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Biomechanical prototype of a prosthesis for the pelvic limb of small puppies

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Abstract:*As humans approach animal approaches, technological advances are becoming increasingly prevalent and accessible in this environment. With a focus on pets, a factor is much desired, but without a major technological advance, the biomechanics of veterinary orthopedics. Currently what have been attending to paraplegic/quadriplegic animals are wheelchairs and trawl bags, however, their uses are still very limited. This is because dogs with low mobility should take turns between the drag bag for everyday life and the wheelchair for physical exercises, and exercises are extremely important to avoid muscle atrophy, overweight, depression, and dependence on the tutor. However, this relay is not practical and this ends up stimulating abandonment or rejection of the animal within the Non-Governmental Organizations (NGOs). This project aims to create an accessible prosthesis for dogs, whose pelvic limb does not present motricity. The main objective is to return mobility to the dog through a prosthesis designed at low cost, from the technology of 3D printing. Being the same, totally personalized through the measurements of the bone structure visualized by reading the tomography in the Software Invesalius 3.1. The purpose is to produce an accessory that allows the dog to remain with her full-time, but with the ease of taking and putting it for hygiene. In addition, prevent the dog from atrophying the remaining muscles and developing obesity and depression due to its situation.*

Keywords:*Biomechanics. Motricity. 3D printing.*

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I. INTRODUCTION

With a population of 54.2 million dogs, Brazil has 2.69 million dogs in conditions of vulnerability, and another 165,200 in the care of 370 NGOs (Non-Governmental Organizations), as stated by Instituto Pet Brasil (2019b). Some of these NGOs have become specialized in welcoming dogs with some type of disability because the number of abandonment and rejection is higher.

NGOs claim that tutors justify rejection due to the high cost they will have with treatments such as acupuncture and physiotherapy, as well as medicines and accessories that help mobility. It is still necessary for future tutors to dedicate more time to cleaning, rotating accessories, and encouraging the practice of physical exercises.

1.1 TypesofProstheses

According to García (2017) and Tilghman (2015) among the needs to return to the routine of small dogs with reduced mobility or permanent paralysis in the front or hind legs, the causes are diverse: some surgical intervention, fractures, accidents, and diseases such as arthrosis severe canine, hip dysplasia, degenerative myelopathy, hernias, arthritis, cerebrovascular accident (CVA), cerebral hypoplasia and paralysis. Limited mobility is also due to the animal's advanced age or obesity, in which it is gradually lost, and can be observed over time.

However, there are cases classified as congenital anomalies, where the patient carries a congenital amputation since birth. According to Beers and Berkow (2000), they are classified into two types: transversal where from a point onwards all the following elements are absent, leaving only an amputation stump; longitudinal where failures occur due to the absence of a specific development completely or partially of limbs such as the fibula, tibia or radius.

Blohmke (2002) points out that transverse anomalies use prostheses with sockets and longitudinal anomalies can have the function of orthosis and prosthesis at the same time. The orthosis has the sole purpose of aligning or assisting the functions of a limb, organ, or tissue and the prosthesis in the sense of replacing them.

Within the cases that do not fit into a congenital anomaly, the fitting can be done immediately, which unfortunately with dogs and even with humans rarely happens, as it requires a specialized team and infrastructure to minimize the risks, as it happens immediately. After surgery remove the limb with a prosthesis adapted to the amputated stump (ARAÚJO, 2016).

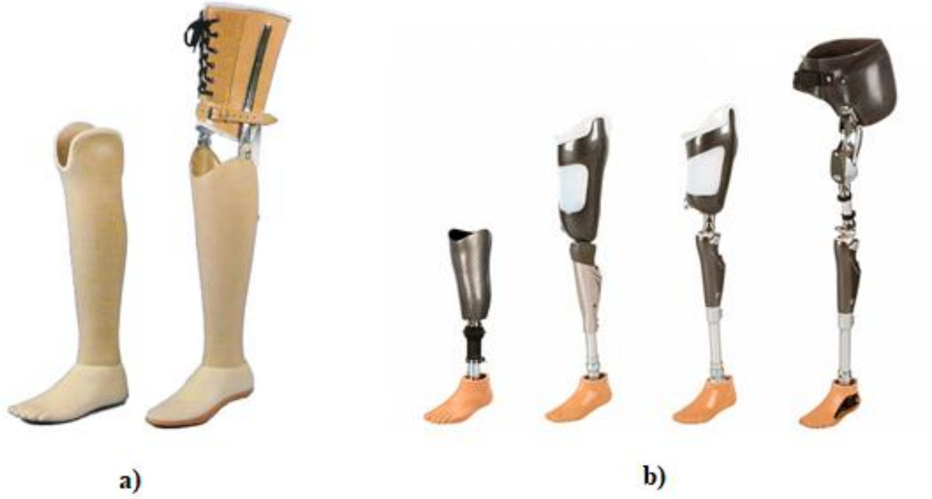
On the other hand, not so indicated, but more common, the intermediate prosthesis can happen at any time after the surgery, and the longer the time without, the more difficult the adaptation becomes, they are usually made with prefabricated prostheses (ARAÚJO, 2016).

After identifying the problem, Blohmke (1994) classifies prostheses into two types of lower limb prosthesis (LL) systems available to humans: conventional, also known as exoskeletal, and modular, also known as endoskeletal.

Considered a traditional prosthesis, Carvalho (2003) explains that the exoskeletal prosthesis, Figure 1a provides support with an aesthetic finish, and can be used in all cases of amputation, despite prioritizing transfemoral amputations and disarticulation of the knee and hip. As an advantage, the system is resistant, durable, and requires little maintenance, but they are simple and do not allow more elaborate activities to be carried out, the aesthetics are not very pleasant, it is difficult to realign, and there are few components and a time-consuming replacement.

Carvalho (2003) adds that the endoskeletal system prosthesis or also known as modular prosthesis, Figure 1b receives this name because its internal support structure is formed by modular mechanical components industrially produced with different configurations. These allow easy alignment and exchange due to their composition of four screws that allow adjustments and alignment corrections in the sagittal, frontal, horizontal, and translation planes, being able to receive rotation and torsion adapters giving greater freedom of movement and consequently comfort.

Figure1. a) Human exoskeletal prosthesis model and b) human endoskeletal prosthesis models.



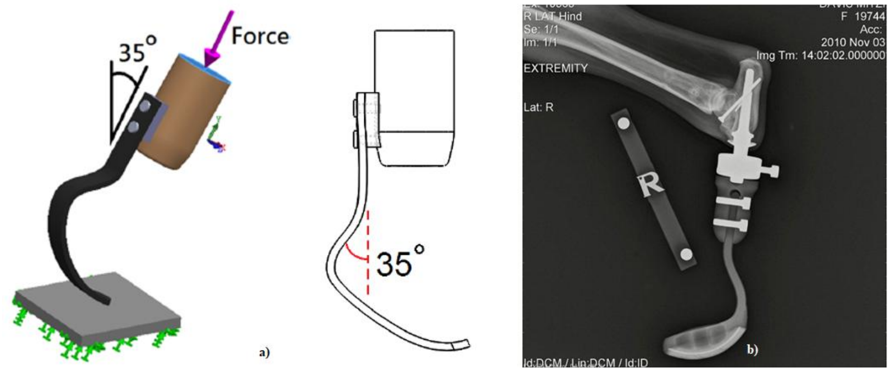
This type of prosthesis is considered superior to conventional prostheses due to its functionality and cosmetic means, being used at all amputation levels with an emphasis on knee and hip disarticulations and transfemoral amputations, excluding only their use in the feet and ankles (CARVALHO, 2003).

