocaudal and lateral median radiograph of the immediate postoperative period.

Aftercare and Follow-up

Postoperative treatment included amoxicillin + potassium clavulanate (20mg.kg dose every 12 hours orally) for 7 days; meloxicam (0.05mg.kg once daily) for 5 days; tramadol hydrochloride

(1mg.kg every 12 hours orally) for 3 days; in addition to daily cleaning of the external fixative with chlorhexidine-based antiseptic spray. The cat has adapted well, demonstrating satisfactory limb support and remains pain-free, with no complications observed 30 days postoperatively.



Figure 14. Photographs of patients with their prostheses. Cases 1 to 6, A to F respectively.

RESULTS AND DISCUSSION

We report a successful clinical case series involving the use of four intraosseous transcutaneous amputation prostheses (ITAPs) for limb preservation in three cats (Cats 1–3) with traumatic pelvic limb injuries. All three achieved satisfactory limb function and pain-free ambulation for 8, 38, and 36 months postoperatively, respectively. Cats 1 and 2 eventually died at 8 and 38 months after surgery, due to complications of Feline Leukemia Virus (FLV) and trauma from a dog attack, respectively. Cat 3 remains alive and continues to exhibit excellent functional outcomes with bilateral femoral ITAPs at 36 months postoperatively.

This series highlights both the potential benefits and possible complications associated with ITAP application in feline pelvic limbs. Osseous integration was consistently favorable across cases, with firm implant anchorage and resilient skin–implant interfaces, without evidence of skin retraction or periprosthetic infection at medium- to long-term follow-up. This represents our case with the longest ITAP follow-up to date. It was also the most challenging, given the cat’s history of multiple previous surgeries aimed at salvaging the pelvic limbs. To the authors’ knowledge, this is the first report of bilateral mid-femoral endoprostheses in cats; only one previous case of bilateral distal femoral application has been documented (Mendonça et al., 2023). The decision to pursue bilateral ITAP implantation was bold, yet it successfully avoided euthanasia, ensured quality of life for the patient, and satisfied the owners.

Although limb amputation is generally well accepted as a positive outcome in veterinary practice, detailed assessments of lifestyle or activity levels in postoperative populations are seldom reported, particularly in long-term follow-up (Dickerson et al., 2015; Goh et al., 2025). In our experience, increasing owner awareness of limb-preservation procedures has led to greater demand for such approaches, which are often advantageous compared with complete amputation. Frequently, distal limb injuries are managed with total amputation, thereby precluding the future application of ITAPs, endo-exoprostheses, or external SSPs.

In Cat 5, the decision to employ an external skeletal fixator (ESF) rather than ITAP was inspired by previous clinical experience reported by Petazzoni and Maciejowski (2025). The patient's young age, skeletal immaturity, and ongoing growth posed a risk for intraosseous implant failure. Therefore, an ESF was chosen to support skeletal development and allow functional adaptation with an external prosthesis. To the authors' knowledge, this represents the first report of ESF prosthesis use in a cat younger than 1 year. Advantages of this approach include reduced risk of skin-implant contamination or implant exposure, minimal invasion, reduced operative time compared to other techniques as well as the possibility of immediate limb use. However, owners must be informed of potential mechanical complications, such as Schanz pin breakage, which require prompt surgical revision.

Cats treated with ITAP did not experience implant-related complications despite limited access to advanced surface treatments such as acid etching, hydroxyapatite or calcium phosphate coatings (Fitzpatrick, 2011; Gorshkov, 2017), silver impregnation, or titanium nitride. ITAPs were originally developed through *in vivo* and *in vitro* studies based on the biology of deer antlers (Pendegrass et al., 2006). Fitzpatrick (2011) introduced perforated flanges and hydroxyapatite coatings to enhance osseous and dermal integration with favorable results. Our implants, in contrast, were manufactured as single-piece titanium alloy devices without coatings, yet clinical outcomes of osseointegration and dermal integration were satisfactory. One major challenge, implant exposure, was effectively mitigated through careful myopexy (Hsu, 2018).

Cats 1, 2, and 4 received calcaneal ITAPs. To the authors' knowledge, this is the first report of osseointegration in the calcaneus using an intramedullary threaded stem. This technique preserved the tibiotarsal joint, favoring feline biomechanics. Although previous studies have reported calcaneal preservation, some authors (e.g., Gorshkov, 2017) opted to initiate prosthetic design at the tibial level. In our approach, joint preservation was prioritized whenever possible, allowing for alternative options at more proximal levels in the event of complications.

Only Cat 4 developed the anticipated complication of implant exposure due to insufficient skin coverage. After 8 weeks, aseptic loosening occurred, likely secondary to biomechanical failure of the exoprosthesis design, which generated excessive lever forces and intermittent lameness. Based on this experience, we recommend that exoprostheses designed for calcaneal ITAPs should incorporate a straight, non-angled paw.

Following consultation with the owners, the ITAP was removed, and culture and sensitivity testing were performed in preparation for a new distal tibial ITAP. Meanwhile, to preserve limb support, an ESF was applied, inspired by the clinical approach of Petazzoni and Maciejowski

(2025). The outcome was so favorable that the owners elected to maintain the ESF permanently. At the time of writing (8 months postoperatively), the cat remained well adapted, with excellent function and high owner satisfaction.

The adaptability and versatility demonstrated in Cat 4 motivated the subsequent use of ESF-based prostheses in additional cases. This approach proved to be a valuable alternative for managing partial limb amputations and ITAP-related complications. Petazzoni and Maciejowski (2025) noted that, based on feline bone diameters and intramedullary canal size, external implants may provide superior biomechanical resistance compared with intramedullary devices. Although no ITAP failures occurred in our series, careful case selection and biomechanical evaluation remain essential. Moreover, external fixators represent a minimally invasive, versatile, and cost-effective option compared with titanium additive manufacturing (Arauz et al., 2021; Harrysson et al., 2015).

Despite decades of research in humans, intraosseous prostheses remain underutilized in veterinary medicine, both among practitioners and owners (Pendegrass et al., 2006; Li & Felländer-Tsai, 2021; Kvale et al., 2022). We believe the present report may encourage veterinarians to develop expertise in limb-preservation techniques and to consider them as viable alternatives to total limb amputation. Unlike amputation, which is irreversible, socket prostheses, intraosseous prostheses, and ESF-based prostheses offer flexible, potentially life-changing solutions across trauma, oncology, vascular, infectious, and neurologic conditions.

Cats 4, 5, and 6 represent the first successful applications of ESF prostheses in feline tibias. These outcomes may directly inform the further development and wider application of this technique. In Case 6, a revision surgery was performed on a cat previously treated with a distal tibial endo-exoprosthesis at another institution. The patient presented with implant exposure and osteomyelitis, yet continued to bear weight. We suspect complications were due to an excessively bulky construct (two plates and an intramedullary stem), compounded by self-trauma. Surgical revision involved thorough irrigation with povidone-iodine solution 10% (Meehan, 2025), debridement of necrotic tissue, wound closure, and stabilization with an ESF using percutaneous threaded pins. Remarkably, the cat resumed weight-bearing within 3 hours postoperatively. This approach allowed infection control, reconstruction of the soft tissues, and maintenance of prosthetic function.

Complications should not be viewed as treatment endpoints. Multiple reports have documented successful revisions (Drygas et al., 2008; Pendegrass et al., 2006; Fitzpatrick et al., 2011; Goh et al., 2025), emphasizing that perseverance and case-specific adaptations can salvage limb-preservation attempts. Solutions include the fabrication of a new ITAP, adjustment of the amputation level, or conversion to ESF prostheses, as described in this series. In our experience, complications are expected because implants are foreign bodies that traverse the skin and remain subject to predictable mechanical and biological risks (Drygas et al., 2008). No “perfect” implant exists; rather, meticulous surgical planning and case-by-case adaptation are key to minimizing complications.

Based on our observations, several technical considerations are critical to success in limb-preservation surgery: Surgical planning must be validated by an experienced orthopedic

surgeon to prevent biomechanical errors; Skin redundancy should be anticipated, leaving extra tissue for closure to avoid postoperative retraction; Layered dissection of skin and muscles at different levels is necessary to achieve adequate implant coverage; Myopexy must be performed correctly to secure muscle groups over the implant, preventing tissue retraction and implant exposure. Daily antiseptic pin care is essential for maintaining skin–implant integrity, whether in ITAP or ESF applications.

Rising owner awareness of limb-preservation techniques is increasing demand for these procedures (Fitzpatrick et al., 2011; Mendonça et al., 2023). In our view, they offer advantages over irreversible total limb amputation (Dickerson et al., 2015; Kneringer & Schnabl-Feichter, 2024). Whenever feasible, preservation of residual bone stock should be prioritized to maintain the possibility of future ITAP or ESF prosthesis application.

We documented the clinical application of five ITAPs and three external fixators in six cats. Although our experience is encouraging, cautious interpretation is warranted when extrapolating these results. In our first ESF case (Cat 4), a Schanz pin fractured at 2 months. We had underestimated tibial pin requirements (initially two pins), but revision with three larger-diameter (2.5 mm) pins provided stable fixation that remains intact at 9 months postoperatively.

Ultimately, the success of limb-preservation surgeries depends on multidisciplinary collaboration and alignment of expectations between surgeons and owners. Patient selection must consider clinical condition, comorbidities, temperament, and owner commitment. Without mutual dedication, limb-preservation is not recommended.

The use of ITAPs and ESF-based prostheses for limb preservation in cats proved feasible and yielded favorable short- and long-term outcomes in this series of traumatic pelvic limb injuries. Despite minor complications, resolution was achievable, allowing limb preservation, improved quality of life, and high owner satisfaction.

REFERENCES

- ARAUZ, P. G. et al. New technologies applied to canine limb prostheses: A review. **Veterinary World**, v. 14, n. 10, p. 2793, 2021.
- CARR, B. J. et al. Retrospective study on external canine limb prosthesis used in 24 patients. **Veterinary Evidence**, v. 3, n. 1, 2018.
- DE FREITAS, I. B. et al. Bilateral Femoral Intraosseous Transcutaneous Amputation Prosthesis (ITAP) in a Cat. **Acta Scientiae Veterinariae**, v. 53, 2025.
- DICKERSON, V. M. et al. Outcomes of dogs undergoing limb amputation, owner satisfaction with limb amputation procedures, and owner perceptions regarding postsurgical adaptation: 64 cases (2005–2012). **Journal of the American Veterinary Medical Association**, v. 247, n. 7, p. 786-792, 2015.

