

## RESEARCH ARTICLE

# Preliminary study on a novel dedicated plate for iliac fractures in dogs

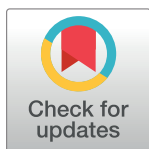
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## Abstract

### Introduction

The aim of this study was to describe and evaluate a novel plate designed specifically for the canine ilium using finite element methods. The cranial portion of the plate had an elliptical shape and contained nine screw holes. The caudal portion of the plate was triangular with three screw holes. Four and three screws were used at the cranial (screw 1 to 4) and caudal (screw 5 to 7) segment of the plate. Finite element models of the plate and canine pelvis were created. A load of 300 N was applied on the femur-hip joint contact area. Values of Von Mises Stress on the plate, screws and the maximum and minimum main stresses in the bone were used to capture the mechanical factors in this study.

### Results

The novel implant had a plate stress of 51.9 megapascals (MPa) with higher stress in the dorsal part of the plate. Screws 2 and 4 showed similar stress values of 17.3 MPa. Screws 1 and 3 were the most loaded (51.9 MPa and 75 MPa, respectively). Screws 5, 6, and 7 showed similar dissipation and stress values (21.55 MPa). There was traction force in the dorsal region of the pubis and compression in the ventral part, with dissipation and values of 15.4 MPa and 23.9 MPa, respectively, acquiring balance between them.

### Conclusion

The novel plate is potentially applicable and specifically suitable for iliac fractures in dogs. The screws distribution modeled proved itself strategical since the simulated stresses were evenly distributed throughout the implant construct.

### OPEN ACCESS

**Citation:** Moi TSM, Minto BW, Macedo AP, Lucena DVF, Malta CAS, Dias LGGG (2022) Preliminary study on a novel dedicated plate for iliac fractures in dogs. PLoS ONE 17(8): e0269313. <https://doi.org/10.1371/journal.pone.0269313>

**Editor:** Carlos E. Ambrósio, USP FZEA: Universidade de Sao Paulo Faculdade de Zootecnia e Engenharia de Alimentos, BRAZIL

**Received:** August 24, 2021

**Accepted:** May 18, 2022

**Published:** August 26, 2022

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**Data Availability Statement:** All relevant data are within the paper and its [Supporting Information](#) files.

**Funding:** TM received a scholarship from the Coordination for the Improvement of Level Personnel - CAPES" (88882.4333686/2019-1) that resulted in this study. The funder had no role in the conception of the study, data collection and analysis, decision to publish or prepare manuscripts.

**Competing interests:** The authors have declared that no competing interests exist.

## Introduction

Fractures of the pelvis account for approximately 25% of all reported fractures in polytraumatized dogs [1–3]. They occur usually after high energy trauma such as motor vehicle induced injuries, or high-level falls and 18 to 46% of these pelvic fractures usually compromise the ilium. Iliac fractures are generally obliquely displaced and are often accompanied by concurrent pubic fractures and sacroiliac luxation [4–6].

Surgical management of iliac fractures usually involves open reduction and lateral contoured-plate application fixed by screws [7, 8]. Other surgical techniques include dorsal or ventral ilium plating, interfragmentary compression achieved by K-wires or lag screws, reduction by screw-wire-polymethylmethacrylate (SWP) composite and/or external skeletal fixation device [2, 4, 9]. Despite such assortment of repair methods available, none of them is properly fit to ensure anatomical shape reduction. This may explain the considerable 21% complication rate, composed mostly of implant-related setbacks [6, 7, 10, 11].

Screw loosening is a common cause of implant-related complication and can subsequently result in poor fracture reduction, narrowing of the pelvic canal, medial acetabular displacement and might scale up to non-unions [2, 4, 12]. Some authors have suggested the poor-quality bone stock in the cranial ilium to be the cause of the high frequency of screw loosening [8, 10]. Several plating techniques have been employed for the repair of iliac fractures such as veterinary cuttable plates, String-of-Pearls™ plates, T plates, Tibial plateau levelling osteotomy locking-compression plates (TPLO), Locking Compression Plates (LCP) and reconstruction plates, in an attempt to optimize better quality bone purchase [6–13].

Custom-made implants developed based on specific anatomical requirements have decreased complication rates in veterinary surgery, noticeable on the prolific recent advances and expanding plate generations suitable for proximal tibial osteotomies to treat cruciate disease in companion animals like TPLO systems, Tibial Tuberosity Advancement (TTA) options, Cora Based Levelling Osteotomy (CBLO) techniques, to cite a few [14]. Even further, patient-specific customized implants developed for people made considerable stiffness improvements compared to prior designs when resisting tension and torsional shear stresses with decreased risk of implant-related failure such as screw loosening [13, 15].

The purpose of this study was to design an anatomically shaped bone plate proper for canine iliac fracture and characterize its properties by finite element modelling. We hypothesized that the novel implant model would properly fit the ilium surface in a strategic anatomical shape with optimal screw distribution. Thus, we aimed at creating a custom-iliac-shaped specific implant suitable for the challenging surgical repair of fractured dogs.

## Materials and methods

### Ethics committee

This study employed canine cadavers and was conducted in accordance with the institutional animal ethics policies and guidelines. It has been approved by the local Ethics Committee on the State University of São Paulo (UNESP)—Jaboticabal / SP, under the protocol (n° 07283/19).

