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Low cost support design for correction of hip dysplasia in medium and large dogs

Diseño de soporte de bajo coste para la corrección de la displasia de cadera en perros medianos y grandes

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ABSTRACT

Keywords:
Biomechanics, hip dysplasia, mechanical design, prosthesis for dogs.

Hip dysplasia is a disease that affects medium and large dogs. It is produced by different causes such as genetics, weight and care of the pet. Currently, in Colombia there are not specialized mechanisms that provide comfort to their lives. Therefore, in the present study, a versatile and standard device was designed to help improve the quality of life of these animals, taking as a reference the breed "German Shepherd". The average weight of the previous one is 28 kilograms and of medium-large size between 45 and 70 centimeters. The device was made considering the health and welfare of the animals considering the mobility and safety of their limbs. Likewise, this mechanism adapts to the canine condition, promoting the use and mobility of its hind legs until mobility is completely lost. Its design and manufacturing cost was 100 USD.

RESUMEN

Palabras clave:
Biomecánica, displasia de cadera, diseño mecánico, prótesis para perros.

La displasia de cadera es una enfermedad que afecta a los perros medianos y grandes. Se produce por diferentes causas como la genética, el peso y el cuidado de la mascota. Actualmente, en Colombia no existen mecanismos especializados que brinden comodidad a su vida. Por ello, en el presente estudio se diseñó un dispositivo versátil y estándar que ayude a mejorar la calidad de vida de estos animales, tomando como referencia la raza "Pastor Alemán". El peso medio del anterior es de 28 kilogramos y de tamaño medio-grande entre 45 y 70 centímetros. El dispositivo fue realizado teniendo en cuenta la salud y el bienestar de los animales considerando la movilidad y seguridad de sus extremidades. Asimismo, este mecanismo se adapta a la condición del canino, promoviendo el uso y la movilidad de sus patas traseras hasta la pérdida total de la movilidad. Su diseño y coste de fabricación fue de 100 USD.

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Introduction

Degenerative genetic diseases are a common denominator in dog breeds, among the most prominent we can speak of hip dysplasia. This is a disease that affects the mobility of the animal by causing a separation of the head of the femur with the concavity of the hip (Figure 1). Among the most affected dog breeds according to the British Veterinary Association are the German Shepherd and the Golden Retriever [1]. However, the number of animals affected in Colombia is an unknown quantity, since not all animals receive the care, monitoring and registration by a veterinarian. One of the entities that has performed the due registration of some animals has been the Association Colombian Canine Club that registered an affectation of this disease greater than 10% [2]. This is a considerably high number considering that in Colombia there are no adequate treatments that help reduce its progress, so in most cases the canine completely loses the mobility of its hind limbs and requires a hip replacement to be able to recover. To avoid pain and help improve the quality of life of their pets, the owners use supportive orthotics which are not manufactured in the country, so they are imported with high acquisition costs, compared to this problem the closest solution is an artisanal production that helps to support the weight of the animal, these are made without a proper design process, so they do not ensure the safety of the dog.

Figure 1. German shepherd with hip dysplasia Source: own elaboration

The study of the different correctors of hip dysplasia in the market allowed us to know what was offered by the companies [3], which works as a starting point for the creation of a useful mechanism that innovates and contributes to the reduction of pain caused by the illness. Since all the hip correctors used do not take into account the degree of dislocation presented by the femur, which generates changes in the dog's ability to support itself according to the progress of the disease. Improvement options were analyzed taking into account the physiognomy of animals and of a specific breed, which was the animal shepherd with an average weight of 32 kilograms and a height of 50 cm, the design was mainly conditioned to improve society with an ergonomic support, low cost and adaptable to solve the problem presented in the canine.

Among the alternatives that were presented was chosen to use an open Grashof mechanism with four links supported by a spring, which supports the loads of the body, this system allows the animal to sit and get up with complete comfort, this type of system has been used in other designs and presents good results in its application. On the other hand, a new System is added, which will be explained in greater detail within this article, this consists of a system of adjustable shock absorber of the support force that the dog receives. This fulfills the objective of this work in the creation of an innovative design that allows to solve the uncontrolled progress of hip dysplasia in large breeds of dogs.

Materials and methods

Detailed design

From a work carried out in conjunction with the research group, the effort data will be used to carry out the in-depth design of the entire support, since the previous one only focused on the frame of this and left aside some details such as those described below.

Link Design

Taking into account the forces of this mechanism, we proceed to carry out the dimensioning of the links through the criteria of resistance of materials, evidenced in equations 1 and 2 [4], which seek to relate normal and shear stresses with a factor of safety in such a way that a safe thickness can be obtained that allows to support said loads, according to the material used.

The forces applied for this calculation are considered in table 1.

Table I. Axial Forces in Links

Link	Axial Force [N]
L_AW	-31,183
L_WB	31,183
P	46,374
Q	-94,704
R	11,498
S_CD	-48,264
S_DE	112,804

However, a material must be selected to perform the respective design of the mechanism, so the possibility of using ABS PC was evaluated, which can be a more expensive material than steel, with USD 1.1 per kilogram [5] and $ 0.88 respectively [6]. However, ABS is easier to manipulate in its manufacturing, since it can be done by additive manufacturing, greatly reducing production costs which will be evaluated in the design description.