The model Cheetah prosthesis in “J” shape is used only in Paralympics, to avoid any advantage over competitors without the prosthesis. However, even Paralympic competitors must follow rules under their prostheses, as shown in Figure 2a. In dogs, this type of prosthesis is due to the limitations of the stump, but unlike the one used in humans, a part is implanted inside the limb called the endoprosthesis and another part is fitted on the external side called an exoprosthesis (Fitzpatrick et al. 2011). The endoprosthesis is an intraosseous prosthesis composed of an inert material inserted into the bone of the stump through the osseointegration technique, as seen in Figure 2b. The part of the exoprosthesis, also known as the Transcutaneous Intraosseous Amputation Prosthesis (ITAP) is fixed to the intraosseous prosthesis that is not immersed in the bone, this intraosseous and transcutaneous relationship transfers the mechanical load from the bone to the prosthetic limb, unlike the stump prosthesis.

Zuniga et al. (2016) point out that due to the complexity and the use of many resources and manpower, ITAP can be very expensive. In addition, it is very easy to fracture the distal part of the bone if the implant is incorrectly inserted. Another concern corresponds to load transfer over the bone and the implant.

Nunamarker and Blauner (1985) and Weigel (2005) explain that a normal patient, without orthopedic alteration, must support 60% of the body weight in the front legs, being 30% in each forelimb. While the hind legs must support the other 40% of their total weight, being 20% on each pelvic limb. Due to the relationship between speed and acceleration, the forces placed on the limbs during the stance phase have a significant increase in these absolute values, with an increase in speed in each form of locomotion.

Figure 2. a) Human exoskeletal prosthesis model and b) human endoskeletal prosthesis models.



1.2 Pelviclimbangulation

Timi et al. (2009) explain that goniometry is the measurement of angles and is used to assess joint flexibility, in this way the doctor can identify and quantify the decrease in the range of motion of a given joint. However, due to the difficulty of measuring the anatomical nomenclature of the movements and not having a precise method, the diffusion of the practice is still limited.

However, understanding the mechanism of locomotion and angulation is of fundamental importance for surgeries such as arthrodesis. Freitas et al. (2014) explain that this surgery is performed by joining the ends of two or more bones in joints with severe pathologies, but for the technique to be successful, the extension and flexion angle, the degree of varus or valgus are required and the rotational or axial alignment of the dog.

Except for theGerman Shepherd, whose croup is dropped, as shown in Figure 3, the maximum normal angles of extension and flexion vary from 65º to 75º. After defining the fusion angle, which is approximately 140º, this angle can still vary from 5º to 10º, as there are situations where the limb ends up decreasing due to surgery, as observed in the first case in Figure 4 (LESSER, 1988; NOGUEIRA AND TUDURY , 2002; EUGENIO, 2004; TURNER AND LIPOWITZ, 2005; JOHNSON AND DUNNING, 2005; FOSSUM 2009).

Figure 3. Flat and drooping croup angulation.

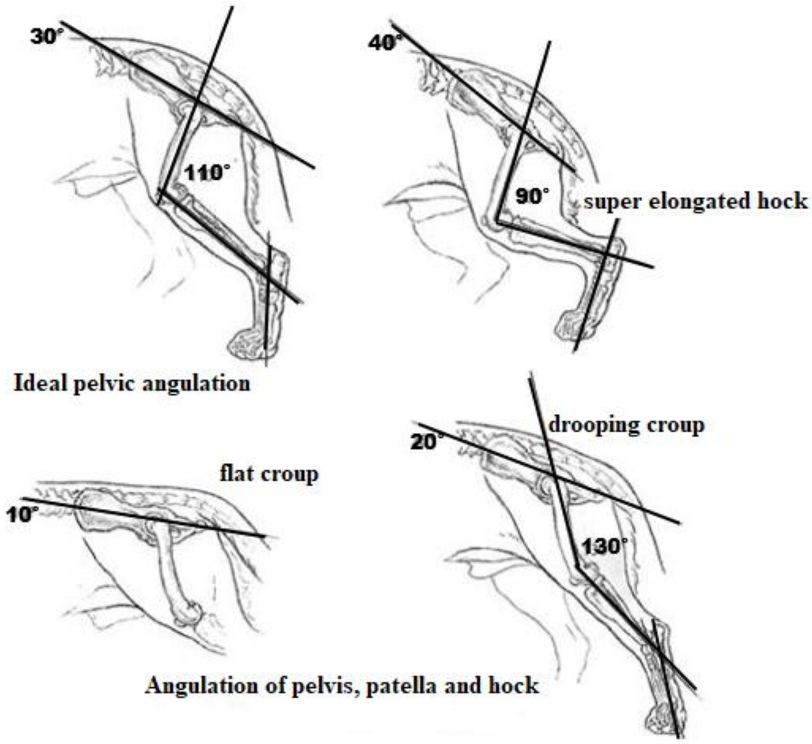
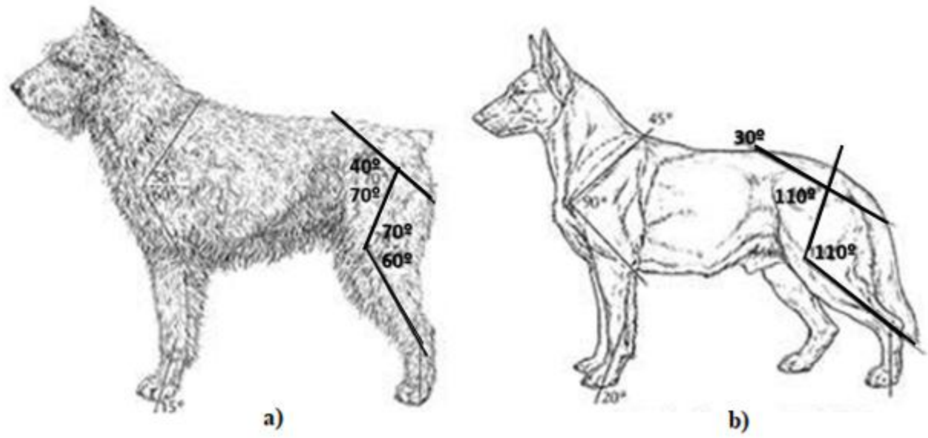


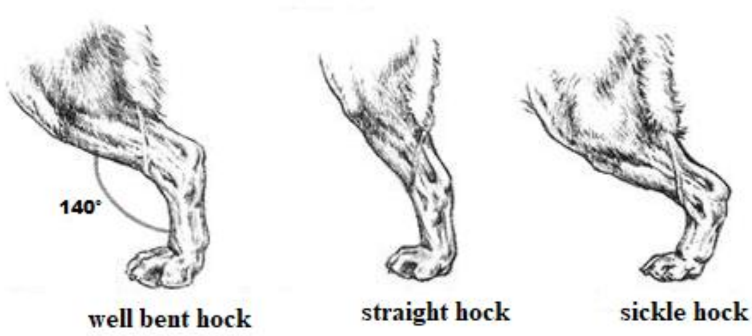
Figure 4. Comparison of ideal angulations between a) Bouvier des Flandres and b) German Shepherd.