- DRYGAS, K. A. et al. Transcutaneous tibial implants: a surgical procedure for restoring ambulation after amputation of the distal aspect of the tibia in a dog. **Veterinary Surgery**, v. 37, n. 4, p. 322-327, 2008.
- FARIA L.G. & ROCHA T.A.S.S. 2022. Órteses e Próteses. In: Minto B.W. & Dias L.G.G.G. (Eds). **Tratado de Ortopedia de Cães e Gatos**. v.1. São Paulo: Medvet, pp.464-481
- FITZPATRICK, N. et al. Intraosseous transcutaneous amputation prosthesis (ITAP) for limb salvage in 4 dogs. **Veterinary surgery**, v. 40, n. 8, p. 909-925, 2011.
- FORSTER, L. M. et al. Owners' observations of domestic cats after limb amputation. **Veterinary record**, v. 167, n. 19, p. 734-739, 2010.
- GOH, M. R. Y; JAMES, D. R. Limb Straightening and Osseointegrated Transcutaneous Amputation Prosthesis in a Dog with Angular Limb Deformity. **VCOT Open**, v. 8, n. 01, p. e28-e34, 2025.
- GORSHKOV S.S. et al. Percutaneous osseointegrated prosthetics of limbs in dogs and cats after partial amputation based on a series of clinical cases. *VetPharma*, No. 4 (38), p. 58-73, 2017.
- HARRYSSON, Ola LA; MARCELLIN-LITTLE, Denis J.; HORN, Timothy J. Applications of metal additive manufacturing in veterinary orthopedic surgery. **Jom**, v. 67, n. 3, p. 647-654, 2015.
- HSU, A.R. Transfemoral amputation adductor myodesis using FiberTape and knotless anchors. **Foot & Ankle International**, v. 39, n. 7, p. 874-879, 2018.
- JARRELL, J.R. et al. Kinetics of individual limbs during level and slope walking with a unilateral transtibial bone-anchored prosthesis in the cat. **Journal of biomechanics**, v. 76, p. 74-83, 2018.
- KIMURA, Shogo et al. Limb amputation for feline appendicular bone tumors results in excellent recovery outcomes and high owner satisfaction with a low incidence of complications. **Journal of the American Veterinary Medical Association**, v. 1, n. aop, p. 1-7, 2025.
- KNERINGER, C.; SCHNABL-FEICHTER, E. Intraosseous Transcutaneous Amputation Prosthesis (ITAP) compared to Exoprosthesis in veterinary medicine—a literature review. **Tierärztliche Praxis Ausgabe K: Kleintiere/Heimtiere**, v. 52, n. 06, p. 359-366, 2024.
- KVALE, E.; RUEDA, R. C.; FITZPATRICK, N. Limb-sparing surgery in two cats using a femoral endoprosthesis with an integrated total knee replacement implant. **Veterinary and comparative orthopaedics and traumatology**, v. 35, n. 02, p. 134-142, 2022.
- LI, Yan; FELLÄNDER-TSAI, Li. The bone anchored prostheses for amputees—Historical development, current status, and future aspects. **Biomaterials**, v. 273, p. 120836, 2021.

- MARCELLIN-LITTLE, D. J. et al. Orthoses and exoprostheses for companion animals. **Veterinary Clinics: Small Animal Practice**, v. 45, n. 1, p. 167-183, 2015.
- MEEHAN, John P. Dilute povidone-iodine irrigation: the science of molecular iodine (I₂) kinetics and its antimicrobial activity. **JAAOS-Journal of the American Academy of Orthopaedic Surgeons**, v. 33, n. 2, p. 65-73, 2025.
- MENCHETTI, Marika et al. Approaching phantom complex after limb amputation in cats. **Journal of Veterinary Behavior**, v. 50, p. 23-29, 2022.
- MENDEZA-DECAL, Rosa et al. Biomechanical Tests on Long-Bone Elliptical Medullary-Canal Endoprostheses for Limb Salvage in Dogs. **Animals**, v. 12, n. 21, p. 3021, 2022.
- MENDONÇA, A. G. C. et al. Fixed bilateral endo-exo prostheses in feline femur-case report. **Arquivo Brasileiro de Medicina Veterinária e Zootecnia**, v. 75, n. 01, p. 107-112, 2023.
- PENDEGRASS, C. J. et al. Nature's answer to breaching the skin barrier: an innovative development for amputees. **Journal of anatomy**, v. 209, n. 1, p. 59-67, 2006.
- PENDEGRASS, C.J.; GOODSHIP, A.E.; BLUNN, G. W. Development of a soft tissue seal around bone-anchored transcutaneous amputation prostheses. **Biomaterials**, v. 27, n. 23, p. 4183-4191, 2006.
- PETAZZONI, M; MACIEJOWSKI, T. Bilateral hindlimb custom-made external-fixation amputee prostheses in a cat. **Companion Animal**, v. 30, n. 8, p. 2-10, 2025.
- RASKE, M.; MCCLARAN, J. K.; MARIANO, A. Short-term wound complications and predictive variables for complication after limb amputation in dogs and cats. **Journal of Small Animal Practice**, v. 56, n. 4, p. 247-252, 2015.
- ROSEN, S.; DUERR, F. M.; ELAM, L. H. Prospective evaluation of complications associated with orthosis and prosthesis use in canine patients. **Frontiers in Veterinary Science**, v. 9, p. 892662, 2022.
- WAGNER, John R. et al. Complications and owner satisfaction associated with limb amputation in cats: 59 cases (2007–2017). **BMC Veterinary Research**, v. 18, n. 1, p. 147, 2022.

CHAPTER 3**Custom-made Endoexoprostheses for limb salvage in 5 dogs**

**The chapter will be formatted and submitted to a journal of the authors' choice.

Custom-made Endoexoprostheses for limb salvage in 5 dogs

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Objective: To report clinical application of Endoexoprosthesis for limb salvage in 5 dogs.

Study Design: Case series.

Sample Population: Client owned dogs with bone tumor, traumatic limb injuries and malformation.

Method: Limb partial amputation allowed insertion of the endoexoprosthesis into the Tibias (n = 5) and radius and ulna (n= 1). Remaining soft tissues including skin were attached around to the implant. The implants were produced by 3D printing titanium by Direct Metal Laser Sintering (DMLS) or machined in the alloy (Ti6Al4V), while the exoprostheses were individually customized through 3D printing using Thermoplastic Polyurethane (TPU) and aluminium. Measures of outcome included subjective assessments of limb function by owners and veterinarians and radiographic.

Results: The patients demonstrated favorable outcomes with limb-preserving procedures, showing adequate limb support postoperatively and high owner satisfaction by avoiding total amputation. Although complications are common in such interventions, they were managed effectively. In this case series, observed complications included pin–skin interface infections (60%; dogs 1, 2, and 4), osteomyelitis (20%; dog 2), and exoprosthesis fractures (40%; dogs 2 and 3). All patients received appropriate treatment and recovered, only the case 2 awaits resolution based on owner availability. No skin retraction or implant exposure was observed in this study, which we believe was largely attributable to the use of a simple myopexy device developed by the authors.

Conclusion:

The use of endo-exoprostheses for limb preservation is feasible and provided favorable short- and long-term outcomes in five dogs with bone neoplasms (3), malformations (1), or traumatic pelvic limb injuries (1). Complications occur but can be managed to preserve the affected limb, provide support, and maintain quality of life, with owner satisfaction.

INTRODUCTION

Osteosarcoma (OSA) is the most prevalent primary bone tumor in dogs and represents a significant clinical challenge for veterinarians worldwide, with amputation of the affected limb considered the surgical gold standard for several decades (Dickerson et al., 2015; Wustefeld-Janssens et al., 2020; O'Neill et al., 2023).

Partial amputations for adaptation of socket or transcutaneous prostheses have evolved in human medicine and are beginning to gain traction in veterinary practice (Raske et al., 2015; Polton et al., 2025). Although both partial and total amputation allow for complete tumor removal with a low risk of infection, they may exacerbate pre-existing orthopedic alterations, particularly in large-breed animals, and can raise owner concerns regarding their pets' quality of life (Kirpensteijn et al., 2000; Panichi et al., 2025).

Technological innovations, particularly additive manufacturing (3D printing) (Thomas et al., 2025), the use of advanced biomaterials, and the implementation of osteointegrated transcutaneous prostheses (ITAPs), represent significant advancements in the development of canine prosthetics (Fitzpatrick et al., 2011; Jeyapalina et al., 2019). These approaches have the potential to optimize locomotor function, enhance animal welfare, and expand available therapeutic options (Kimura et al., 2025). However, the integration of these techniques into routine veterinary practice depends on controlled clinical studies, standardized surgical protocols, and systematic evaluation of long-term functional and survival outcomes (Harrysson et al., 2015; Arauz et al., 2021; Yazawa et al., 2024).

Socket prostheses (SSPs) remain the most frequently reported form of amputation prosthesis in veterinary literature (Rosen et al., 2022; Wendland et al., 2023). Challenges primarily relate to species variability and patient-owner compliance. The main complications include discomfort, infection, pressure ulcers, necrosis, poor fit, device failure, and poor patient acceptance (Marcellin-Little et al., 2015; Overmann and Forsberg, 2019; Wagner et al., 2022; Kneringer and Schnabl-Feichter, 2024).

Endo-exoprostheses are limb-preserving surgical devices developed to address the limitations of SSPs. Through an internal implant (endoprosthesis) anchored to the patient's bone, an exoprosthesis can be connected via a percutaneous connector rod that transverses the skin. Despite advances, reports in veterinary medicine remain limited, including transcutaneous tibial implants in a dog (Drygas et al., 2008), intraosseous transcutaneous amputation prostheses (ITAP) in four dogs (Fitzpatrick et al., 2011), bilateral femoral application in a cat (Mendonça et al., 2023), and the innovative custom-made bilateral femoral fixation in a cat (Petazzoni and Maciejowski, 2025).

The main challenges associated with amputation prostheses are the maintenance of healthy bone-implant and skin-implant interfaces, implant exposure, fractures, and stump infections. Several studies have sought to address these challenges and reduce complications, ranging from implant customization to advanced surface coatings, which continue to evolve (Pendegrass et al., 2006; Drygas et al., 2008; Fitzpatrick et al., 2011; Li and Felländer-Tsai, 2021; Mendaza et al., 2022; Kvale et al., 2022).

We hypothesized that the application of an endoexprosthesis would be technically achievable, foster stable and long-lasting integration with osseous and dermal tissues, and facilitate functional limb use when paired with an appropriate exoprosthesis. Our objective was to describe the development, application, monitoring and complications in 6 endoexprotheses in 5 dogs.

MATERIALS AND METHODS

This study was approved by the Ethics Committee on the Use of Animals (CEUA) of the Agricultural Sciences Sector at the Federal University of Paraná (UFPR), Brazil, under protocol number 051/2022, in accordance with the regulations issued by the National Council for the Control of Animal Experimentation (CONCEA). All owners signed an informed consent form prior to participation in the study.

Each patient was evaluated according to their clinical, physiological and biomechanical characteristics in search of the best development of the implant for limb preservation.

The implants were produced by 3D printing titanium by Direct Metal Laser Sintering (DMLS) or machined in the alloy (Ti6Al4V).

The surgical planning of the amputation site of each limb consisted of measuring the diameter of the medullary canal and its corticals based on orthogonal radiographic projections and/or computed tomography of the limb using medical imaging software, Radiant[®] DICOM Viewer software.

From this careful medical evaluation, the implants were designed and applied in each case. The machined implants had an average production time of 8 days, while the titanium 3D printed implants were 30 days. The exoprotheses were made in CAD software (Fusion 360[®] and SolidWorks[®]) and FDM 3D printing in Thermoplastic Polyurethane (TPU) or manufactured in aluminum.

The specific patient devices were produced by Cão Medica[®], Engevet[®] and Cubo Biomedical[®] company 3d titanium. They ranged from intramedullary (Fig 1A), hybrids (Fig 1B, E) and orthogonal plates (Fig 1C, D).

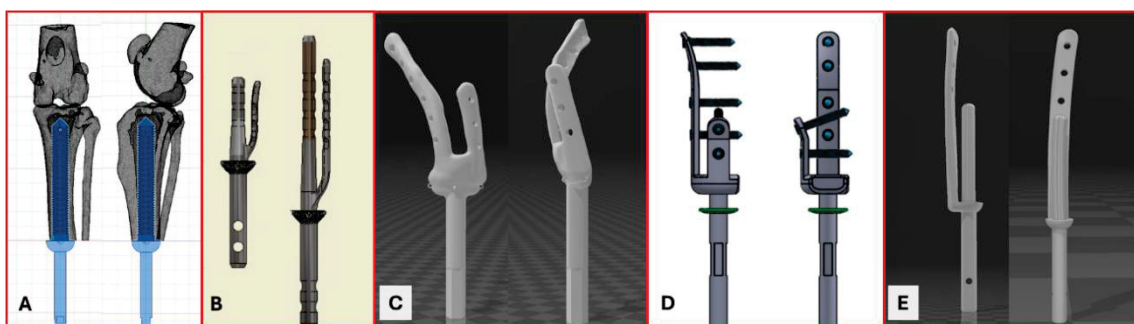


Figure 1. Illustrative image of the implant planning for patients in two views, cranial and medial, respectively, from dog 1 (A) to dog 5 (E).