### Geometric details and implant design

Five dog cadavers that weighed between 25 and 30 kg were included in this study. We collected and measured their pelvic girdle (Table 1) to record their pelvic shape and extrapolate the average geometrical dimensions of the novel canine iliac plate (CIP). We aimed at ensuring a universal shape that would fit all the included cadaveric pelvic models. We recorded measures of

**Table 1. Measures of cadaveric pelvic dog bones.**

	Value 1	Value 2	Value 3	Value 4	Breed	Weight	Age
Pelvis 1	3.6 cm	2.4 cm	2.6 cm	10.2 cm	Boxer	27.3 kg	4 years
Pelvis 2	3.3 cm	2.2 cm	2.4 cm	9.9 cm	Bull Terrier	26.2 kg	3 years
Pelvis 3	3.3 cm	2.2 cm	2.7 cm	9.5 cm	Chow Chow	28.1 kg	4 years
Pelvis 4	3.5 cm	2.3 cm	2.7 cm	9.9 cm	Mixed Breed	25.8 kg	2 years
Pelvis 5	3.7 cm	2.3 cm	2.2 cm	9.5 cm	Golden Retriever	28.9 kg	3 years

cm: centimeter

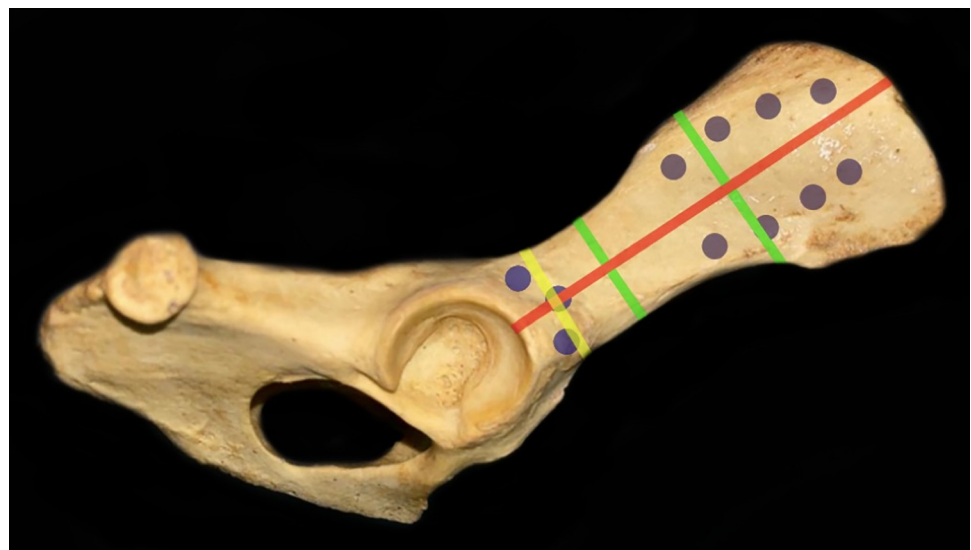
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their pelvic bones in four different landmarks: iliac wing width (value 1), iliac body width (value 2), the width of the region cranial to the acetabulum (value 3) and the length from the cranial acetabular ridge to the iliac crest (value 4). These landmarks are displayed on Fig 1.

We performed a throughout literature review to expand our understanding of the canine pelvis and the main risk factors that may impair iliac osteosyntheses. We mapped the pelvic region to set the landmarks according to bone stock quality, allowing better bone purchase by the screws, especially in the cranial aspect of the ilium. We also identified the anatomical landmarks considering possible plate designs and suitable shapes that ought to ensure balanced stress distribution and, therefore, avoid overloading situations that could loosen the screws.

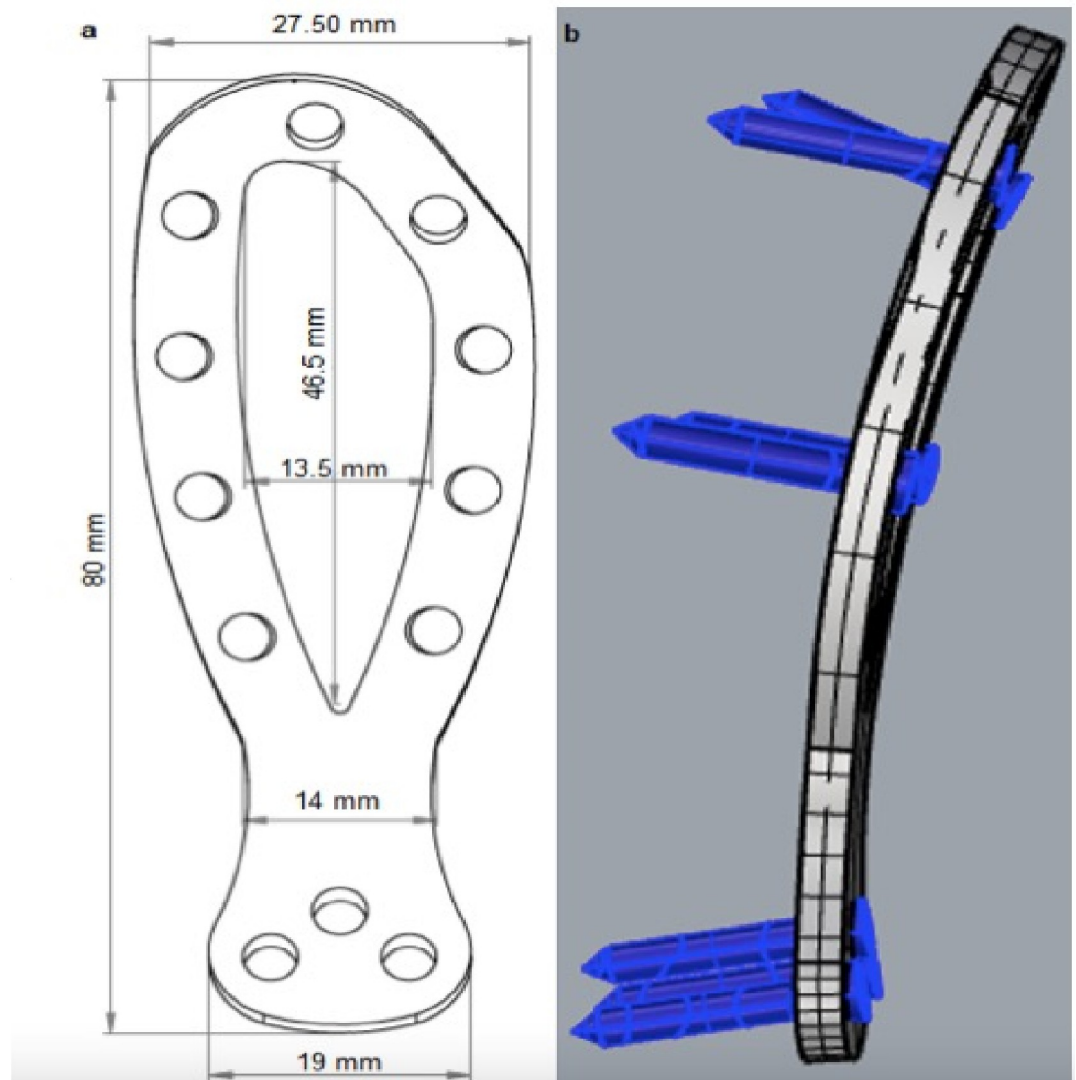
The novel plate model was then created in an elliptical shape measuring 80 mm in length and 27.5mm and 19mm in width in the cranial and caudal regions, respectively; the transition area from the cranial to the caudal region was 14mm wide and 3mm thick. The central area of the ellipse was hollow and measured 13.5mm in width and 46.5mm in length (Fig 2A), allowing the design to follow the shape of the wing and the body of the ilium and be more versatile.