Dyce et al. (1990) completely explaining about the tarsal joints also located in the pelvic limb, whose function is to unite the distal end of the tibia to the tarsal bones and the proximal end of the metastatic bones. This joint is of the ginglymus (hinge) type and has an atypical uniaxial movement (flexion and extension), as there is an obliquity in the connecting edges and grooves of the tibia and talus, imposing a lateral deviation of the foot when brought forward in flexion.

This joint has normal flexion angles of around 65° to 75° and 90° to 110° in extension. In arthrodesis, the fusion angle approaches 140º, as shown in Figure 5. (NOGUEIRA AND TUDURY, 2002; EUGENIO, 2004; TURNER AND LIPOWITZ, 2005; JOHNSON AND DUNNING, 2005, FOSSUM, 2014).

Figure 5. Bendingangle.



1.3 ExistingMaterials

To bring the replaced joint or limb closer to the original, technology has been looking for a light and resistant material. Among the most technologically advanced, Batista Jr. et al. (2006) and Oliveira et al. (2013) cites duralumin, titanium, cobalt-chromium-molybdenum alloy, stainless steel, and carbon fiber, with emphasis on duralumin and titanium due to their lightness and strength as high as steel.

To decide on the fabrication material, it is necessary to identify the type of prosthesis as mentioned by Araujo (2011) and Doreto et al. (2014).

a) Exoskeletal: initially they were only made of wood, later they moved to plastic where they are usually used for bathing and geriatric. Currently, some techniques use rigidand light foams covered with plastic resins reinforced with fiberglass and/or carbon to obtain a slightly more comfortable structure, in addition to these materials there are still exoskeletal prostheses made of PVC or polypropylene, but all these materials are due to their rigidity do not allow for elaborate movements.

b) Endoskeletal: its support is formed by mechanical components of tubular/modular appearance that optimizes weight support, usually the tubes are made of more sophisticated materials such as aluminum, steel, titanium, or carbon fiber. For finishing, they are covered with flexible foam shaped to simulate a human limb. Due to these high-tech materials, it is possible to find modular knees from monocentric with a lock to polycentric with hydraulic and pneumatic units.

Blohmke (1997) argues that steel components present strength, however without delivering lightness. Aluminum demonstrates greater lightness but limits the load capacity due to its low mechanical strength.

Titanium can offer the best mechanical properties in terms of lightness and strength, however, it has the highest cost.

In this way, currently, to have a comfortable and long-lasting prosthesis, you would have to pay dearly, therefore, 3D printer filaments were selected according to criteria evaluated by filament companies such as Cammada, 3dlab, Magigoo, 3dFila, Filament2Print, CombTech and All3dp. Based on the tests carried out by these companies, the main characteristics are shown in Figure 6.

Figure 6. Filamentsproperties

Properties of the filaments								
very low	blue	green	yellow	orange	red	very high		
has the characteristic	X		doesn't have the characteristic					
	PLA	ABS	PETG	TPE	Nylon	Tritan	PC	Peek
thermal resistance	green	orange	yellow	yellow	orange	red	red	red
chemical resistance	yellow	green	orange	orange	orange	red	orange	red
impact resistance	green	yellow	orange	orange	red	orange	orange	red
friction resistance	green	green	orange	blue	orange	orange	orange	red
durability	green	orange	orange	red	orange	red	red	red
hardness/stiffness	yellow	orange	orange	green	orange	red	orange	red
flexibility	green	yellow	yellow	red	orange	orange	yellow	yellow
contraction (warp)	green	orange	yellow	yellow	green	blue	green	green
difficulty of use	blue	yellow	green	red	yellow	yellow	yellow	green
level of detail	orange	green	green	orange	orange	yellow	orange	orange
weightlessness	orange	yellow	orange	orange	orange	orange	orange	orange
cost	green	green	green	green	orange	yellow	orange	red
transparency	yellow	blue	orange	yellow	green	red	red	green
hygroscopic			X		X		X	
solvable		X						
FastSafe			X					
biodegradable	X							
toxic		X						

In addition to the materials mentioned, there are professional materials that were excluded due to difficult access and printing, exotic and creative filaments were also excluded for reasons of being for aesthetic use.

Within the materials presented, the properties of the material used in human prostheses and the filaments with the most relevant characteristics for the printing of the product will be evaluated. From the previous table, HIPS and PVA have already been excluded, as they are support materials for the printing of more complex parts, therefore they are easily soluble.

Polyacid Lactic (PLA), despite being a non-toxic and inexpensive material, is influenced by air humidity, so it is only advisable for parts that will not be stressed. In this way, the dog could not, for example, walk on a wet floor.

Acrylonitrile Butadiene Styrene (ABS) is made from petroleum, so constant contact with the skin is not advisable, as it may cause allergies or skin injuries.

Glycol-modified Polyethylene Terephthalate (PETG) is one of the noblest of materials, as it is more flexible and durable than PLA and easier to print than ABS, and can be printed on any printer (open, closed with or without bed heated). In addition, it is mechanically, chemically, and thermally resistant, its warp is considerable, and can print large parts. During printing it becomes sticky and so its layers are perfect, making FoodSafe widely used in beverage bottles.

In the case of Thermoplastic Elastomer (TPE), it is an extremely resistant filament to hostile environments that include chemical exposure, heat, and UV rays, however, despite its lightness and durability, it is an excessively flexible material and does not providestability to the animal.

Polyamide (Nylon) is a material of excellence, as well as PETG, it is widely used in high impact and tension parts because despite being light, it has a chemical, mechanical and thermal resistance. However, if exposed to ambient air, it has its maximum absorption of water molecules in just 18 hours.

As Tritan is superiorto PLA, ABS, and PETG, for printing an extremely high extrusion temperature is required and the printer tube cannot be made of Teflon, like most. It is considered engineering plastic, as it is ideal for functional prototypes and large parts, but requires a more elaborate 3D printer.