The inclusion criteria for this case series were dogs treated in the orthopedic routine with bone neoplasia, malformation and severe musculoskeletal trauma that allowed the use of endoexoprosthesis for limb preservation. Cancer patients were only submitted to the surgical procedure after staging and exclusion of metastasis.

RESULTS

Dog 1

A 12-year-old neutered male, 31kg, Cimarron Uruguay was admitted for evaluation of intermittent progressive left pelvic limb lameness. The patient presented with mild swelling in the distal region of the tibia and was referred for orthopedic evaluation and possible limb-sparing selection. Orthogonal radiographs revealed increased volume and evidence of osteolytic lesions in the distal third of the left tibia. A bone biopsy and computed tomography were recommended to enable tumor resection and limb preservation with a customized implant. However, between the time of the biopsy and the CT scan, the owner declined any surgical procedure. The biopsy result indicated benign spindle cell proliferation, and the owner refused surgical intervention, believing it was not a neoplasm. The tumor subsequently exhibited slight growth, and once the patient was unable to bear weight on the limb, the owner returned seeking treatment. Conservative techniques were excluded due to tumor progression, and partial amputation at the mid-tibia level was selected for the application of an osseointegrated prosthesis. The patient underwent preoperative evaluations, including bloodwork, cardiac examination, and thoracic radiography, all of which showed no abnormalities. Computed tomography was used for surgical planning, osteotomy level determination, implant customization, and endo-exoprosthesis design with the aid of CAD software. The implant was machined from titanium and consisted of a threaded intramedullary pin with a diameter of 11.5 mm, a proximal hole for fixation with a 2.5 mm Steinmann pin, a flange 22 mm in width, and a connector rod 8 mm in diameter. Additionally, a surface treatment known as “shot peening” was applied to the titanium flange and the initial portion of the connector rod (Fig. 2D).

Surgical Technique

The patient was positioned in dorsal recumbency, with a skin incision made at the distal third and a muscular incision at the mid-third of the limb. A transverse osteotomy was performed using a sagittal saw blade under continuous saline irrigation of both the blade and bone. After partial limb removal, the intramedullary canal was prepared with sequential reamers ranging from 3.5 mm to 9 mm in diameter. The threaded intraosseous implant was then inserted with the aid of a manual Jacobs chuck introducer. During surgery, an intraoperative complication was encountered in which the implant diameter exceeded the actual canal size. This issue was resolved by additional canal reaming followed by final impaction of the prosthesis. The musculature was sutured around the implant flange with 0 nylon, the soft tissues with 2-0 nylon, and the skin with 3-0 nylon. The amputated limb was submitted for histopathological examination. Due to the technical difficulty encountered during implant insertion and to promote osseointegration, the patient was restricted from weight-bearing on the implant for three weeks.

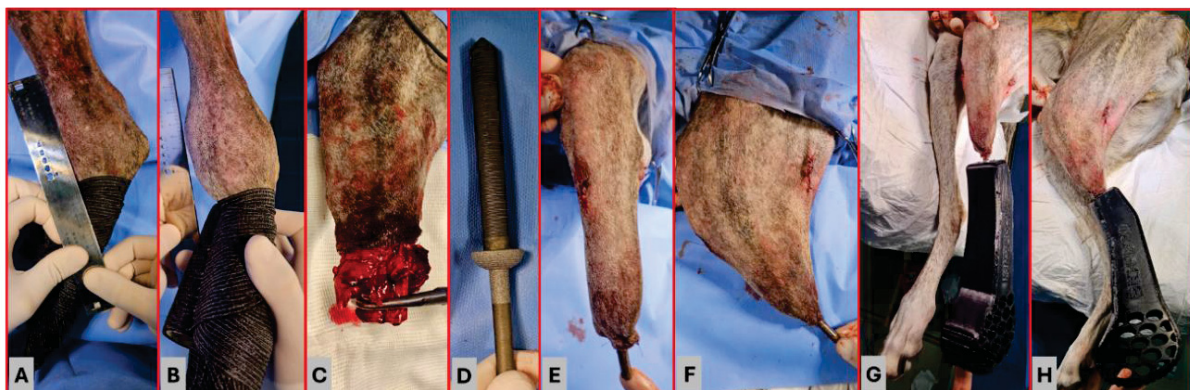


Figure 2. Photographic images of the intraoperative moment of the patient 1. A: lateral view of the distal tibial neoplasm and B: frontal view; C: surgical appearance after amputation; D: intramedullary implant; E: frontal and lateral view (F) after surgery and G: final frontal and lateral aspect (H) after the application of the exoprosthesis.

Aftercare and Follow-Up

The patient was hospitalized for 24 hours for initial care in the hospital. Received cephalixin (22 mg/kg orally every 12 hours) was administered for 21 days; meloxicam (0,1 mg/kg orally every 24 hours) for 5 days; tramadol hydrochloride (1 mg/kg orally every 12 hours) for 5 days; dipirona (25mg/kg orally every 12 hours) for 5 days and neomycin ointment was applied to the skin-ITAP interface at the time of bandage change. After 15 days, the histopathological result came out, which confirmed Grade III Osteosarcoma. He was referred for oncological care and chemotherapy with Doxorubicin every 21 days + Piroxicam for 21 days.

After three weeks, the exoprosthesis was implanted, and the patient adapted quickly, achieving adequate weight-bearing without pain or lameness. Following the second chemotherapy session (42 days postoperatively), the patient developed an inflammatory reaction around the implant. A culture and antimicrobial susceptibility test were performed, revealing contamination by *Proteus sp.*, which was sensitive to several antibiotics. Amoxicillin–clavulanate (22 mg/kg, every 12 hours for 15 days) was selected, effectively controlling the periprosthetic infection. The patient remained clinically stable, well-adapted, and ambulated normally using the prosthesis, with the owners reporting high satisfaction, while continuing the chemotherapy protocol. Unfortunately, six months after surgery, the patient developed pulmonary metastasis and was euthanized.

DOG 2

An 8-year-old intact male, 18.9kg, mixed-breed was rescued after had been abandoned on the train tracks, where it was struck by a train, resulting in the loss of the distal portion of both tibias and presenting in a state of shock. An initial emergency surgery was performed, consisting of an amputation as distal as possible in order to preserve soft tissues for wound closure and to allow subsequent application of an endoexoprostheses at the tibias. The patient

initially received treatment to repair severe limb injuries and, after nine months, underwent CT imaging for the planning of customized intraosseous percutaneous endoprostheses. The implants were designed using CAD software (Fusion 360), and 3D-printed PolyLactic Acid (PLA) biomodels were produced to test and correct potential planning errors. After several trials, hybrid implants were selected, consisting of an internal rod combined with a medial locking plate, with its screws traversing the rod. The finalized files were then sent for 3D printing in titanium using laser sintering (Fig. 3). Following printing, the implants were forwarded to a veterinary company for machining of the locking screw threads in the plate holes with locked titanium screws 2.7mm.



Figure 3 A: Final 3D prototyping of the patient's implants. B: Completion of the laser printing of the titanium implants. C: Presentation of the implant after removal of the holders. Carried out in partnership with the Renato Archer Information Technology Center – Campinas -SP.

Surgical Technique

The patient was positioned in dorsal recumbency, and an iodophor adhesive drape was applied to protect the surgical field and reduce potential skin contamination (Fig. 4A). Medial tibial incisions were performed, followed by muscle dissection. Distal stump osteotomies were carried out using a sagittal oscillating saw with a 1-mm blade (Fig. 4B). The medullary canal was subsequently prepared with reamers to achieve a diameter of 6–8 mm, and the plate fitting site was refined using a 2-mm Kerrison rongeur. After positioning the implants into the intramedullary canal, locking screws were inserted with the aid of the Engevet guiding system. The porous collar was designed to promote both osseointegration and dermal integration. Musculature was sutured using PGCL 0 suture material, and the skin was closed with 3-0 nylon (Sultan). At the conclusion of the procedure, the patient's exoprostheses were attached (Fig. 4).

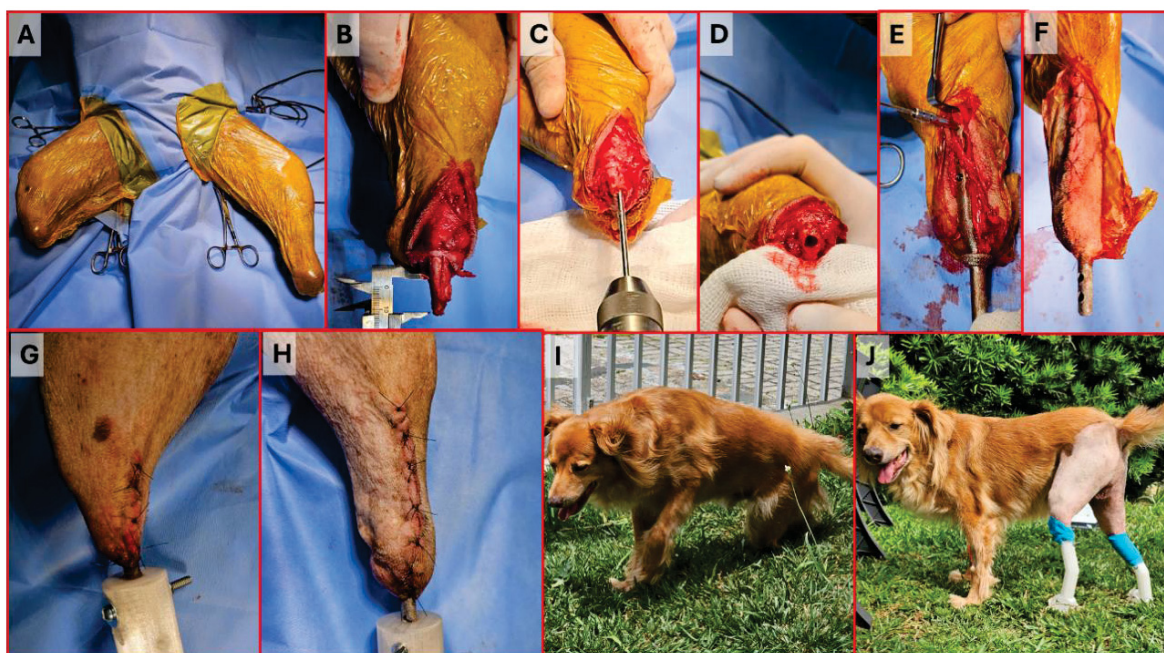


Figure 4. A: Photograph of the patient in the supine position properly dressed for the surgical procedure. B: caliper with measurement for resection and alignment of the left pelvic limb stump; C: milling of the intramedullary canal with a drill; D: preparation of the channel; E: implant properly applied in the left tibia; F: final aspect of the skin suture and stump of the left limb; G: right and left limb (H) after the end of the procedure with coupled exoprosthesis; I: Patient's posture before the procedure; J: Patient's posture 4 hours after the limb salvage procedure.

Aftercare and, Follow-Up

Postoperative treatment included Cefovecin Sodium (Convenia® - 8 mg/kg, subcutaneous every 15 days for 2 repetitions), meloxicam (Maxicam®- 0.1 mg/kg, orally every 24 hours for 5 days), tramadol hydrochloride (Cronidor®- 2 mg/kg, orally every 12 hours, for 5 days), dipirona (25mg/kg every 12hours for 5 days) and daily cleaning with chlorhexidine-based antiseptic once daily, continuous use. The patient remained hospitalized for 24h for surgical site monitoring. The patient experienced difficulty ambulating with the prostheses, which were slightly long and structurally fragile. After a few hours of use, the left exoprosthesis collapsed and required replacement. The patient subsequently ambulated well for six months; however, the right external prosthesis, being longer, exerted a lever effect that resulted in instability of the intraosseous implant. Consequently, the implants were removed, followed by Betadine lavage (Meehan, 2025), culture, and antibiogram testing. Local application of calcium sulfate impregnated with vancomycin and gentamicin was performed to control the local infection and allow for future surgical revision.