The cranial part of the plate, consisting of two branches, formed a semi-ellipse with four holes in each branch and a hole in the cranial curvature. The caudal part had a triangular shape with three holes. The holes of the cranial portion were 6° divergent, directed toward the edge of the ilium, due to the higher bone density found in this region. Conversely, the caudal



**Fig 1. Schematic representation of the landmarks used for pelvic assessments performed on dog cadavers to ensure fitness and determine optimal shape dimensions of the novel canine iliac plate.**

<https://doi.org/10.1371/journal.pone.0269313.g001>



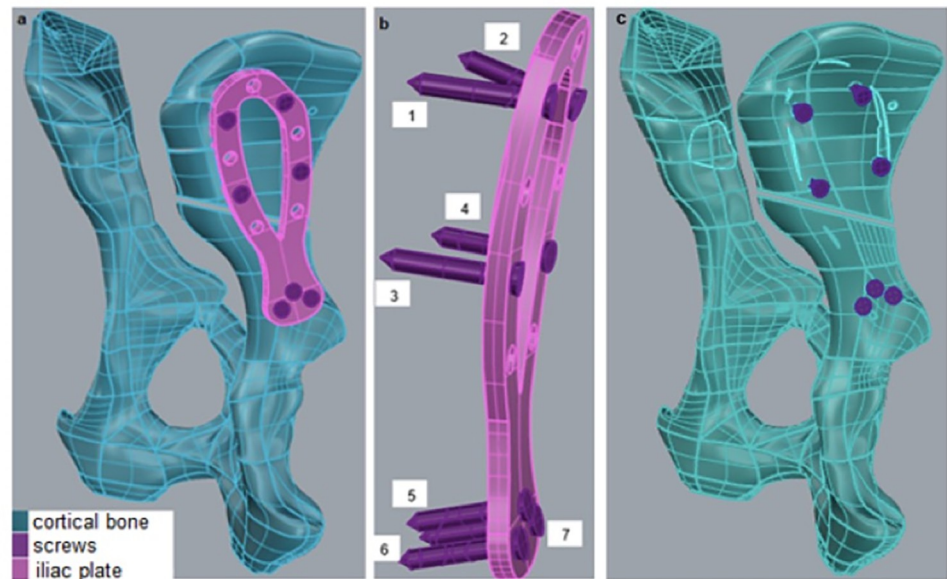
**Fig 2.** Schematic representation of the new model plate with measurements (a) and pre-direction of the screws (b).

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holes in the plate were directed caudally at an angle of  $12^\circ$  for fixation into better bone stock (Fig 2b). The plate and screw set were equivalent to a 3.5-mm system with a pre-defined contour angle of  $27^\circ$ , with 20-mm-long screws and a 2.8-mm core.

A pelvis without fracture of a young dog (25 kg, mixed-breed) that had died from causes unrelated to the study was produced using computed tomography data (Shimadzu SCT -7800 CT, Kyoto, Japan). All images were processed in a “*stl*” file in cross section by Invesallius software to identify the outline of various hard tissues (cortical and spongy bone).

The virtual development of the plate was performed using computer aided design according to the measures previously mentioned. The file was exported in a step format to Rhinoceros 6.0 (McNeil, Assoc USA). In Rhinoceros, the pelvis design was developed with an existing gap of 2 mm in the right hemipelvis, as an oblique fracture in the iliac body, in addition to the setting plate and the screws to the pelvis. The screws used for fixing the plate to the pelvis were distributed in such a way that four were located in the cranial portion (two in each semi-



**Fig 3.** Lateral plate mounted on the osteotomized pelvis in tridimensional illustration (a). Detail of the screws inserted (b). Bone model illustration without the bone plate to denote the anatomical position of the osteotomy gap in relation to the body of the ilium (c).