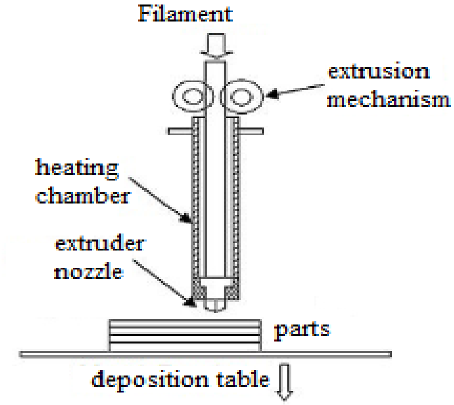
Polycarbonate (PC) is one of the strongest filaments on the list, despite being hygroscopic, it is extremely durable and resistant to impact and heat, however, it has certain flexibility that eventually deforms the product, making the life of the project longer.

Finally, Polyetheretherketone (PEEK) is a filament that resembles titanium because it has a high chemical, thermal, and stress resistance. It is a high-performance material, resisting exposure to x-ray and gamma radiation, making its use common in medical and semiconductor components. Despite all these components, it is easy to use, just needing a printer that reaches 400ºC for extrusion. However, it is an extremely expensive material, making the objective of a low-cost prosthesis unfeasible.

1.4 3D printing

The most used manufacturing process today is Fused Deposition Modeling (FDM). As the creator Crump (1992) cites, in this process the thermoplastic is heated in a nozzle until it reaches a temperature that allows extrusion through the nozzle, thus depositing material layer by layer, as shown in Figure 7. FDM printers are priced below the others, with a final quality finish and compatibility in a wide variety of filaments with affordable raw material.

Figure 7. Scheme of the manufacturing process - FDM



Each 3D printer works according to the manufacturing process predetermined by the chosen model, some settings must be analyzed in a particular way for each project. From the choice of filament, data such as nozzle temperature and bed temperature are specified by the manufacturer, but with the limitation of the printer, as some reach higher temperatures than others.

Other factors that define the strength of your part are filled percentage and layer type. Through slicing software, it is possible to set these and other settings such as the height of the layers, printing speed, temperature parameters, and other parameters before giving the command to create the Gcode, the code which the 3D printer interprets to perform the print.

Ribeiro (2019) cites that the FDM process has the advantage in the construction of structural panels, as it has the facility of just defining the shape and percentage of filling, the thickness of the faces, and the orientation of the print.

The filling percentage depends on the weight and stiffness you want for your part, as the higher the percentage, the more massive the part becomes, which may take longer to be ready, as it requires a greater amount of material to extrude. The filling refers to the type of layer you choose, with the option: of straight, triangle, star, beehive, or cubic, among others, as can be seen in Figure 8.

The beehive or honeycomb type has very common use in the aerospace environment, because as stated by Dias et al. (2016), for years the mechanical behavior of thermoplastic core panels has been studied for different materials and filling. In short, the honeycomb structure promotes high strength and mass, giving greater resistance to fatigue.

Bitzer (2012) explains that the use of thermoplastic materials has been explored in the form of honeycomb panels for a long time outside the AM, in general, the arrangement is heated by fusing the nodes between the cells without the need for adhesive tape. For the production of the 3D panel, the printer creates between two plates an interior filling with a hexagonal pattern material core, each layer is thin, but with dense and strong faces, as seen in Figure 9with different levels of filling.

Figure 8. Partfillcomparison.

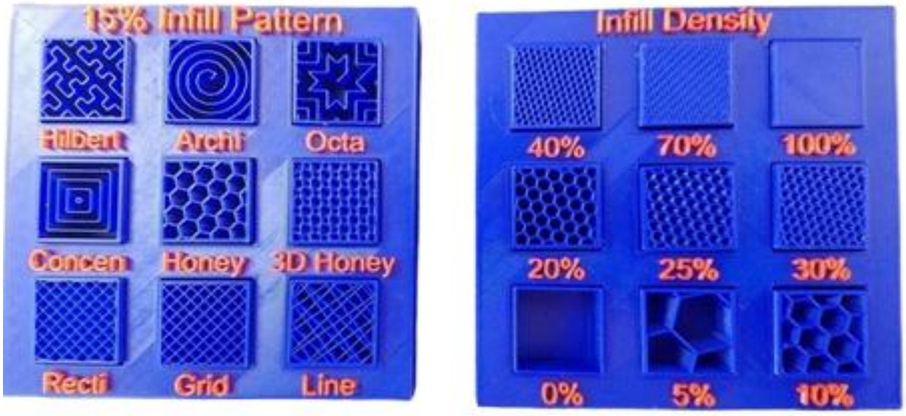
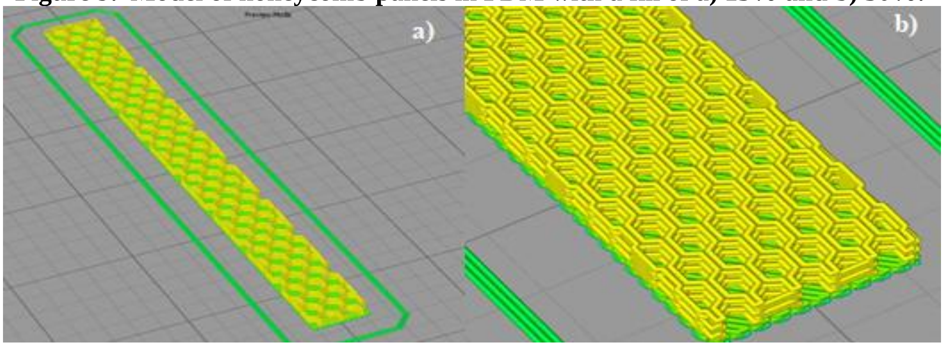


Figure 9. Model of honeycomb panels in FDM with a fill of a) 15% and b) 50%.



Ribeiro (2019) cites that the performance of the honeycomb structure depends on the properties of the faces and the core, the core can have its density and filling pattern varied according to the size of the cells, whereas the faces depend mainly on the number of layers stacked and the orientation of each to form the faces. Bitzer (2012) adds that when loaded, the panel may suffer deflection due to bending from the stiffness of the faces or deflection caused by shearing from the stiffness of the core.

II. EXPERIMENTAL PROCEDURE

Because it is a personalized study, the entire construction of the prototype was based on models of human prostheses and animal physiology.

2.1 Prototype

For the study in question, a tomography in DICOM format was used, where the pelvic limb of the dog was extracted using the InVesalius 3.1 software. The extraction and reconstruction through DICOM images served as a mold for the construction of the prototype through the Auto Desk Inventor 2020 Software.

The prototype combined the design of the human Cheetah prosthesis with the support that makes it possible to attach the accessory to the animal's body, allowing the dog to have the mobility to walk, sit and lie down with an angulation of 70º to 140º, according to the nature of dogs. The idea was to leave a gap that allows a helical torsion spring to move within that angle and get stuck on a pin that was printed along with the bottom.

After finishing the CAD part, PETG and ABS filament was chosen for printing, due to their ease of printing and resistance. In this way, these materials were created by Inventor to perform the CAE simulation that predicts the weaknesses of the prototype. After the tests, the file was saved in STL format and transferred to a slicer software, the chosen one was Simplify3D 4.1.2, available at the university.