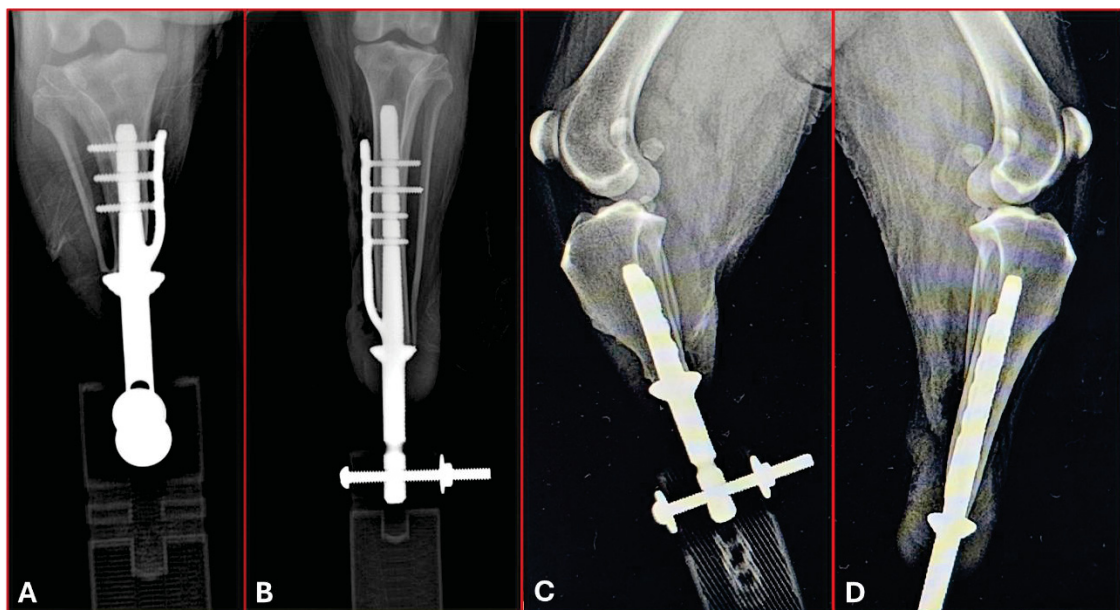


Figure 5. X-rays of the patient in the immediate postoperative period. A: anteroposterior projection of the right and left limb (B). C: medial-lateral radiographic projection of the right and left limb (D)

DOG 3

A 2-year-old intact female, 30kg, golden retriever, with malformation in the radius and right ulna. Performed radiography for follow-up during growth and computed tomography for surgical planning and customization of the dedicated implant. Due to the limited bone stock, it was not possible to place an osteointegrative implant. Therefore, two plates one on the radius and the other on the ulna were used in an attempt to preserve and utilize the remaining limb stump. The implant was designed in CAD software and 3D printed in titanium by Direct Metal Laser Sintering (DMLS) by Cubobiomedical[®] and received surface treatment with titanium nitride. The external prosthesis was 3D-printed using TPU and cutting guide were customized to assist in osteotomy.

Surgical Technique

Following appropriate limb preparation, the patient was positioned in left lateral recumbency, and the surgical site was aseptically prepared with 0.5% alcoholic chlorhexidine and draped with a sterile field. A craniolateral approach to the radius was performed, with a skin incision dissection and distal region exposure for application of the 3D guide in PoliLactic Acid High Temperature (HT-PLA) sterilized in autoclave. In this case, the stump was preserved without distal incision. A central perforation was created, and the external connecting rod was passed through it to minimize skin retraction and implant exposure. The cranial aspect of the radius and the lateral aspect of the ulna were minimally

dissected to reduce the risk of complications, such that the main incision was limited to the lateral surface. The plate was positioned, and the holes were filled with 3.5-mm in the ulna and 2.7mm in the radius with titanium locking screws. Muscular closure was performed using 2-0 polydioxanone (PDS) with interrupted and Sultan sutures, and dead space was minimized with 3-0 PDS. The skin was closed with 3-0 nylon sutures (Figure 6). Endoexoprosthesis was coupled 1 week after the operation due to the time for its manufacture.

Aftercare and Follow-up

Postoperative treatment included Cephalexin (22 mg/kg, orally every 12 hours) for 15 days, meloxicam (0.1 mg/kg, orally every 24 hours) for 5 days, tramadol hydrochloride (4 mg/kg, orally every 12 hours) for 5 days, dipirona (25mg/kg orally every 12hours) for 5 days and daily cleaning with chlorhexidine-based antiseptic and neomycin ointment was applied to the skin-pin interface once daily, for 30 days. The patient remained hospitalized for 24hours for surgical site monitoring. After 1 week, the prosthesis was attached and physiotherapy was started 2 times a week for adaptation. There was no contamination at the pin-skin interface, seroma or any other complication. After 45 days, the patient cracked the exoprosthesis and was replaced. At the time of this report, 6 months postoperatively, the patient exhibits no signs of pain or orthopedic complications and uses the member satisfactorily.

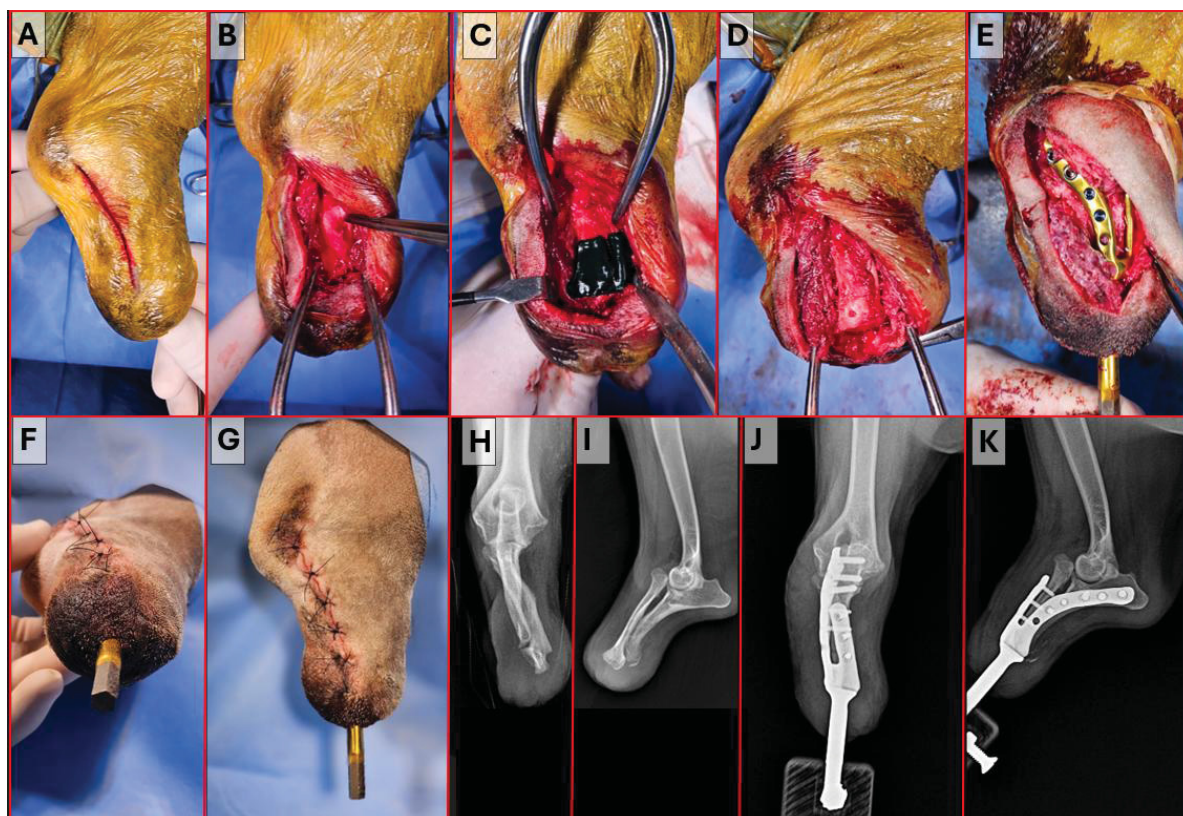


Figure 6. Stages of the surgical procedure. A: preparation and incision of skin on the lateral aspect of the malformed limb. B: dissection preserving the patient's stump; C: Application of the 3D printed cutting guide in PLA HT; D: final appearance after osteotomy with a linear saw; E: application of the prosthesis in the limb; F: photograph shows the final aspect of the surgical procedure around the external implant and a lateral view (G); H: anteroposterior and medial lateral radiographic projection (I) of the right elbow; J: Radiograph of the patient in the immediate postoperative period in the anteroposterior and medial lateral projection (K).

DOG 4

A 10-year-old neutered female German Shepherd, weighing 36.8 kg, presented for orthopedic evaluation due to left pelvic limb lameness. Since January, the owner had sought veterinary care in an attempt to clarify the diagnosis. In February 2025, a bone biopsy was performed at another service, where osteomyelitis was suspected. Histopathology revealed multifocal to coalescing osteonecrosis (mild to moderate), mildly atypical spindle cell proliferation, and bone proliferation with remodeling. The patient was treated for osteomyelitis without improvement, with progressive bone enlargement. In May 2025, the owner sought our team, and bone tumor was immediately suspected. Surgical planning was initiated using orthogonal radiographs. For this case, an orthogonal double-plate implant was selected, particularly due to the strong suspicion of malignancy and the prolonged period of unsuccessful clinical management. The implant was machined in titanium, consisting of one cranial and one medial plate with 3.5-mm locking screws and an external connector rod

measuring 8 mm. To prevent excessive skin retraction, we developed a myopexy device (Fig. 7G), consisting of a perforated titanium component that allows fixation of soft tissues and reduces tractional forces on the stump. The exoprosthesis was fabricated in aluminum (Fig. 7H, I).

Surgical Technique

The surgical procedure was similar to the technique described in dog 1. The patient was positioned in dorsal recumbency, and the limb was prepared and draped with surgical adhesive. A skin incision was made at the distal third of the tibia, with muscle resected at the mid-diaphyseal level and bone transected proximally to ensure adequate surgical margins. Osteotomy was performed using an oscillating saw under continuous irrigation with saline solution to prevent thermal necrosis. Minimal dissection was then carried out to allow insertion of the locking screws, followed by muscle closure. In this patient, a device for myopexy was developed, which enabled approximation of the surrounding muscles to the implant using 2-0 nylon in Sultan sutures, subcutaneous closure with 3-0 polyglycolide-co-caprolactone (PGCL), and skin closure with 3-0 nylon in Sultan suture (Fig 7). A temporary exoprosthesis was placed in the patient while the final version was ready. The removed limb was sent for histopathology.