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ellipse), with the other three located in the caudal portion of the plate, as shown in Fig 3. The screws were fixed using the freeze contact.

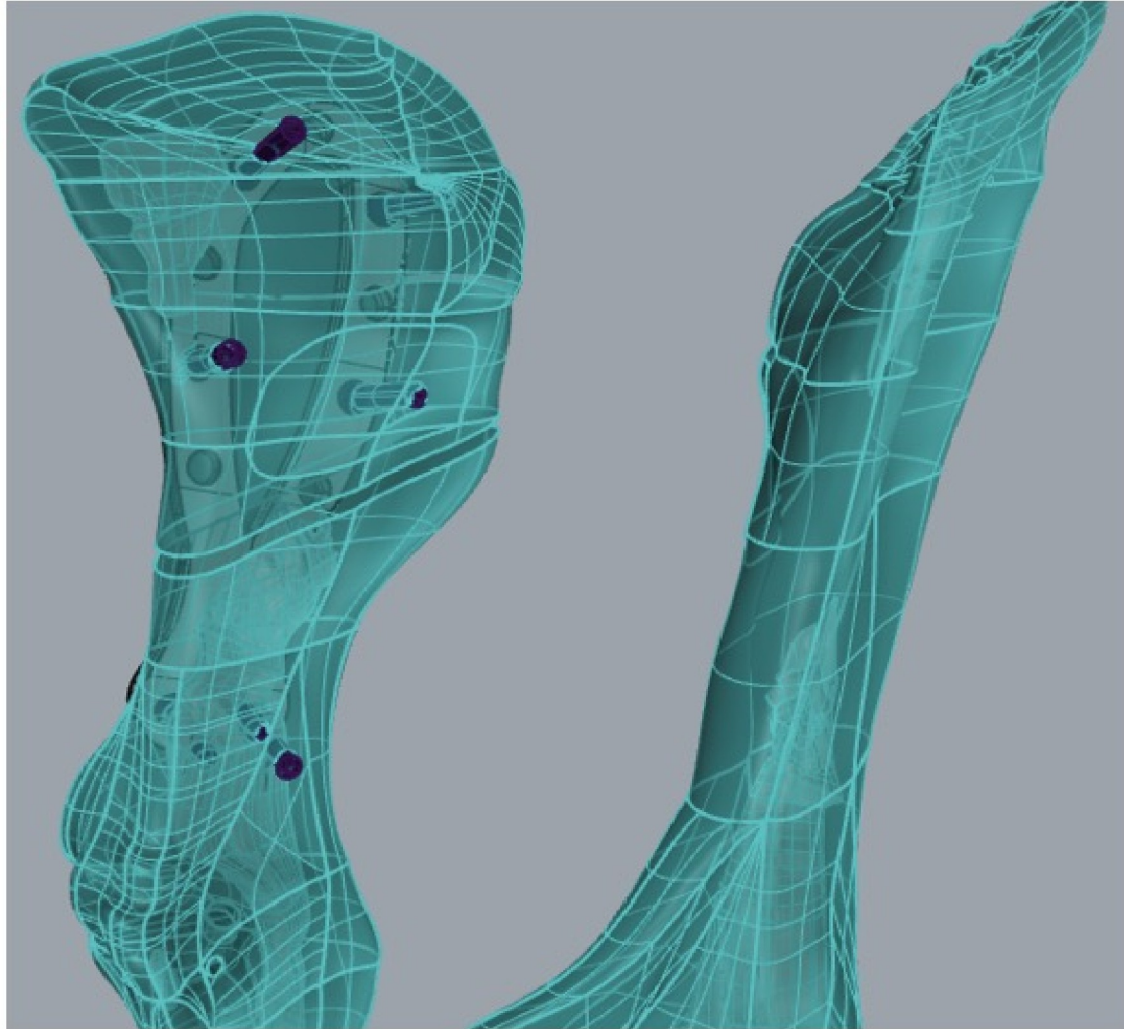
### FE analysis

We exported the model images to SimLab software (2018 version). Then we developed tridimensional pelvic mesh based on four-node isoparametric tetrahedral finite element models. We also added the novel plate design held by the bone screws. We used an average 0.6 mm element size to differentiate cortical from cancellous bone, whereas we used 0.8 mm-sized plate elements and 0.9 mm-sized screw elements for the computed model.

The CIP system was considered as being made of 316L stainless-steel so we could assess the implant's strength and define its rigidity as a fixation method. We based our expected knowledge of the material's properties on previous data found on the literature. In such sense, we considered cortical bone to have modulus of elasticity (E) of 17000 MegaPascals (MPa) and a 0.25 Poisson's ratio ( $\nu$ ), while cancellous bone was thought to have  $E = 776$  MPa and  $\nu = 0.3$ . Values of 316 L stainless-steel alloy of  $E = 200,000$  MPa and  $\nu = 0.3$  were used for modeling the plate and screws [8, 16–18].

The contact between the surfaces were defined as slides used to detect mechanical contact between the plate and the pelvis. The mechanical contact between the screws and the osteotomized pelvis was defined via a glue contact between the matching nodes in the contact bodies. The proposed plate will work with locking screws and so the contact between the plate and screw has been considered glued. The same boundary conditions were applied in the FE model to evaluate the different stiffness values.

A 300 N load was applied to all FE models [11]. This net force was composed of loads on the x, y and z axes, and the resulting load vector was directed to the ventromedial region. The constraining function that would be exerted by the sacrum and the lumbar spine on a real patient was mimicked by the nodes connecting the pelvic bone to the vertebral spine. We proceeded to a static analysis then.