In Simplify3D it is necessary to choose the settings according to the chosen filament, available printer, and resistance of the desired final product. With the popularity of the FDM manufacturing process in MA, due to the ease of using the machine at a relatively low cost, the chosen 3D printer that is available in the INOVA department of UNIGRAN was the Core A2v2 of the GTMax3D brand, a reference in the market.

When setting all the data, the slicer itself saves all the settings in the GCode format (G Code), so the file is transferred to an SD memory card and plugged into the print.

2.2 Mounting

With the parts ready, it was possible to add some treatment before assembling. When assembling, fit the chosen torsion helical spring onto the pin and lock the pin of the lower part on the upper part. An elastic band was sewn to the upper part and a piece of rubber was glued to the lower part to avoid contact directly.

2.3 Test

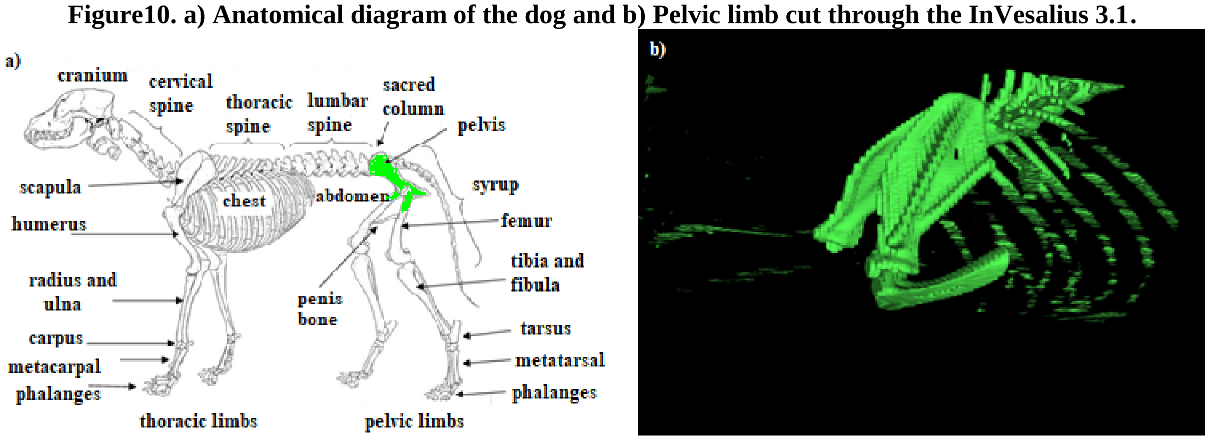
After the assembly, the part was sent to an axial compression press available at the Civil Engineering Laboratory UNIGRAN to compare the results with the CAE simulation. In this type of test, it is possible to measure the speed, displacement, and force applied to the same part and different materials.

III. RESULTS AND DISCUSSIONS

3.1. Prototype design

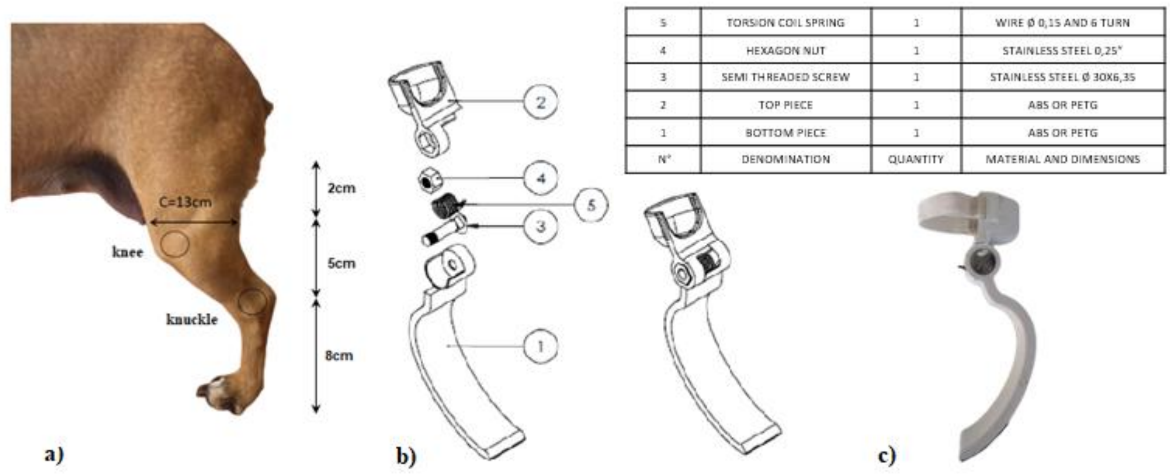
For the development of the project, the initial idea of using the cast taken from the CT in InVesalius was not feasible, as the available exam did not have a complete view of the patient's pelvic limb, obtaining only a partial image. If compared with a normal canine skeleton, it was noticed that with this CT it was only possible to visualize the pelvis and the beginning of the femur, being that what would be necessary would be the tibia, fibula, tarsus, metatarsus, and phalanges, as shown in Figure 10 below:

Figure10. a) Anatomical diagram of the dog and b) Pelvic limb cut through the InVesalius 3.1.



In this way, it was necessary to take the measurements of a dog with an entire pelvic limb to have a dimensioning for the project in CAD. The dog taken as a reference is a pinscher breed weighing 3.6 kg, as shown in Figure 11 a.

Figure 11. a) Reference dog measurement b) design in CAD c) design in ABS.



5	TORSION COIL SPRING	1	WIRE Ø 0,15 AND 6 TURN
4	HEXAGON NUT	1	STAINLESS STEEL 0,25"
3	SEMI THREADED SCREW	1	STAINLESS STEEL Ø 30X6,35
2	TOP PIECE	1	ABS OR PETG
1	BOTTOM PIECE	1	ABS OR PETG
N°	DENOMINATION	QUANTITY	MATERIAL AND DIMENSIONS

The limb was separated into two parts, the upper part where the fixation was located and the lower part that would be the substitute for the animal's paws, between them there is a connecting link that had the function of a knee. With the thigh measurement, it was possible to create a support for the knee stump. This support allows the back of the thigh to be supported and with the help of a 1x10cm elastic band, the prosthesis is fixed to the animal's body. The elastic goes through a hole designated for it and is secured to it by a simple seam. With the measurements of the screw, the spring, and the data from the arthrodesis surgery, where it is known that the angle of the animal between lying down and walking varies from 60º to 140º, respectively, the project was made in the CAD of Inventor 2020 that can be observed in Figure 11 b) and design in ABS (Figure 11 c).