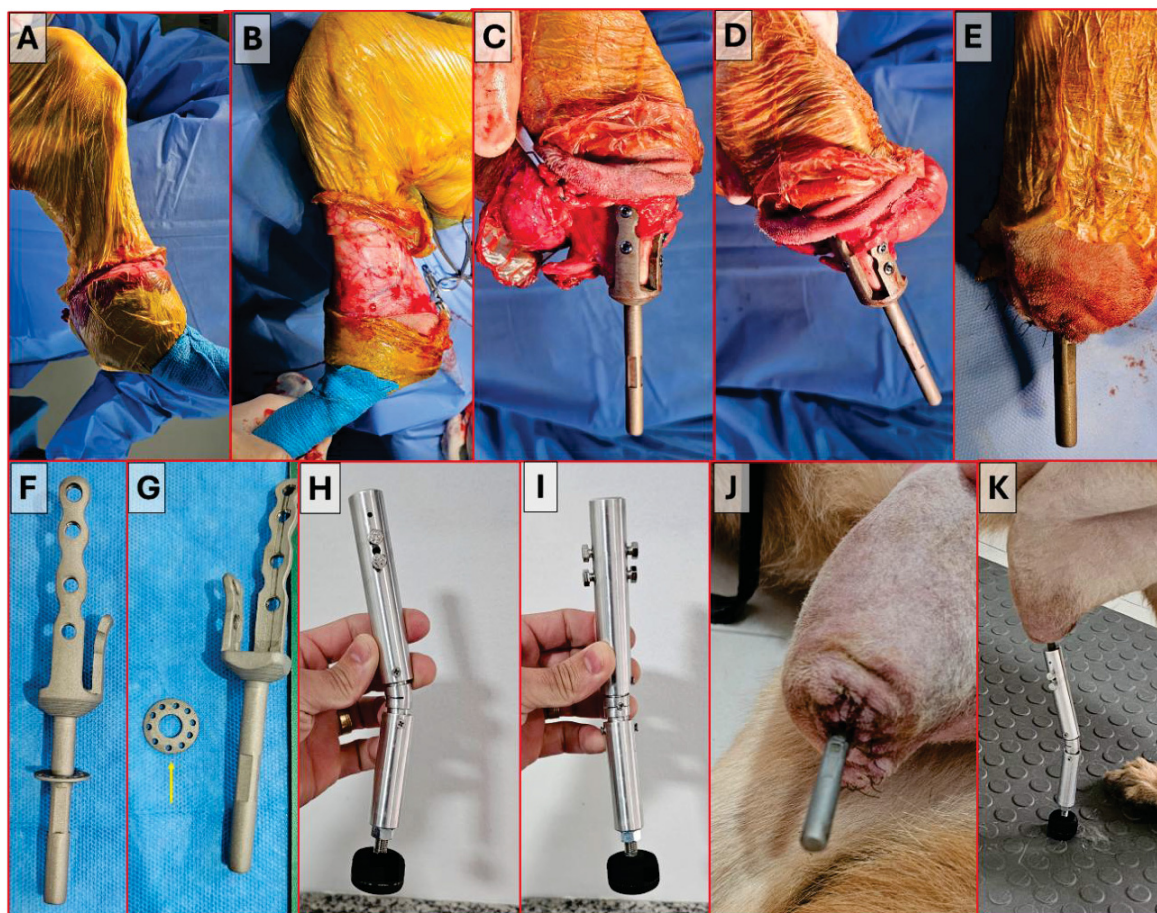


Figure 7. Photographs of the surgical approach. A: Preparation of the patient and skin incision just above the tumor. B: dissection of soft tissues and identification of neoplasia; C: lateral view after the application of the plate to the patient's tibia and frontal view (D); E: final appearance of the stump after the procedure and skin suture. F and G: photograph of the titanium machined implant in the medial view and the presence of the device for myopexy (yellow arrow); H: photograph of the medial and cranial view (I) of the aluminum machined exoprosthesis; J: appearance of the surgical wound 15 days after surgery; k: patient adapting to the prosthesis.

Aftercare and Follow-up

Cephalexin (20 mg/kg, orally every 12 hours) for 15 days, meloxicam (0.1 mg/kg, orally every 24 hours) for 5 days, tramadol hydrochloride (4 mg/kg, orally every 12 hours) for 3 days and dipirona (25mg/kg orally every 12 hours) for 5 days. Use of an Elizabethan collar was mandatory until suture removal at 15 days, and daily wound dressing with povidone-iodine was performed. The patient remained hospitalized for 24h for surgical site monitoring. During hospitalization, the patient already began to show interest in bearing weight on the limb. After 5 days the Histopathological examination revealed a highly productive osteoblastic osteosarcoma.

After 2 weeks, the patient returned for evaluation, suture removal, and replacement of the definitive external prosthesis. The patient was consistently weight-bearing, without lameness or pain, and exhibited good skin-to-implant healing. The immediate postoperative and 30-

day radiographs are shown in Figure 8. Due to financial constraints, the owner was only able to initiate chemotherapy with carboplatin 45 days after surgery. At the time of this report, the dog was in good condition, with no skin retraction, well-adapted, and undergoing chemotherapy sessions (4 months postoperatively).

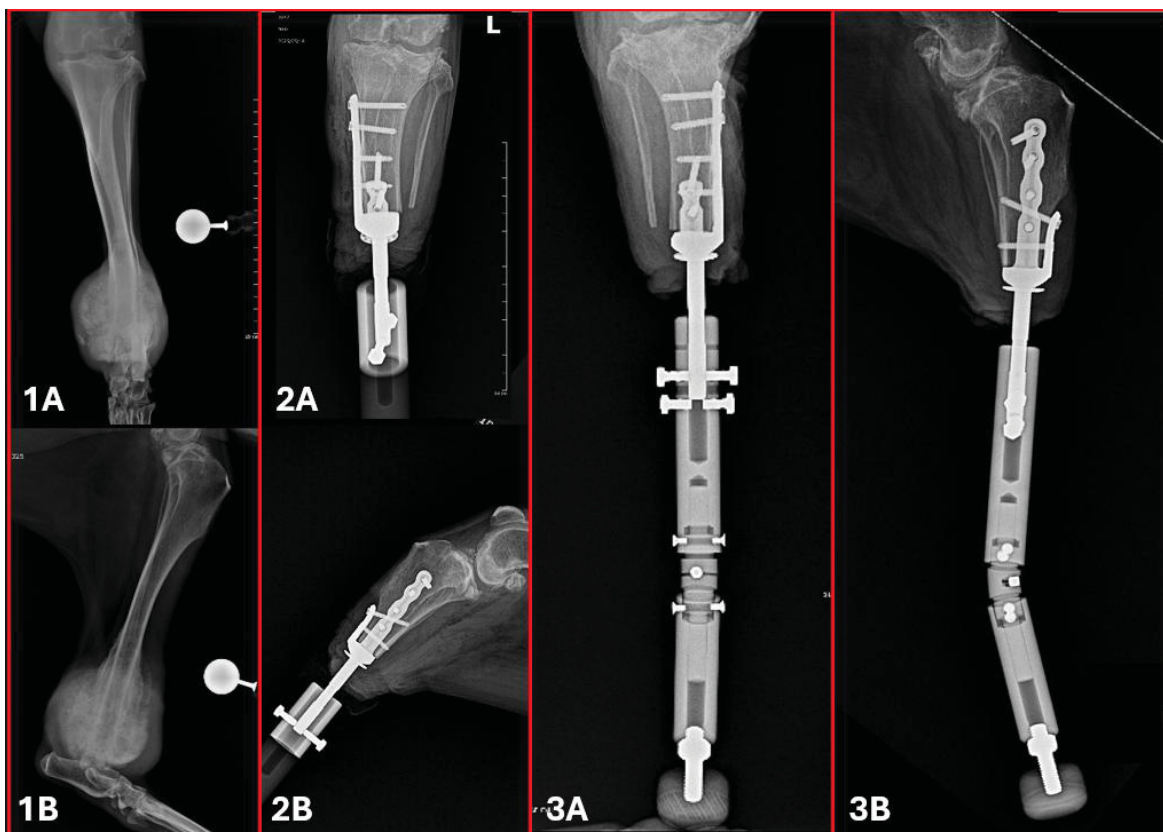


Figure 8. 1A: Preoperative X-ray of the patient in the craniocaudal and medial lateral view(1B); Immediate postoperative radiograph in cranial (2A) and mediolateral (2B) views; 3A: X-ray 30 days postoperatively in the cranial and mediolateral view (3B) of the patient with the connected exoprosthesis.

DOG 5

A 6-years-old neutred male, 42kg, Belgian Shepherd Groenendael. The patient presented with right hindlimb lameness and had previously undergone evaluation by an oncologist, who performed a bone biopsy due to suspected Distal tibial osteosarcoma. Computed tomography was requested to evaluate the presence of pulmonary metastases and to assist in surgical planning of the affected limb, surgical planning, implant development, and exoprosthesis. Development of an implant with an internal nail and medial locked plate. Osteotomy guide was also produced by 3D printing in biocompatible resin and the implant was produced by 3D printing titanium.

Surgical Technique

The dog was positioned in dorsal recumbency to facilitate a surgical approach to the tibia. Once properly prepared, the limb was isolated with iodophor adhesive, and a skin incision was made at the distal third, with the muscle incision slightly more proximal and the

osteotomy performed at the mid-diaphyseal level of the tibia with the 3D cutting guide, ensuring adequate surgical margins. The blood vessels were ligated using 2-0 PGCL, and after removal of the distal portion of the limb, the intramedullary canal was prepared. Subsequently, the implant was positioned and secured with three 3.5-mm diameter locking screws, each 26 mm in length. A titanium myopexy device was fabricated, and the musculature was sutured through its holes using 2-0 nylon to ensure proper fixation and prevent postoperative complications. The subcutaneous tissue was closed with 2-0 PGCL, and the skin was sutured with 3-0 nylon in a Sultan pattern. At the end of the procedure, the exoprosthesis was attached, and the patient was transferred to anesthetic recovery (Figure 9) and underwent postoperative radiography (Fig 10). The patient was aggressive in behavior; therefore, it was discharged home 4 hours postoperatively.

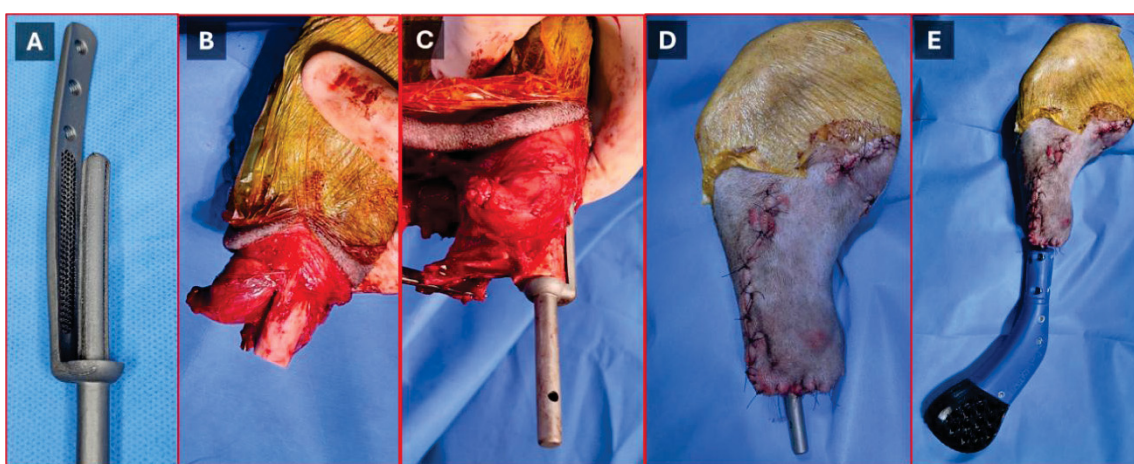


Figure 9. A: photograph of the implant printed on titanium; B: intraoperative imaging after tumor resection; C: application of the implant; D: final appearance of the limb after surgery and (E) applied exoprosthesis at the end of the procedure.

Aftercare and Follow-up

Postoperative treatment included amoxicillin + potassium clavulanate (20mg/kg dose every 12 hours orally) for 7 days; firocoxib (5mg/kg once daily) for 5 days; tramadol hydrochloride (4mg/kg every 12 hours orally) for 3 days; in addition to daily cleaning at the interface skin-pin with chlorhexidine-based antiseptic spray. The amputated limb was submitted for histopathological examination to guide further treatment. The dog is adapting, has satisfactory support of the limb, without complications so far 15 days postoperatively.