**Fig 4. Medial view of the screws inserted in the cranial and caudal segments of the ilium.**

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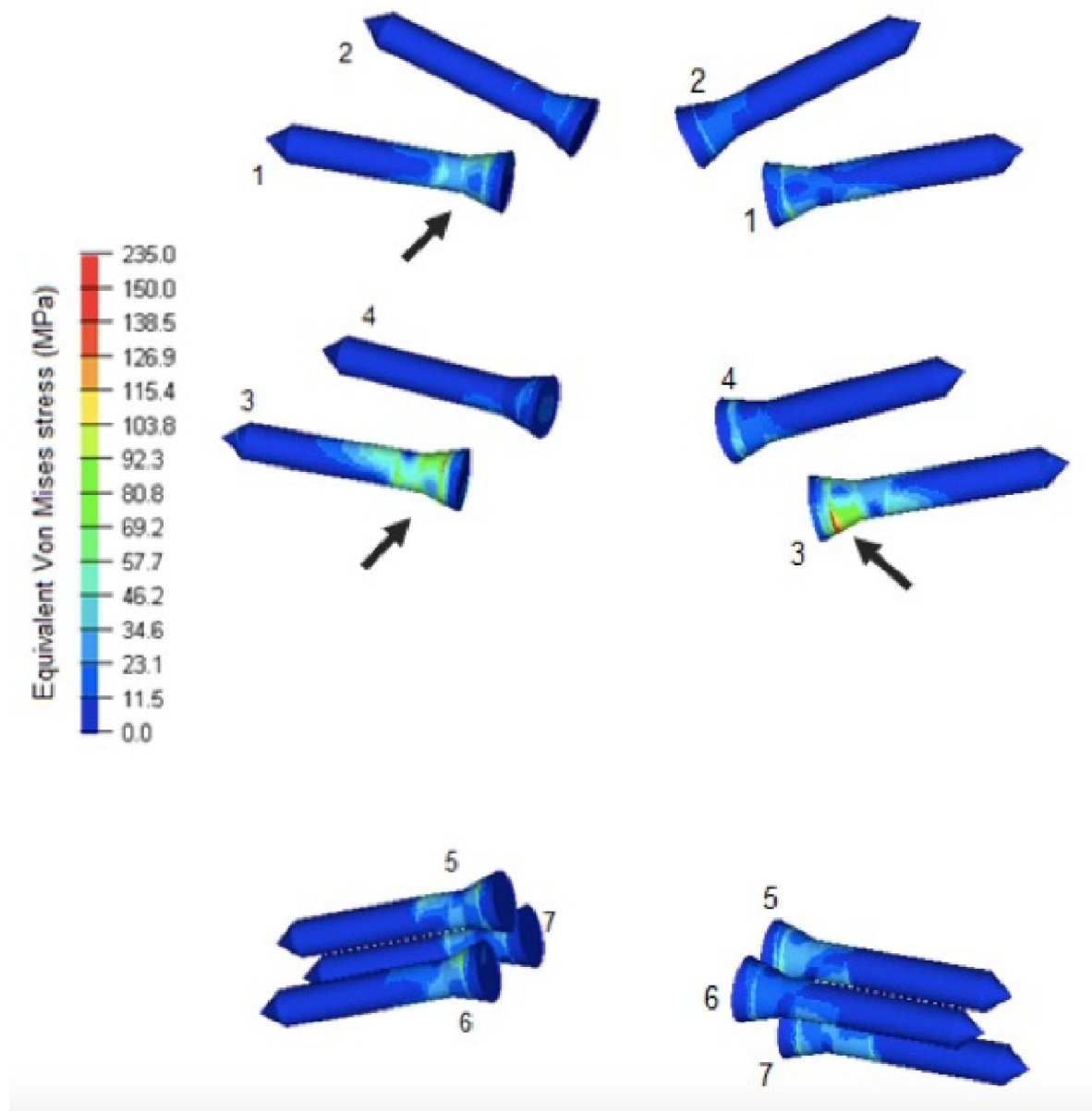
### Data analysis

The von Mises equivalent principal stresses provide a convenient representation of the resulting stresses on the given plate, as well as on the screws and the maximum and minimum main stresses on the bone, that is why we sought to evaluate it. We quantitatively analyzed the stresses generated on the external and internal surfaces of the implant's body and its respective components using HyperView™ GER's software. We took the results in account to assess and record the largest areas values of stress concentration.

## Results

### Stress distribution on screws

The caudal screws, with 12° of caudal inclination, allowed suitable bone stock screw purchase (Fig 4). The cranial screws, in being 6° divergent with cranial inclination, could be placed in parts of the ilium with significant good bone purchase and, additionally, multiples screws could be used in the same segment.



**Fig 5. Von Mises stresses in megapascals obtained from studying the inserted seven inserted screws in the dorsal and ventral view.**

<https://doi.org/10.1371/journal.pone.0269313.g005>

Screws 2 and 4 were the least loaded and withstood similar stress of 17.3 MPa. Screws 1 and 3 underwent the highest stresses, reaching 51.9 MPa and 75 MPa, respectively. There was similar stress and dissipation in screws 5, 6 and 7, with a mean value of 40.4 MPa (Fig 5). Screws seem to have had all the same point of tension concentration in the region of the screw body, close to the head of the screw (Table 2).