3.2. PartPrinting

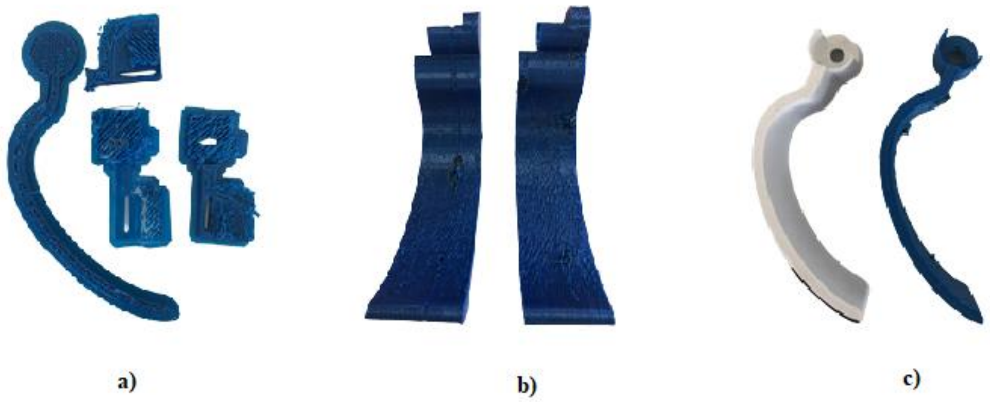
The same part was printed on two different materials, however, some settings were changed for each filament, as mentioned in Table 1.

Table 1. Configuration by the filament.

	PETG	ABS
Extrusionmultiplier	0.85	0.95
Fill	Fullhoneycomb	Rectilinear
Fillpercentage	80%	90%
Bedtemperature	85ºC	110ºC
Nozzle temperature in the first layer	250ºC	245ºC
Nozzle temperature in the other layers	235ºC	230ºC

With ABS everything went as planned, however, the same did not happen with PETG. At first, there were several clogs in the extruder nozzle, as the extruder itself is outside the 3D printer, making a printer not suitable for such a filament. Figure 12 a) shows the first printing attempts. In addition, the pieces that were finished also had filament clogging, which resulted in small cracks on the surface, in addition to several stringing (angel hair) that are lint on the piece, the vast majority was removed soon after printing, but it follows Figure 12 b) with the result. Due to blockages in the nozzle, it was not possible to print the upper part in PETG, but in ABS the project was able to be completed perfectly, however it must be remembered that ABS is not recommended for constant contact with the skin, so before use, it is recommended to carry out some varnishing treatment of the piece, but in this case, it was not used.

Figure 12. a) Flaws on first impressions with PETG b) surface imperfections of the PETG material and c) comparison printing on ABS and PETG.

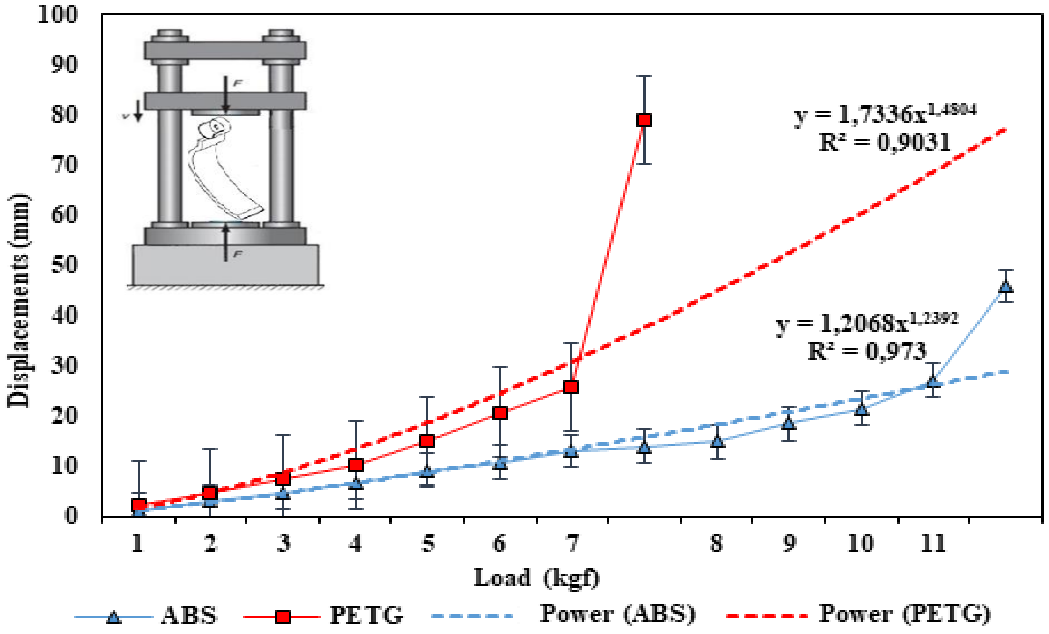


The problem with PETG could be that it would work if you put a printing filter that works with a bushing that lubricates and cleans the filament or printing on another 3D printer, in any case on the printer available at the college the PETG finish (blue filament) compared to ABS (white filament) left something to be desired, as shown in Figure 12c). In the area of contact with the floor, a piece of an air chamber with cyanoacrylate-based adhesive was glued to avoid slipping accidents, as shown in Figure 12 c).

3.3. Tests

An axial compression press to observe the displacement of the part according to the weight, thus obtaining the following result as shown in Figure 13.

Figure 13.Graph showing compression behavior between ABS and PETG.



It is worth mentioning that only the ABS broke after holding 2 minutes and 10 seconds with the weight of 11 kgf out of a total of 5 minutes and 20 seconds. The PETG did not break, but it deformed a lot until it escaped the press and held the weight of 7 kgf for 5 minutes and 55 seconds out of a total of 8minutes and 30 seconds with a speed of 10 mm/min in both. Resulting in parts as shown in Figure 14.

Figure 14.Graph showing compression behavior between ABS and PETG.

As demonstrated, PETG is an elastic material that was able to deform much more without breaking, even with the gaps it did not interfere so much in the final result. Another factor that may have interfered was the choice of filling for each one, because as mentioned in the theoretical foundation, the beehive style is more resistant than the straight one, in addition to the percentage of filling of each one having been set differently, since the PETG with 10% less can be able to flex much more.

It was not possible to simulate CAE in Inventor due to its simulation limitation, so SolidWorks 2018 was used, ABS is already in the catalog, and only PETG had to be added with its respective property, as shown in Table 2.

Table 2. PETG properties.

Property	value	Unity
Elastic module	$2.20x10^9$	N/m^2
Poisson'scoefficient	0.43	Adm

Shear module	$3.19x10^8$	N/m^2
Specificmass	$1.27x10^5$	Kg/m^3
Tensilestrength	$2.6x10^7$	N/m^2
Thermalexpansioncoefficient	273.15	K
Thermalconductivity	0.2	W/m.K
Specificheat	$1.3x10^3$	J/kg.K

After setting the PETG properties, the simulation was performed with a refined mesh with 88888 nodes, where it was possible to compare the displacement after 1 kgf as shown in Figure 15, displacement 5 kgf as shown in Figure 16 and at its maximum, with 7 kgf as shown in Figure 17.

Figure 15.Application of 1 kgf in PETG material with a displacement of a) 2.25 mm in the axial compression press and b) 4.12 mm in Solidworks.