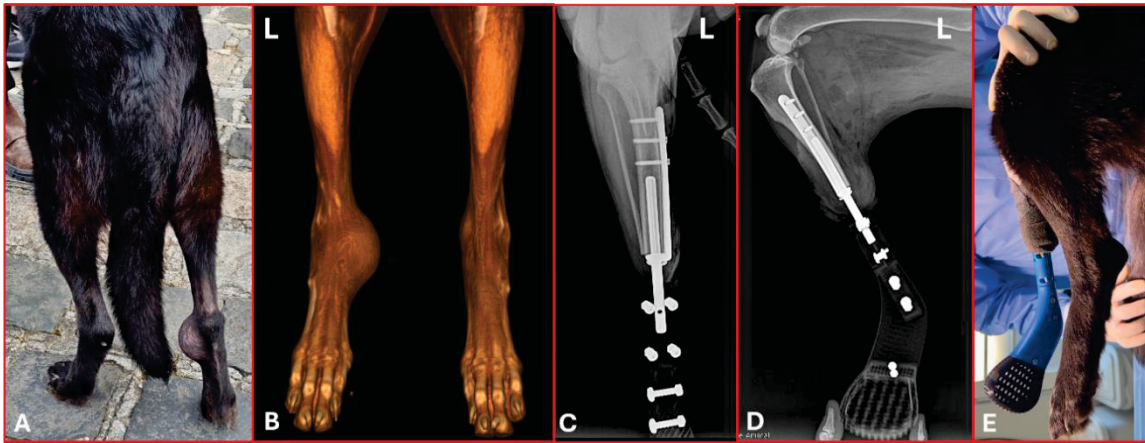


Figure 10. A: Photograph showing the patient's pelvic limbs, the increase in volume in the right heel is noted; B: segmentation of the tomographic image for preoperative evaluation and surgical planning; C: immediate postoperative radiograph in craniocaudal and medial lateral view(D); E: final and comparative aspect with the contralateral limb.

DISCUSSION

We report a series of five dogs with endo-exoprostheses in the pelvic limb: three cases due to neoplasia (cases 1, 3, and 5), one case of severe trauma affecting both tibiae (case 2), and one case of congenital malformation of the radius and ulna (case 3), totaling six implants (Figure 11). Of the five dogs, three cases (2, 3, and 5) involved customized implants produced via 3D-printed titanium, while the remaining two cases (1 and 4) utilized machined titanium implants.

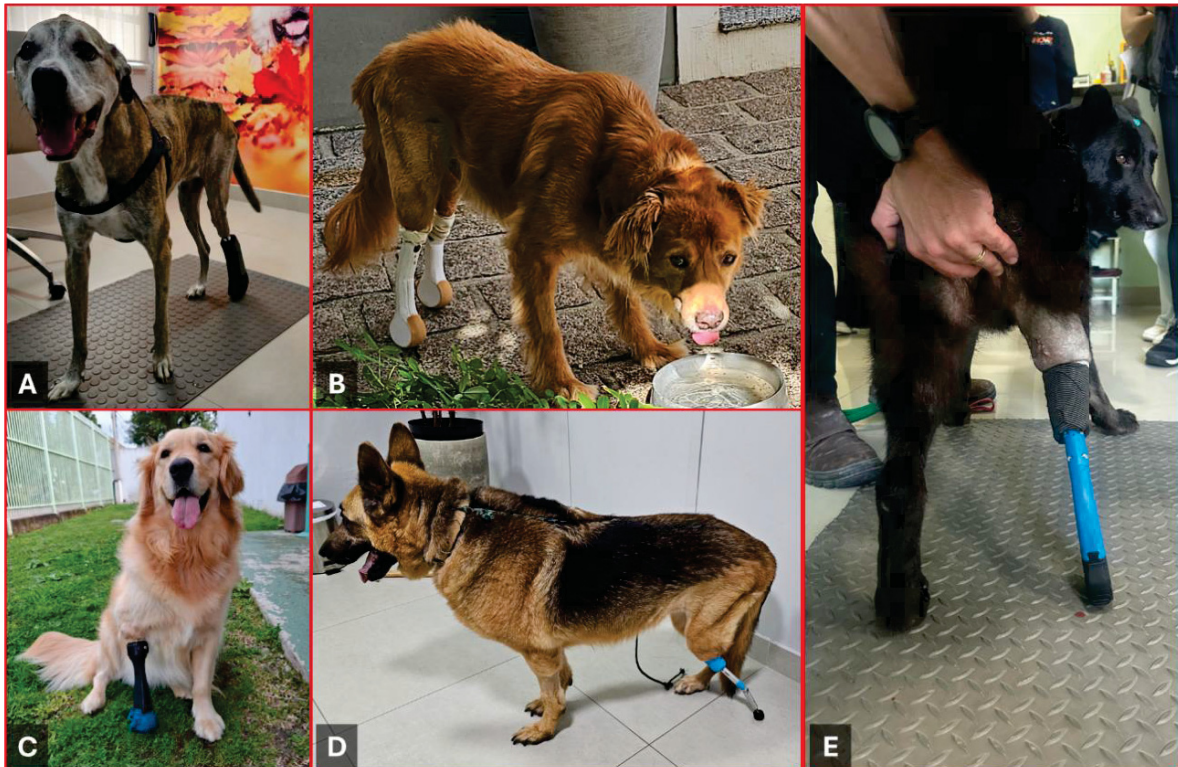


Figure 11. The five patients in chronological order described in the work with their prostheses.

Case 2 represented our first patient with a titanium implant manufactured via DMLS. Surgical planning was particularly challenging due to the patient being a shelter dog with several dermatological comorbidities and the requirement for bilateral tibial application. Despite these challenges, the procedure was successfully performed, allowing functional use of the limbs for six months. After this period, the patient developed a stifle infection, with loosening of the right-side implant and periosteal reaction on the left side. Both implants were subsequently removed, and cultures and antibiograms were performed to guide appropriate treatment, with future surgical revision planned.

We believe two factors contributed to the failure in this case: (1) no post-printing finishing was performed on the titanium implant, leaving the external component—connecting to the prosthetic paw—rough (while the internal component roughness was desired), and (2) limitations in the design and material strength of the exoprosthesis, which suffered fatigue hours after use. Biomechanically, this created a lever effect on the implant fixed to the bone, progressively forcing the implant until instability and contamination occurred. The team considers two possible solutions: customization of two new endo-exoprostheses with appropriate external finishing or use of an external skeletal fixator as a limb prosthesis, as described by Petazzoni and Maciejowski (2025) in a cat, and with clinical experience in medium- to large-sized dogs.

Large-breed dogs have a higher incidence of bone tumors and are frequently candidates for total limb amputation. This scenario has evolved due to technological advances and increased awareness among owners and veterinarians. It is important to emphasize that indications for endo-exoprostheses must be carefully considered, ranging from potential case selection to the level of owner commitment throughout the treatment (Mendonça et al., 2023).

Case 3 was our second titanium 3D-printed implant. Malformation of the forearm with radial head luxation and angular deviation posed a significant challenge in deciding whether to preserve the elbow. We opted for a more robust stabilization of the ulna to allow joint mobility and better patient adaptation. In the event of bone or implant complications, the humerus could be used as a support for a new intraosseous implant. The patient undergoes physiotherapy twice weekly to assist with prosthetic limb support and weight bearing.

We observed that patients with preoperatively healed stumps did not experience complications related to skin retraction. We attribute this phenomenon to prior or naturally

healed myopexy. Nonetheless, we recommend preserving distal healing and applying the transcutaneous pin through a different stoma than the primary approach. This preserves soft tissue approximation and reduces skin-implant inflammatory processes.

For patients without a preexisting stump, as in cases 1, 4, and 5, we used a device for myopexy, which aided in the fixation of muscles and soft tissues. No postoperative skin retraction was observed, suggesting this may be a viable solution for similar complications in future cases. Gottschalk (2016) and Hsu (2018) describe myopexy in transfemoral human amputees as a procedure to stabilize the adductor magnus muscle, maintaining both the mechanical axis and femoral alignment. This facilitates prosthetic adaptation and improves gait.

The three neoplasm cases were distal to the pelvic limb: two in the tibia and one in the calcaneus. Case 4 had sought veterinary care since January 2025 and underwent unsuccessful treatment for fungal and bacterial osteomyelitis. Nonetheless, limb-sparing treatment of the proximal tibia was possible, particularly given the dog's large size, as we know that, in the medium- to long-term, other limbs and the vertebral column may be affected (Kirpensteijn, 2000). Case 2 represents a medium-sized patient (18.9 kg) with bilateral lesions, while the other dogs were large breed with a mean weight of 34.9 kg.

Neoplasms were predominantly osteosarcomas, diagnosed histopathologically (cases 1, 4, and 5). Unfortunately, dog 1 was euthanized six months postoperatively due to pulmonary metastasis. Dog 4 is six months postoperative, receiving oncologic treatment with preserved quality of life, limb support, and owner satisfaction. Dog 5 was the last to undergo surgery and will begin the appropriate chemotherapy protocol.

Patient and owner selection is critical for success. Complications are expected in these approaches, as the implant is a foreign body subjected to daily mechanical stress. The animal must tolerate handling, medication administration, and wound care, while the owner must commit to maintaining functional prosthetic support to optimize quality of life. When complications arise, it is important to remember that they can be resolved, as described by Drygas (2008), Fitzpatrick (2011), and Petazzoni and Maciejowski (2025), and do not necessarily mandate total limb amputation.

Exoprostheses currently lack standardization across species. We encountered significant challenges in producing devices sufficiently strong and effective, which likely contributed to implant instability in case 2. This field remains underexplored both clinically and

biomechanically, particularly regarding real-life gait simulation in heavy patients. Common 3D-printed materials often cannot withstand such loads, and no material currently combines sufficient flexibility to bear weight, deform, and avoid fracture at the exoprosthesis extremity. Greater flexibility in the “foot” component may reduce implant stress and prevent cyclical loading and fracture. As publications like this increase, veterinarians and engineers can develop improvements for future cases.

Access to titanium 3D printing (DMLS) in Brazil remains limited and costly, restricting widespread use of custom-made implants. Through research collaboration, we applied the technique in three patients; however, the interval between planning and printing was longer (mean 30 days) than for machined implants. Few veterinarians possess CAD modeling skills, complicating implant and exoprosthesis design, as engineers often lack comprehensive anatomical knowledge necessary for optimal planning, guide application, and biomechanics. We anticipate these challenges will be overcome as more veterinary professionals acquire software proficiency, reducing production time.

Surgical planning must be led by an experienced veterinary orthopedic surgeon, as even with an experienced team, errors may occur. Despite multiple virtual planning iterations, use of bone biomodels, and preoperative rehearsal, intraoperative challenges—such as tumor enlargement or guide fracture—can compromise the procedure. Expertise is essential for limb-sparing surgery, which may appear straightforward but involves detailed soft tissue management.

Complications observed in this case series included: pin–skin interface infection (60%; dogs 1, 2, 4), osteomyelitis (20%; dog 2), and exoprosthesis fracture (40%; dogs 2 and 3). All patients received appropriate treatment, and only case 2 awaits resolution based on owner availability. Several studies document successful revision procedures in endo-exoprosthesis complications, demonstrating that perseverance and consistency can yield positive outcomes and preserve the limb (Pendegrass, 2006; Drygas et al., 2008; Fitzpatrick et al., 2011; Gorshkov et al., 2017; Goh et al., 2025; Petazzoni and Maciejowski, 2025). Management strategies range from fabrication of a new intraosseous implant, modification of amputation level, to use of external fixators as limb prostheses. Despite complications in this series, investing in limb-salvage solutions is a valid and promising alternative.

3D printing in small animal orthopedics represents a revolutionary tool, capable of transforming complex case management through customized functional solutions. Despite

advances, standardization, new biomaterials, and clinical studies are required to establish routine practice (Memarian et al., 2022; Kimura et al., 2025; Sarpong et al., 2025).

We believe this work may encourage veterinarians to specialize in this technique and recommend limb-salvage procedures, providing a tangible alternative to total limb amputation. While amputations are irreversible, socket prostheses, intraosseous implants, and external fixator prostheses can become increasingly utilized, transforming veterinary practice in traumatology, oncology, and other fields.