### Implant stress distribution

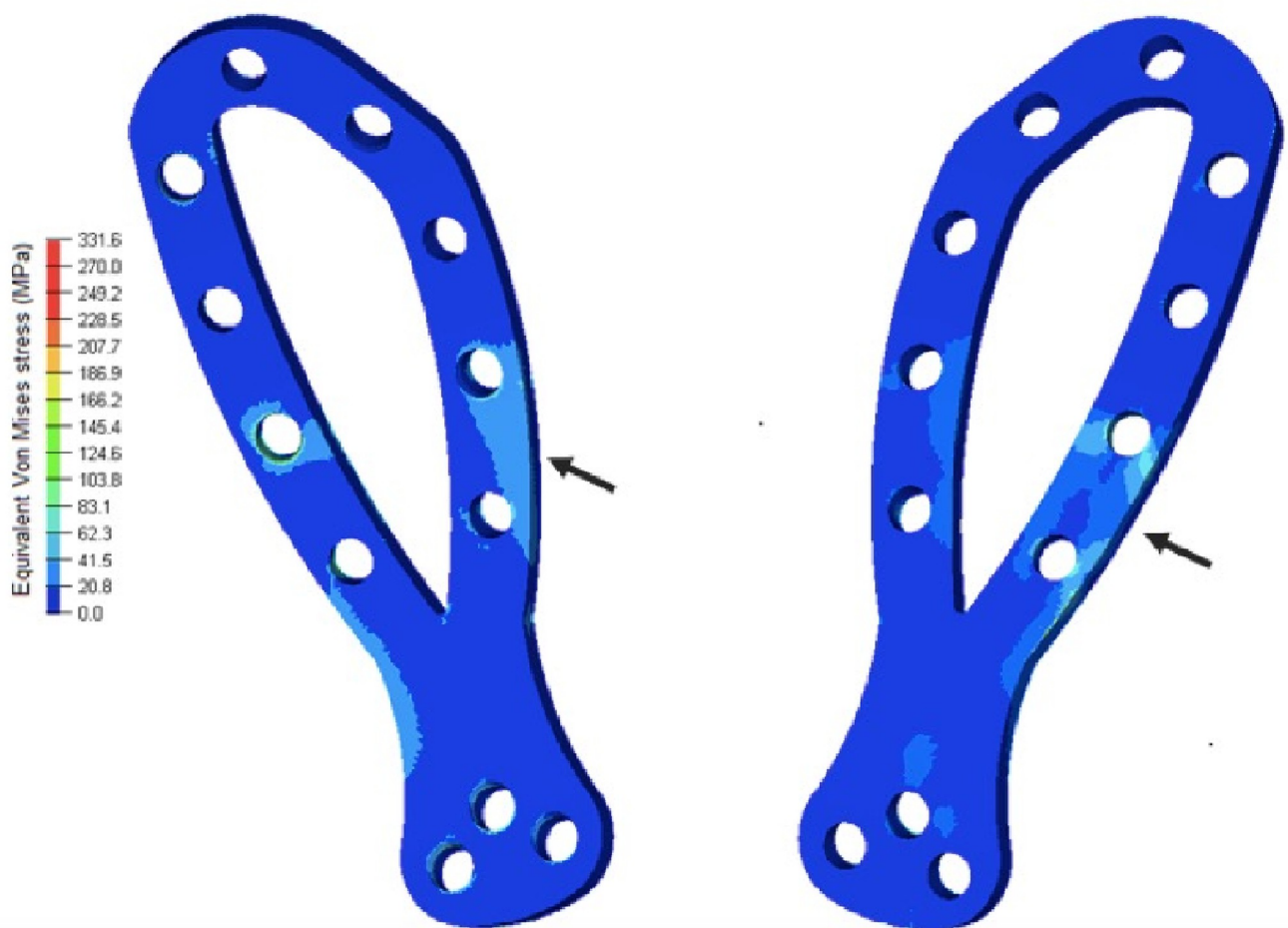
The most loaded region of the cranial part, mainly dorsal region, of the CIP was close to the osteotomy gap (indicated by the black arrow in Fig 6) in each semi-ellipse, with tension values of 51.9 MPa. In the caudal region, there was proper dissipation of forces between the plate and

**Table 2. Values of Von Mises stress in the screws.**

	Screw von Mises stresses on screws	Traction stress values in the orifice of screws in cortical bone	Compression stress values in the orifice of screws in cortical bone
Screw 1	51.9 MPa	Null	Null
Screw 2	17.3 MPa	Null	Null
Screw 3	75 MPa	Null	23.9 MPa
Screw 4	17.3 MPa	Null	Null
Screw 5	40.4 MPa	21.55 MPa	19.25 MPa
Screw 6	40.4 MPa	21.55 MPa	19.25 MPa
Screw 7	40.4 MPa	21.55 MPa	19.25 MPa

MPa: megapascal

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**Fig 6. Von Mises stress in megapascals in the internal and external region for the novel iliac plate.**

<https://doi.org/10.1371/journal.pone.0269313.g006>



the screws. The intrinsically predefined angulation adequately created the potential possibility of proper positioning.

### Distribution of stress in cortical bone

The insertion sites of screws 3, 5, 6, and 7, and the dorsal region of the pubis experiences traction forces in the pelvis. Compression loading occurred in the ventral region of the pubis and in the insertion sites of screws 3, 5, 6, and 7.

The values for traction of the regions were 15.4 MPa for the pubis and screws 5, 6, and 7, and 21.55 MPa for screw 3. The compression values for the pubis and screw hole 3 were the same (23.9 MPa). The insertion sites of screws 5, 6, and 7 showed a mean value of 19.25 MPa ([Table 2](#)).

### Discussion

In view of the broad theoretical and clinical foundations demonstrating the benefits of dedicated surgical implants in human medicine and dentistry [19], veterinary medicine must also move in this direction, which has already occurred for several procedures [12, 14, 15]. There is a lack of implants available for the surgical repair of iliac fractures; the present research bridges this gap with an implant developed specifically for the ilium, with promising benefits from its design and observed results.