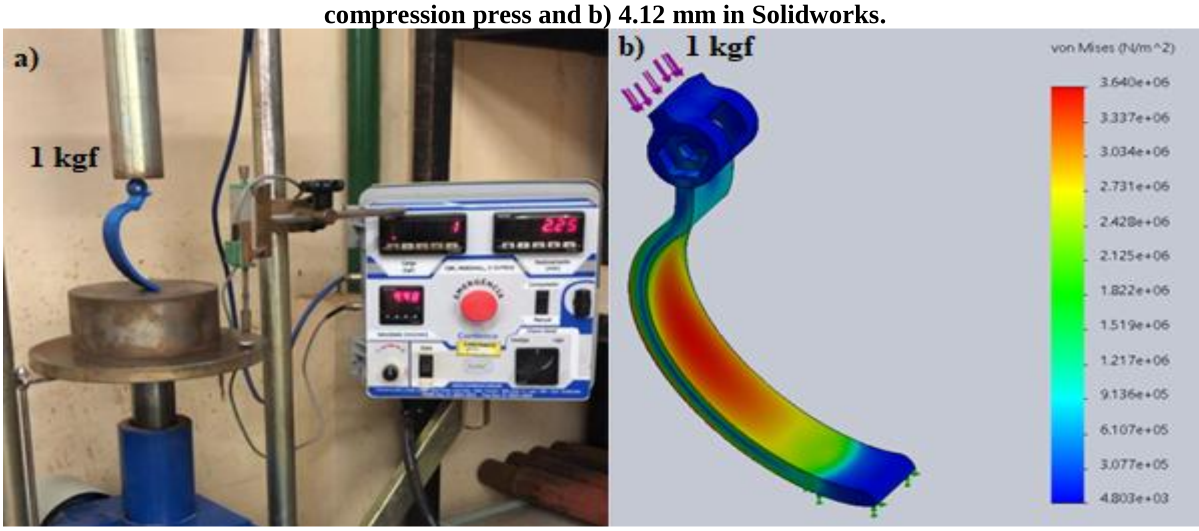


Figure 16.Application of 5 kgf in PETG material with a displacement of a) 15.25 mm in the axial compression press and b) 29.93 mm in Solidworks.

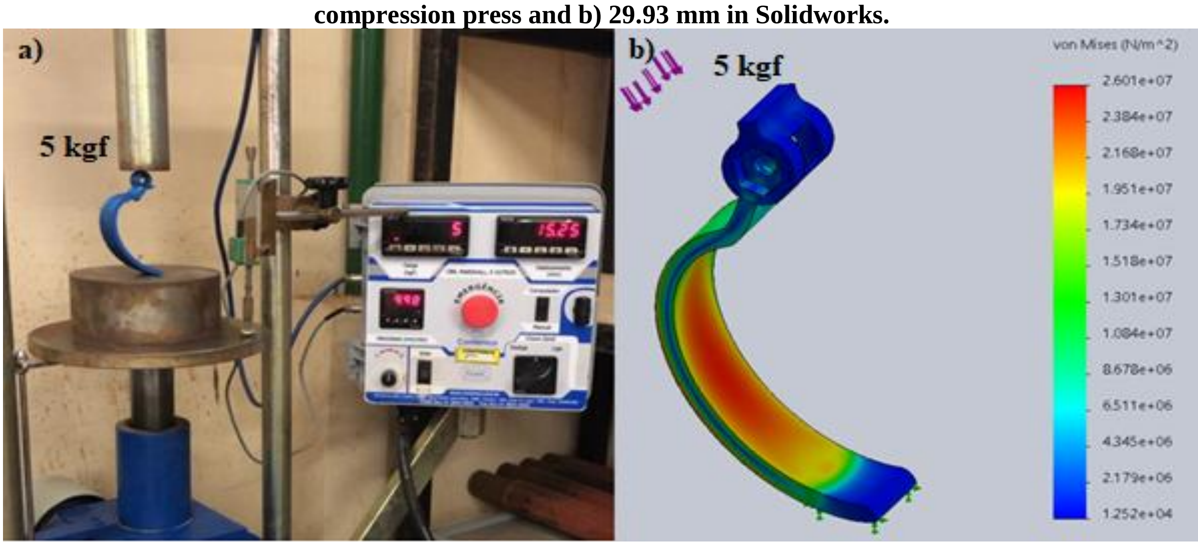
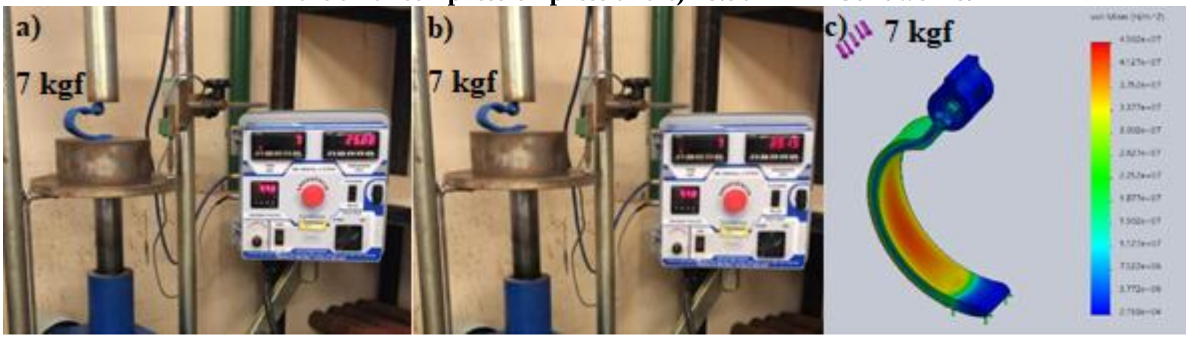


Figure 17.Application of 7 kgf in PETG material with a displacement of a) 25.88 mm, b) 78.87 mm in the axial compression press and c) 48.96 mm in Solidworks.



With ABS, the simulation was also performed with a refined mesh of 88776 nodes, where it was possible to compare the displacement after 1kgf as shown in Figure 18, displacement 5kgf as shown in Figure 19 and at its maximum with 11 kgf as shown in Figure 20.

Figure 18.Application of 1 kgf in ABS material with a displacement of a) 1.28 mm in the axial compression press and b) 4.62 mm in Solidworks.