Key points to reduce endo-exoprosthesis complications include: (1) surgical planning must be validated by an experienced veterinary surgeon to minimize biomechanical and technical errors; (2) anticipate skin retraction at closure, leaving excess tissue; (3) section skin and muscles at different heights for optimal implant coverage; (4) myopexy involves correctly suturing muscle groups over the implant or bone, preventing muscular and dermal retraction and implant exposure. In this series, the authors developed a rounded, perforated titanium device to aid muscle fixation and prevent retraction; (5) continuous daily antiseptic cleaning is essential for pin–skin integrity and infection prevention.

The use of endo-exoprostheses for limb preservation is feasible and provided favorable short- and long-term outcomes in five dogs with bone neoplasms (3), malformations (1), or traumatic pelvic limb injuries (1). Complications occur but can be managed to preserve the affected limb, provide support, and maintain quality of life, with owner satisfaction.

ACKNOWLEDGMENTS

We thank Bionostic[®] for performing patient CT scans, Engevet[®] and Cão Medica[®] for partnership in machined implant development, the Renato Archer Research Institute[®] and Cubobiomedical[®] for 3D-printed titanium implants, and 3Dlifelab[®], Bespokevet[®], and Crysthian Callegaro for assistance in exoprosthesis development.

REFERENCES

ARAUZ, P. G. et al. New technologies applied to canine limb prostheses: A review. **Veterinary World**, v. 14, n. 10, p. 2793, 2021.

DICKERSON, V. M. et al. Outcomes of dogs undergoing limb amputation, owner satisfaction with limb amputation procedures, and owner perceptions regarding postsurgical adaptation: 64 cases (2005–2012). **Journal of the American Veterinary Medical Association**, v. 247, n. 7, p. 786-792, 2015.

- DRYGAS, K. A. et al. Transcutaneous tibial implants: a surgical procedure for restoring ambulation after amputation of the distal aspect of the tibia in a dog. **Veterinary Surgery**, v. 37, n. 4, p. 322-327, 2008.
- FITZPATRICK, N. et al. Intraosseous transcutaneous amputation prosthesis (ITAP) for limb salvage in 4 dogs. **Veterinary surgery**, v. 40, n. 8, p. 909-925, 2011.
- GOH, Melissa RY; JAMES, Daniel R. Limb Straightening and Osseointegrated Transcutaneous Amputation Prosthesis in a Dog with Angular Limb Deformity. **VCOT Open**, v. 8, n. 01, p. e28-e34, 2025.
- Gorshkov S.S., Ulanova N.V., Manuilova V., Tverdokhlebov S.I. Percutaneous osseointegrated prosthetics of limbs in dogs and cats after partial amputation based on a series of clinical cases. **VetPharma**, No. 4 (38), 2017, pp. 58-73.
- GOTTSCHALK, F. The importance of soft tissue stabilization in trans-femoral amputation: English version. **Der Orthopäde**, v. 45, n. Suppl 1, p. 1-4, 2016.
- HARRYSSON, O. L.A; MARCELLIN-LITTLE, D. J.; HORN, T. J. Applications of metal additive manufacturing in veterinary orthopedic surgery. **Jom**, v. 67, n. 3, p. 647-654, 2015.
- HSU, Andrew R. Transfemoral amputation adductor myodesis using FiberTape and knotless anchors. **Foot & Ankle International**, v. 39, n. 7, p. 874-879, 2018.
- JEYAPALINA, S. et al. Variation in bone response to the placement of percutaneous osseointegrated endoprostheses: A 24-month follow-up in sheep. **PLoS One**, v. 14, n. 10, p. e0221850, 2019.
- KIMURA, S. et al. Limb amputation for feline appendicular bone tumors results in excellent recovery outcomes and high owner satisfaction with a low incidence of complications. **Journal of the American Veterinary Medical Association**, v. 1, n. aop, p. 1-7, 2025.
- KNERINGER, C.; SCHNABL-FEICHTER, E. Intraosseous Transcutaneous Amputation Prosthesis (ITAP) compared to Exoprosthesis in veterinary medicine—a literature review. **Tierärztliche Praxis Ausgabe K: Kleintiere/Heimtiere**, v. 52, n. 06, p. 359-366, 2024.
- KIRPENSTEIJN, J. et al. Ground reaction force analysis of large breed dogs when walking after the amputation of a limb. **Veterinary Record**, v. 146, n. 6, p. 155-159, 2000.
- KVALE, E.; RUEDA, R. C.; FITZPATRICK, N. Limb-sparing surgery in two cats using a femoral endoprosthesis with an integrated total knee replacement implant. **Veterinary and comparative orthopaedics and traumatology**, v. 35, n. 02, p. 134-142, 2022.LI, Y.; FELLÄNDER-TSAI, L. The bone anchored prostheses for amputees—Historical development, current status, and future aspects. **Biomaterials**, v. 273, p. 120836, 2021.

- MARCELLIN-LITTLE, D. J. et al. Orthoses and exoprostheses for companion animals. **Veterinary Clinics: Small Animal Practice**, v. 45, n. 1, p. 167-183, 2015.
- MEEHAN, J. P. Dilute povidone-iodine irrigation: the science of molecular iodine (I₂) kinetics and its antimicrobial activity. **JAAOS-Journal of the American Academy of Orthopaedic Surgeons**, v. 33, n. 2, p. 65-73, 2025.
- MEMARIAN, P. et al. Active materials for 3D printing in small animals: current modalities and future directions for orthopedic applications. **International Journal of Molecular Sciences**, v. 23, n. 3, p. 1045, 2022.
- MENDONÇA, A. G. C. et al. Fixed bilateral endo-exo prostheses in feline femur-case report. **Arquivo Brasileiro de Medicina Veterinária e Zootecnia**, v. 75, n. 01, p. 107-112, 2023.
- MENDEZA-DECAL, Rosa et al. Biomechanical Tests on Long-Bone Elliptical Medullary-Canal Endoprostheses for Limb Salvage in Dogs. **Animals**, v. 12, n. 21, p. 3021, 2022.
- O'NEILL, D. G. et al. Dog breeds and conformations predisposed to osteosarcoma in the UK: a VetCompass study. **Canine Medicine and Genetics**, v. 10, n. 1, p. 8, 2023.
- OVERMANN, A. L.; FORSBERG, J. A. The state of the art of osseointegration for limb prosthesis. **Biomedical engineering letters**, v. 10, n. 1, p. 5-16, 2020.
- PANICHI, E. et al. Limb-Sparing Surgery and Stifle Arthrodesis Using Patient-Specific 3D-Printed Guides and Endoprosthesis for Distal Femoral Chondrosarcoma in a Dog: A Case Report. **Animals**, v. 15, n. 5, p. 673, 2025.
- PENDEGRASS, C.J.; GOODSHIP, A. E.; BLUNN, G.W. Development of a soft tissue seal around bone-anchored transcutaneous amputation prostheses. **Biomaterials**, v. 27, n. 23, p. 4183-4191, 2006.
- PENDEGRASS, C. J. et al. Nature's answer to breaching the skin barrier: an innovative development for amputees. **Journal of anatomy**, v. 209, n. 1, p. 59-67, 2006.
- PETAZZONI, M; MACIEJOWSKI, T. Bilateral hindlimb custom-made external-fixation amputee prostheses in a cat. **Companion Animal**, v. 30, n. 8, p. 2-10, 2025.
- POLTON, G. et al. Osteosarcoma of the appendicular skeleton in dogs: Consensus and guidelines. **Frontiers in Veterinary Science**, v. 12, p. 1633593, 2025.
- RASKE, M.; MCCLARAN, J. K.; MARIANO, A. Short-term wound complications and predictive variables for complication after limb amputation in dogs and cats. **Journal of Small Animal Practice**, v. 56, n. 4, p. 247-252, 2015.
- ROSEN, S.; DUERR, F. M.; ELAM, L. H. Prospective evaluation of complications associated with orthosis and prosthesis use in canine patients. **Frontiers in Veterinary Science**, v. 9, p. 892662, 2022.

SARPONG, J.; KHANAFER, K.; SHEIKH, M. 3D-Printed Prosthetic Solutions for Dogs: Integrating Computational Design and Additive Manufacturing. **Designs**, v. 9, n. 5, p. 107, 2025.

THOMAS, C. et al. Orthopedic applications of 3D printing in canine veterinary medicine. **Frontiers in Veterinary Science**, v. 12, p. 1582720, 2025.

WAGNER, J. R. et al. Complications and owner satisfaction associated with limb amputation in cats: 59 cases (2007–2017). **BMC Veterinary Research**, v. 18, n. 1, p. 147, 2022.

WENDLAND, T. M.; SEGUIN, B.; DUERR, F. M. Prospective evaluation of canine partial limb amputation with socket prostheses. **Veterinary Medicine and Science**, v. 9, n. 4, p. 1521-1533, 2023.

WUSTEFELD-JANSSENS, B. G. et al. Analysis of outcome in dogs that undergo secondary amputation as an end-point for managing complications related to limb salvage surgery for treatment of appendicular osteosarcoma. **Veterinary and comparative oncology**, v. 18, n. 1, p. 84-91, 2020.

YAZAWA, D. et al. Three cases of dogs with osteosarcoma of the forelimb treated with liquid nitrogen for limb-sparing surgery using autologous bone. **Journal of Veterinary Medical Science**, v. 86, n. 6, p. 700-707, 2024.

FINAL CONSIDERATIONS

This thesis demonstrates that the development and clinical application of custom-made endo-exoprostheses, supported by advanced 3D modeling and additive manufacturing, represent a feasible and promising alternative for limb preservation in veterinary medicine. The results obtained in cats and dogs indicate that, despite the inherent surgical and biomechanical challenges, this approach can restore limb support, enable functional rehabilitation, and provide substantial improvement in the quality of life of partially amputated patients.

The case series presented herein confirmed that complications—such as infection, implant instability, and exoprosthesis fractures—are relatively frequent but can be strategically managed without requiring total limb amputation. Importantly, the absence of skin retraction or implant exposure in this study underscores the relevance of appropriate surgical planning and the adoption of a simple yet effective myopexy device developed by the authors.

However, several obstacles still hinder the widespread adoption of this technique. Among these are the high costs and limited availability of titanium 3D printing, the lack of standardization in prosthetic design across species, breeds, and the need for closer collaboration between veterinarians and engineers to optimize implant design and surgical execution. In addition, further research is needed to refine biomaterials, enhance soft tissue integration, and evaluate long-term functional and biomechanical outcomes in larger cohorts.

Beyond its direct clinical contributions, this work emphasizes the transformative potential of 3D printing in veterinary orthopedics. By enabling the production of patient-specific implants and devices, additive manufacturing expands treatment options in traumatology, oncology, and congenital malformations. The findings of this thesis contribute to consolidating limb-salvage techniques as realistic alternatives to total amputation, aligning veterinary practice with ongoing advances in human osteointegration surgery.

In conclusion, the application of endo-exoprostheses in small animal practice is not only technically feasible but also clinically advantageous. With continued refinement of surgical protocols, biomaterials, and prosthetic designs, and with the growing expertise of veterinary professionals in digital planning and custom implant fabrication, this technique has the potential to become a standard tool for limb preservation. Ultimately, investing in the development of endo-exoprostheses represents a significant step toward improving animal welfare and redefining the limits of orthopedic surgery in veterinary medicine.