During the development of the canine iliac plate (CIP), we sought to overcome the most challenging problems of lateral fixation of iliac fractures, in particular poor bone stock in the cranial segment for screw fixation [6] and reconstruction of the anatomical curvature of the ilium [5, 13, 16, 20]. Achieving better bone purchase was maximized with divergent angle configurations of the holes in the cranial segment of the plate, allowing the screws to be positioned in a thicker peripheral region of the ilium, more dorsally or ventrally. This potentially increased the implant's capacity to distribute load and resist forces.

The elliptical shape and multiple divergent holes in the cranial portion of the implant can, potentially, improve fixation to the iliac wing and cranial portion of the body of the ilium, which is usually performed using non-specific implants such as the TPLO plate or double plating fashion [6, 8]. These adaptations have improved the plate's bone purchase in the cranial segment [6, 10]; however, it may not improve force distribution.

The anatomical pre-contoured 27° angled shape contributed to restore the iliac curvature. In a hypothetical surgical scenario, it could potentially fit the bone surface without further need of plate contouring. This fact, allied with the strategical divergent angles of the screws, met our expectations of the plate's full potential and desired mechanical behavior of the plate [13].

During the analyses, it was observed that the most loaded screws were one and three. That might be explained by the overloading of the location of the screws—based on mechanical forces acting on the ilium region and the hip joint that are known to be highest loading scenario [19, 21]. The region has endured the highest tension because it is suffering compressive loads on its surface during load applications. The homogeneous and strategical distribution of the screws make the CIP potentially more resistant than straight or adapted plates, which tend to have specific stress concentration. This increases the chance of implant failure, usually represented by fractures in the caudal segment and/or screw loosening [6, 9]. Further studies are necessary to objectively demonstrate mechanical differences between the CIP and other plates.

Screw 3 was the closest to the fracture line and withstood maximum tension of 80.8 MPa. Considering that a common complication of iliac surgeries is loosening of the cranial screw [2, 10, 20], by being near to the fracture line and not being overloaded—the minimum stress

recorded was 87.52 MPa [3, 6], we believe that the novel design has potential to avoid such complications in a hypothetical clinical scenario.

The inverted triangular base shaft (caudal end) of the CIP allowed the positioning of three slightly angled screws, improving implant reach of good quality bone stock just cranially to the acetabulum, optimizing the expected fitness for any given plate on such landmark [14]. Implant application in this region can be challenging depending the size of the fractured fragments and the surgical options available, markedly reduced if one only has conventional long straight plates [4, 13, 14, 22].

Different materials behave differently, and future studies are necessary. Titanium's modulus of elasticity resembles that of the bone and not so much that of the stainless steel. Steel resists less to cyclic fatigue and tends to plastically deform easier [23].

Summary, the load distribution between the cranial and caudal portions of the CIP can be acknowledge. Based on our results and considering the forces and stress dissipations, we believe that it is possible to predict the elasticity of the plate. Extrapolating to a clinical scenario, we hypothesize that the CIP might provide a mechanical-friendly behavior that would prevent interfragmentary motion.

This study describes the steps to develop a novel bone implant and the finite elements data analysis of the same bone plate customized to fit the canine ilium. The novel plate is potentially applicable and specifically suitable for iliac fractures in dogs. Ours was an *in vitro* study and further comparative and biomechanical studies are necessary to clinically validate our implant.

## Supporting information

### S1 File.

(PDF)

## Author Contributions

**Conceptualization:** Tryssia S. M. Moi, Bruno W. Minto, Ana P. Macedo, Dayvid V. F. Lucena, Caio A. S. Malta, Luis G. G. G. Dias.

**Formal analysis:** Tryssia S. M. Moi, Ana P. Macedo, Dayvid V. F. Lucena.

**Methodology:** Tryssia S. M. Moi, Ana P. Macedo, Dayvid V. F. Lucena, Caio A. S. Malta, Luis G. G. G. Dias.

**Software:** Tryssia S. M. Moi, Ana P. Macedo, Caio A. S. Malta.

**Visualization:** Bruno W. Minto.

**Writing – original draft:** Tryssia S. M. Moi, Bruno W. Minto.

**Writing – review & editing:** Tryssia S. M. Moi, Bruno W. Minto, Ana P. Macedo, Caio A. S. Malta, Luis G. G. G. Dias.

## References

1. Fitzpatrick N, Lewis D, Cross A. A biomechanical comparison of external skeletal fixation and plating for the stabilization of ilial osteotomies in dogs. *Vet Comp Orthop Traumatol* 2008; 21:349–57. <https://doi.org/10.3415/vcot-06-10-0072> PMID: 18704242
2. Doornink MT, Nieves MA, Evans R. Evaluation of ilial screw loosening after triple pelvic osteotomy in dogs: 227 cases (1992–1999). *JAVMA* 2006; 226:535–41. <https://doi.org/10.2460/javma.229.4.535>
3. Hutchinson GS, Griffon DJ, Siegel AM, et al. Evaluation of an osteoconductive resorbable calcium phosphate cement and polymethylmethacrylate for augmentation of orthopedic screws in the pelvis of