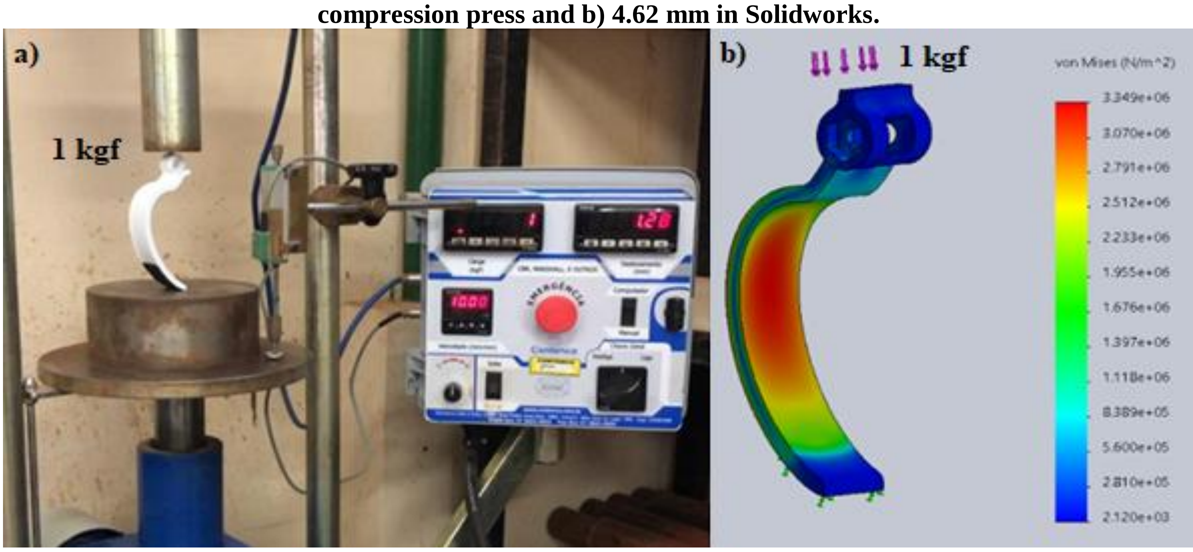


Figure 19.Application of 5 kgf in ABS material with a displacement of a) 9.26 mm in the axial compression press and b) 34.82 mm in Solidworks.

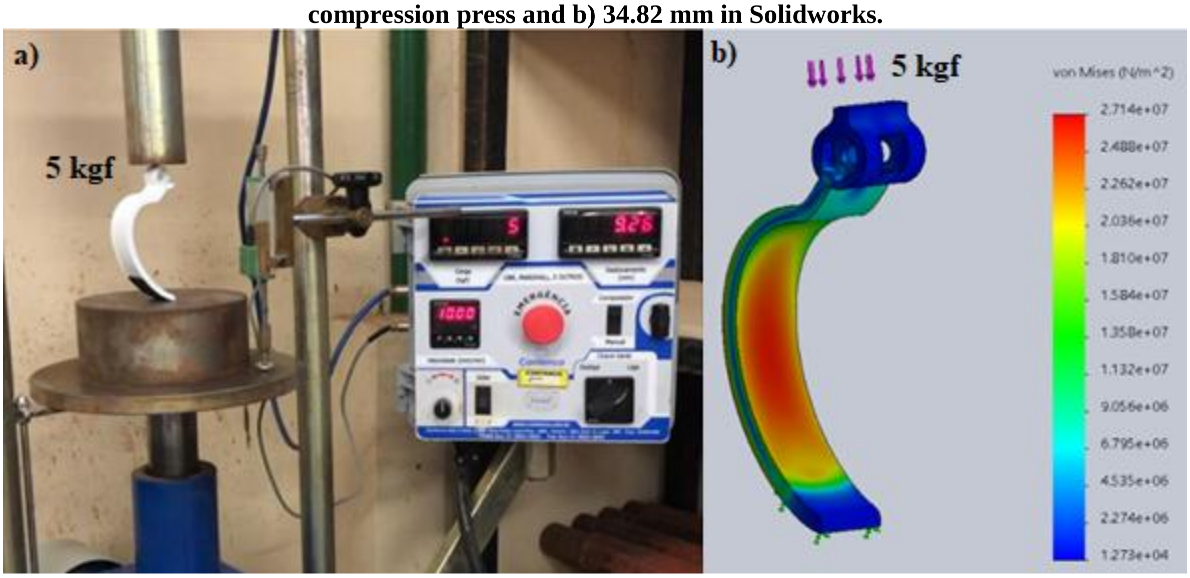
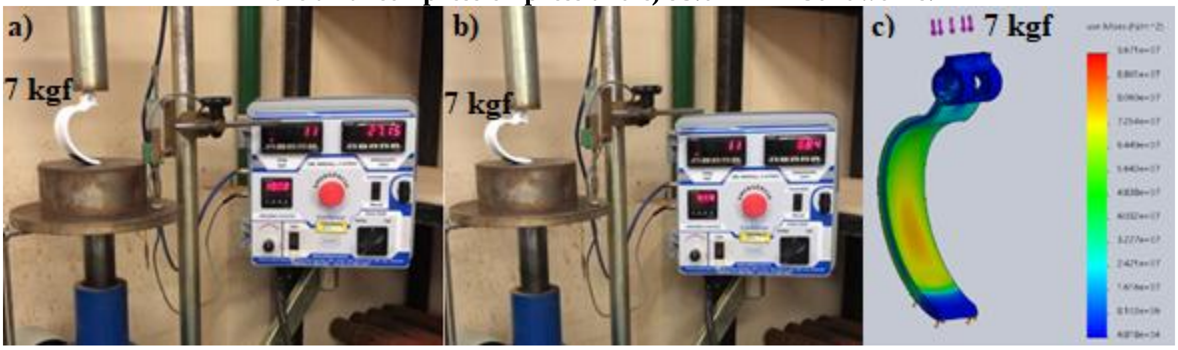


Figure 20.Application of 7 kgf in ABS material with a displacement of a) 27.15 mm, b) 45.7 mm in the axial compression press and c) 93.6 mm in Solidworks.



It is worth remembering that such a difference in the result may be due to SolidWorks considering the part 100% filled with material, which, as seen in Table 2, is not true. Another detail is that in the press after 40mm of displacement it was zeroed, so the final distance is always the sum of the previous displacement with the current one.

Another opinion is about how each one was simulated, as PETG was not able to print the upper part, so only the lower part of both materials was simulated in the press, while in SolidWorks CAE it was not possible to simulate with the entire upper part, because the support where the stump goes is a very complex geometry for SolidWorks, and it is preferable to simulate it in other software such as Ansys, which is more robust.

IV. CONCLUSION

The present work was able to demonstrate the functioning of the prototype, showing that it is possible to return the dog's mobility at a low cost. The angulation is standard for all dogs, except for the German Shepherd, so although the prosthesis takes into account the measurements of a small animal, it is enough to have the measurements, preferably in a CT scan, to customize the prosthesis in a larger size.

Taking into account that a pelvic limb supports 20% of the animal's weight, we concluded that the PETG prosthesis would support a dog up to 35kg and the ABS prosthesis would support up to 55kg. Although dogs of that weight would have a larger prosthesis, which would soon support the weight with a huge margin of safety.

In short, the project managed to demonstrate the initial idea, and should only have some improvements so that it can be commercialized. The veterinarians present during the development of the project were very pleased with the idea and were approved by all, and it may be a project that, in partnership with other areas, can evolve into a pneumatic prosthesis or even a subcutaneous fixation.

Conflict of interest

There is no conflict to disclose.

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