REFERENCES

- AIMAR, A.; PALERMO, A.; INNOCENTI, B. The Role of 3D printing in medical applications: A State of the Art. **Journal of Healthcare Engineering**, v. 21, n. 5340616, Mar 2019. Disponível em: Acesso em: 15 Jun. 2024. <http://dx.doi.org/10.1155/2019/5340616>.
- AL-SHALAWI, F. D. et al. Biomaterials as implants in the orthopedic field for regenerative medicine: metal versus synthetic polymers. **Polymers (Basel)**, v. n. 7;15(12):2601. Jun 2023. Disponível em: <https://www.mdpi.com/2073-4360/15/12/2601>. Acesso em: 10 Mai 2024. <http://dx.doi.org/10.3390/polym15122601>.
- ARAUZ, P. G, et al. New technologies applied to canine limb prostheses: A review. **Veterinary World**.;14(10):2793-2802. Oct 2021. Acesso em: 10 Mai 2024. <http://dx.doi.org/10.14202/vetworld.2021.2793-2802>.
- DETORA, M. D.; BOUDRIEU, R. J. Complex angular and torsional deformities (distal femoral malunions): preoperative planning using stereolithography and surgical correction with locking plate fixation in four dogs. **Veterinary and Comparative Orthopaedics and Traumatology**, v. 29, n. 5, p. 416–425, set. 2016. DOI: <https://doi.org/10.3415/VCOT-15-08-0145>
- DRYGAS, K.A. et al. Transcutaneous tibial implants: a surgical procedure for restoring ambulation after amputation of the distal aspect of the tibia in a dog. **Veterinary Surgery**, v.37, p.322–327, 2008.
- FITZPATRICK, N. et al. Intraosseous transcutaneous amputation prosthesis (ITAP) for limb salvage in 4 dogs. **Veterinary Surgery**, v.40, n.8, p.909-25. Dez 2011. Acesso em: 10 Mai 2024. <http://dx.doi.org/10.1111/j.1532-950X.2011.00891.x>.
- FITZPATRICK, N. et al. Custom-built constrained uniaxial and rotating hinge total knee replacement in cats: Clinical application, design principles, surgical technique, and clinical outcome. **Veterinary Surgery**.v.50, p.1283–1295, 2021.<https://doi.org/10.1111/vsu.13606>
- GORSHKOV, S.S. et al. Percutaneous osseointegrated limb prosthetics in dogs and cats after partial amputation based on a series of clinical cases. **VetPharma**, n. 4, 2017.
- GORSHKOV, S. S.; ULANOVA, N. V. **Traumatologia e ortopedia interativa de pequenos animais**. Vol. 2. Moscou, Biblioteca Científica, 2019.
- JEYAPALINA, S. et al. Radiographic evaluation of bone adaptation adjacent to percutaneous osseointegrated prostheses in a sheep model. **Clinical Orthopaedics and Related Research**, v. 472, n. 10, p. 2966–2977, out. 2014. Acesso em: 10 Mai 2024. <http://dx.doi.org/10.1007/s11999-014-3523-z>.
- MARCELLIN-LITTLE, D. J. et al. Orthoses and exoprostheses for companion animals. **Veterinary Clinics of North America: Small Animal Practice**, v. 45, n. 1, p. 167–183, Jan. 2015. DOI: <https://doi.org/10.1016/j.cvsm.2014.09.009> Acesso em: 13 maio 2024.

MENDONÇA, A. G. C. et al. Endo-exoprótese bilateral fixa em fêmur de felino-relato de caso. **Arquivo Brasileiro de Medicina Veterinária e Zootecnia**, v. 75, p. 107-112, 2023.

MENDONÇA, Alan Gleison Cabral de; FERNANDES, Thaiza Helena Tavares. Exoprótese fixa em rádio de cão: relato de caso. **Nosso clínico**, p. 12-16, 2019.

MENG, M. et al. Clinical applications and prospects of 3D printing guide templates in orthopaedics. **Journal of orthopaedic translation**, v. 34, p. 22-41, 2022. Acesso em: 15 Jun 2024. <http://dx.doi.org/10.1016/j.jot.2022.03.001>.

MENG, M. et al. 3D printing metal implants in orthopedic surgery: methods, applications and future prospects. **Journal of Orthopaedic Translation**, v. 42, p. 94-112, 2023. DOI: 10.1016/j.jot.2023.08.004. PMID: 37675040; PMCID: PMC10480061.

MEMARIAN, P. et al. Active materials for 3D printing in small animals: current modalities and future directions for orthopedic applications. **International Journal of Molecular Sciences**, v. 23, n. 3, p. 1045, 2022. Acesso em: 15 Jun 2024. <http://dx.doi.org/10.3390/ijms23031045>.

MINTO, B. W.; DIAS, L. G. G. G. **Tratado de ortopedia de cães e gatos**. Vol 1. São Paulo: Medvet, 2022.

PENDEGRASS, C. J. et al. Nature's answer to breaching the skin barrier: an innovative development for amputees. **Journal of anatomy**, v. 209, n. 1, p. 59-67, 2006. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2100310/#b18>. Acesso em: 15 Jun. 2024. <http://dx.doi.org/10.1111/j.1469-7580.2006.00595.x>

SEERAM, E. Computed Tomography: A Technical Review. **Radiologic technology**, v. 89, n. 3, 2018.

SÉGUIN, Bernard et al. Limb-sparing in dogs using patient-specific, three-dimensional-printed endoprosthesis for distal radial osteosarcoma: A pilot study. **Veterinary and comparative oncology**, v. 18, n. 1, p. 92-104, 2020. <https://doi.org/10.1111/vco.12515>

TIMERCAN, Anatolie et al. Personalized 3D-printed endoprostheses for limb sparing in dogs: Modeling and in vitro testing. **Medical engineering & physics**, v. 71, p. 17-29, 2019. <https://pubmed.ncbi.nlm.nih.gov/31327657/>. Acesso em: 22 Mai 2024. <http://dx.doi.org/10.1016/j.medengphy.2019.07.005>.

APPENDICES

APPENDICE 1 – Article published in *Acta Scientiae Veterinariae*, 2025

Acta Scientiae Veterinariae, 2025, 53(Suppl 1): 1051.

CASE REPORT
Pub. 1051

ISSN 1679-9216

Bilateral Femoral Intraosseous Transcutaneous Amputation Prosthesis (ITAP) in a Cat

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Danielle Buche², Vanessa Wotkoski Benoni², Jéssica Gonçalves Clock³ & Peterson Triches Dornbusch¹

ABSTRACT

Background: Intraosseous transcutaneous amputation prosthesis (ITAP) is a limb-salvage technique that involves anchoring an implant to the bone, enabling external prosthetic attachment via osseointegration. This approach offers an alternative to traditional amputation by preserving skeletal support and functional integration. Despite its increasing use in human medicine, ITAPs have been scarcely studied in veterinary practice, and no standardized guidelines exist for implant selection, considering the anatomical variability among species and breeds. This case report describes the successful application of ITAP in a cat following severe complications from bilateral femoral osteosynthesis, with a 27-month follow-up.

Case: A 1-year-old male cat, missing for 54 days, returned home with bilateral Salter-Harris type I femoral fractures. The patient underwent multiple unsuccessful surgical attempts, leading to complications such as contamination, bacterial resistance, Rush pin migration, plate exposure, osteomyelitis, and the need for muscle and skin flap reconstruction. Given the failure of all limb-preserving options, ITAP placement in the bilateral femoral diaphysis was proposed as an alternative to total limb amputation, aiming to restore independence and mobility. Preoperative planning involved computed tomography (CT) imaging, with Radiant[®] software used for image segmentation, bone viability assessment, and osteotomy height determination. A custom-designed titanium intramedullary implant was developed using CAD software. The surgical procedure was uneventful, and the patient was hospitalized for 3 days for postoperative monitoring. Fifteen days postoperatively, skin dehiscence and implant exposure were observed in the left femur. A revision surgery was performed, including implant coverage, bacterial culture, copious Betadine[®] lavage, and wound closure with 2-0 nylon sutures for the musculature and 3-0 for the skin. *Enterococcus faecium* was identified, and a 3-week course of compounded marbofloxacin was prescribed, leading to complete wound healing without further complications.

Discussion: The failure of prior fracture management necessitated the use of ITAP as an alternative to bilateral femoral amputation, ultimately resulting in excellent adaptation and quality of life. This case highlights the potential of osseointegrated implants in veterinary patients, demonstrating that ITAP can provide a durable and functional limb-salvage solution. The implant was designed with a fully intramedullary titanium structure to promote osseointegration, ensuring long-term biomechanical stability. A key feature was the inclusion of an anti-rotational locking pin to counteract rotational forces that could compromise implant integrity and prosthetic function. One of the major challenges in ITAP application is dermal integration, which is crucial to preventing ascending infection and soft tissue breakdown. Poor skin adherence to the implant can lead to complications such as infection, retraction, implant exposure, and mechanical failure, as reported in similar cases. The necessity for surgical revision in this patient underscores the importance of meticulous implant design and strict postoperative wound management. Long-term implant success also relies heavily on owner compliance, as proactive care and infection monitoring are essential to maintaining functionality and preventing complications. ITAP offers a functional alternative to total limb amputation by preserving biomechanics, restoring mobility, and improving quality of life. After 27 months, the patient showed no signs of implant failure or mobility impairment. Continued advancements in implant technology and surgical techniques will be essential to optimizing ITAP outcomes and expanding its application in veterinary medicine.

Keywords: Osseointegration, limb sparing, orthopedics, endo-exo prosthesis, surgery.

DOI: 10.22456/1679-9216.145883

Received: 21 March 2025

Accepted: 3 August 2025

Published: 30 August 2025

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APPENDICE 2 – Ethics committee approval



UNIVERSIDADE FEDERAL DO PARANÁ
SETOR DE CIÊNCIAS AGRÁRIAS
COMISSÃO DE ÉTICA NO USO DE ANIMAIS

CERTIFICADO

Certificamos que o protocolo número 051/2022, referente ao programa de pesquisa “**Desenvolvimento e aplicação de endo e exopróteses em animais associados a tecnologia 3D**”, sob a responsabilidade de **Peterson Triches Dornbusch** – que envolve a produção, manutenção e/ou utilização de animais pertencentes ao filo Chordata, subfilo Vertebrata (exceto o homem), para fins de pesquisa científica ou ensino – encontra-se de acordo com os preceitos da Lei nº 11.794, de 8 de Outubro de 2008, do Decreto nº 6.899, de 15 de julho de 2009, e com as normas editadas pelo Conselho Nacional de Controle da Experimentação Animal (CONCEA), e foi aprovado pela COMISSÃO DE ÉTICA NO USO DE ANIMAIS (CEUA) DO SETOR DE CIÊNCIAS AGRÁRIAS DA UNIVERSIDADE FEDERAL DO PARANÁ - BRASIL, com grau 3 de invasividade, em 21/12/2022.

Finalidade	Pesquisa
Vigência da autorização	Janeiro/2023 até Maio/2025
Espécie/Linhagem	<i>Canis lupus familiaris</i> (canino) <i>Felis catus</i> (felino)
Número de animais	20
Peso/Idade	Variável/variável
Sexo	Macho e fêmea
Origem	Sob tutela

*A autorização para início da aula se torna válida a partir da data de emissão deste certificado.


CERTIFICATE

We certify that the protocol number 051/2022, regarding the research program “**Development and application of endo and exo prosthesis in animals associates with 3D technology**” under **Peterson Triches Dornbusch** – which includes the production, maintenance and/or utilization of animals from Chordata phylum, Vertebrata subphylum (except Humans), for scientific or teaching purposes – is in accordance with the precepts of Law nº 11.794, of 8 October 2008, of Decree nº 6.899, of 15 July 2009, and with the edited rules from Conselho Nacional de Controle da Experimentação Animal (CONCEA), and it was approved by the ANIMAL USE ETHICS COMMITTEE OF THE AGRICULTURAL SCIENCES CAMPUS OF THE UNIVERSIDADE FEDERAL DO PARANÁ (Federal University of Paraná, Brazil), with degree 3 of invasiveness, on 2022, December 21th.

Purpose	Research
Validity	2023 January until 2025 May
Specie/Line	<i>Canis lupus familiaris</i> (canine) <i>Felis catus</i> (felino)
Number of animals	20
Weight/Age	Variable/variable
Sex	Male and female
Origin	Sob tutela

*The authorization to start the research becomes valid from the date of issue of this certificate.

Curitiba, 21 de dezembro de 2022

Documento assinado digitalmente
 ALEX MAIORKA
 Data: 22/12/2022 18:32:35-0300
 Verifique em <https://verificador.iti.br>

Alex Maiorka
Coordenador
Comissão de Ética no Uso de Animais
AG - UFPR