- canine cadavers. *Am J Vet Res* 2005; 66:1954–60. <https://doi.org/10.2460/ajvr.2005.66.1954> PMID: 16334956
4. Bruce CW, Gibson TWG, Runciman RJ. A comparison of conventional compression plates and locking compression plates using cantilever bending in an ilial fracture model. *Vet Comp Orthop Traumatol* 2014; 27:430–5. <https://doi.org/10.3415/VCOT-14-01-0001> PMID: 25345445
  5. Mills J. Transilial interlocking plate stabilisation of a sacral fracture and an ilial fracture in a dog. *Vet Comp Orthop Traumatol* 2009; 22:70–3. PMID: 19151875
  6. Kenzig AR, Butler JR, Priddy LB, Lacy KR, Eelder SH. A biomechanical comparison of conventional dynamic compression plates and string-of-pearls™ locking plates using cantilever bending in a canine ilial fracture model. *BMC Vet Res* 2017; 13:222–7. <https://doi.org/10.1186/s12917-017-1139-8> PMID: 28705189 PMCID: PMC5508706
  7. Breshears L, Fitch RB, Wallace LJ, Wells CS, Swiderski JK. The radiographic evaluation of repaired canine ilial fractures (69 cases). *Vet Comp Orthop Traumatol* 2004; 17:64–72. <https://doi.org/10.1055/s-0038-1636484>
  8. Zanetti EM, Terzini M, Mossa L, et al. A structural numerical model for the optimization of double pelvic osteotomy in the early treatment of canine hip dysplasia. *Vet Comp Orthop Traumatol* 2017; 30:256–64. <https://doi.org/10.3415/VCOT-16-05-0065> PMID: 28636062
  9. Perren SM, Klaune K, Pohler O, Predieri M, Steinemann S, Gautier E. The limited contact dynamic compression plate (LC-DCP). *Arch Orthop Trauma Surg* 1990; 109:304–10. <https://doi.org/10.1007/BF00636166> PMID: 2073447
  10. Rose SA, Bruecker KA, Petersen SW, Uddin N. Use of locking plate and screws for triple pelvic osteotomy. *Vet Surg* 2012; 41:114–20. <https://doi.org/10.1111/j.1532-950X.2011.00927.x> PMID: 22150566
  11. McCartney M, Macdonald B, Ober CA, Lorza RL, Gómez FS. Pelvic modelling and the comparison between plate position for double pelvic osteotomy using artificial cancellous bone and finite elements analysis. *BMC Vet Res* 2018; 14:100. <https://doi.org/10.1186/s12917-018-1416-1> PMID: 29554909 PMCID: PMC5859441
  12. Garnett SD, Daye RM. Short-term complications associated with TPLO in dogs using 2.0 and 2.7 mm plates. *J Am Anim Hosp Assoc* 2004; 50:396–404. <https://doi.org/10.5326/JAAHA-MS-6074>
  13. Meeson RL, Geddes AT. Management and long-term outcome of pelvic fractures: a retrospective study of 43 cats. *J Feline Med Surg* 2017; 19:36–41. <https://doi.org/10.1177/1098612X15606958> PMID: 26445978
  14. Chou P, Runyon C, Bailey T, Béraud R. Use of Y-shaped TPLO plates for the stabilization of supracotyloid ilial fractures in four dogs and one cat. *Vet Comp Orthop Traumatol* 2013; 26:226–32. <https://doi.org/10.3415/VCOT-12-05-0060> PMID: 23677125
  15. Karan NB, Akinci HO. A novel approach for horizontal augmentation of posterior maxilla using ridge split technique. *J Craniofac Surg* 2019; 30:1584–8. <https://doi.org/10.1097/SCS.00000000000005124> PMID: 31299774
  16. Wahnert D, Windolf M, Brianza S, et al. A comparison of parallel and diverging screw angles in the stability of locked plate constructs. *J Bone Joint Surg Br* 2011; 93:1259–64. <https://doi.org/10.1302/0301-620X.93B9.26721> PMID: 21911539
  17. Oh JK, Sahu D, Ahn YH, et al. Effect of fracture gap on stability of compression plate fixation: a finite element study. *J Orthop Res* 2009; 28:462–7. <https://doi.org/10.1002/jor.20990>
  18. Polikeit A, Ferguson SJ, Schamaldar P. Ellbogendysplasie beim Hund: finite-elemente-analyse. *Biomedizinische Technik* 2007; 52:308–14. <https://doi.org/10.1515/BMT.2007.052>
  19. Zhao L, Tian D, Wei Y, et al. Biomechanical analysis of a novel intercalary prosthesis for humeral diaphyseal segmental defect reconstruction. *Orthop Surg* 2018; 10:23–31. <https://doi.org/10.1111/os.12368> PMID: 29484857
  20. Scrimgeour A, Witte P, Craig A. Locking T-plate repair of ilial fractures in cats and small dogs. *Vet Comp Orthop Traumatol* 2017; 30:453–60. <https://doi.org/10.3415/VCOT-17-01-0015> PMID: 29202509
  21. Guthrie JW, Kalf S. Tibial plateau levelling osteotomy locking-compression plates for stabilization of canine and feline ilial body fractures. *J Small Anim Pract* 2017; 59:232–7. <https://doi.org/10.1111/jsap.12803>.
  22. Case JB, Dean C, Wilson DM, Knudsen JM, James SP, Palmer RH. Comparison of the mechanical behaviors of locked and nonlocked plate/screw fixation applied to experimentally induced rotational osteotomies in canine ilia. *Vet Surg* 2011; 41:103–13. <https://doi.org/10.1111/j.1532-950X.2011.00913.x> PMID: 22092198
  23. Zhu M, Ye H, Fang J, et al. Engineering high resolution micropatterns directly onto titanium with optimized contact guidance to promote osteogenic differentiation and bone regeneration. *ACS Applied Materials & Interfaces*. 2019; <https://doi.org/10.1021/acsami.9b16050> <https://doi.org/10.1021/acsami.9b16050> PMID: 31680521