The tensile strength of ABS PC is 41 MPa [7], which is sufficient to withstand the resulting stresses that are not large enough to use another, more resistant material. On the other hand, low carbon steel with a Sy of 140 MPa [8] is used for the pins, ensuring that there is no shear failure in any pin of the mechanism that can cause serious injury to the canine.

$$\sigma = \frac{Sy}{N} = \frac{F}{b * h} \tag{1}$$

$$\tau = \frac{\sigma}{2} = \frac{4 * V}{\pi * d^2} \tag{2}$$

$Where$:

$\sigma = Normal\ load\ effort$

$N = Safety\ factor$

$d = Pin\ diameter$

$V = Shear$

$h = Link\ thickness$

$b = Link\ width$

However, the elements subjected to axial compression loads were also analyzed by buckling (equations 3 and 4 [9]), in order to obtain a thickness of piece that really ensures the stability of the animal, without presenting any possible risk to a fracture or deflection. The modulus of elasticity of ABS PC is 2.1 GPa [10].

$$Fcr = \frac{\pi^2 * E * I_{min}}{L^2} \qquad (3)$$

$$Imin = \frac{1}{12} * h * b^3 \qquad (4)$$

$Where$:

$E = Modulus\ of\ elasticity$

$I = Moment\ of\ inertia$

$L = Length$

According to the results obtained, the thickness that each link must have is selected to support all loads.

Design damping system

From the solution obtained for Grashof, we seek to innovate and apply the results in an adjustable splint that allows the support force to be adjusted in the canine according to the disease progression. Therefore, the design of a damping system that meets the requirements set forth in section 2.1 is carried out.

When wanting to have a variable force system, the most effective is the use of a spring, which graduates its original state according to the compression to which it is found, for this purpose it is possible to use different mechanisms that fulfill that purpose (Figure 5) [11]. From this, the nut-screw mechanism was chosen, taking into account that the transmission of the rotation can be carried out at 90 degrees with respect to the drive shaft. This is due to the fact that if the rotation is carried out on the same axis of movement, an unstable base would have to be connected to a rotating element with a fixed one. In the same way, the movement of the nut would have to be carried out by means of another tool since it had no space to do it only with the hands, while the use of a transmission at ninety degrees allows the application of different accessories that avoid this situation.

For this 90 degree transmission, that is, perpendicular axes, the literature recommends bevel gears because we do not have enough space for an endless crown transmission.

		Stairs		Screw Nut		Pin	
Adjustable	5	2	10	4	20	3	15
Easily to use	4	2	8	2	8	2	8
Easy assembly	3	4	12	3	9	2	6
Comfortable	3	4	12	3	9	2	6
			42		46		35

Figure 5. QFD spring adjustment mechanism.

Source: self made

In this way, the following elements were chosen for the damping system: spring, bevel gears, bearings, screw-nut, drive shaft and frame. Its operation is given thanks to a force exerted by the human that becomes torque and is transmitted through bevel gears that connect the axes perpendicularly, with this it is possible to transmit the rotation in the axis of the screw, responsible for performing a relative displacement with respect to the nut that compresses or releases the spring and with it the force of help to the canine can be adjusted.

However, this configuration prevents the regression of the movement, this is a consequence of the screw nut arrangement, since the nut does not transmit rotational movement to the screw due to the small angle of transmission between these elements. The amount of torque that must be applied in order to adjust the spring is defined by equation 5 [9].

$$T = \frac{fD_m}{2} * \frac{l + \pi f D_m}{\pi D_m - fl} \qquad (5)$$

$Where$:

$f = Strength$

$Dm = Average\ screw\ diameter$

$l = screw\ length$

When applying the rotation by hand, some gears are moved and they drive a screw that compresses or decompresses a spring, changing the compression force that it performs on the body of the shock absorber. The spring is calculated according to the maximum compression value, that is, by the value thrown by the static on the segment D. The gear ratio was chosen according to the amount of force and speed that the user could apply. Its design was carried out according to the load it had to bear.

Structural analysis using FEA

Once the defined model with the real values was obtained, a test was performed with the results obtained in a structural analysis (finite elements) in SolidWorks. Since, with this it is possible to verify the behavior of the link in front of the loads submitted and to know the concentration points of stresses where failures can occur, so that in the case that it does not resist making the respective change of the dimensions or the material.

Results and Discussion

Description of the design

However, the results obtained when applying the design methodology are presented. However, the analyzes were carried out with the restrictions on the lengths and angles of the Grashof, as these are related to the forces used for the sizing of the links. Below are the necessary lengths to meet the design conditions [4].

Table II. Lengths of the elements

Elements	Lenghts [mm]
L	250
S	80
P	160
Q	180

Table 3 describes the angles that form between each of them with the idea of showing a static scheme in the active position of the canine.

Table III. Angles found through kinematic analysis

Elements	Ángles [°]
LQ	65,000
QS	39,746
SP	33,976
PL	47,745

It should be noted that the axial loads in Table 1 have a division of loads in the elements L and S, since they are divided by a shear force that distributes the axial loads according to the direction being analyzed, this is how it occurs the element L_AW consisting of the axial force in L from node A to the load W.

Starting from the static solution of the mechanism, its movement was analyzed from its initial position to its final position. For which, element Q, which directs the movement due to the displacement of the dog's hip, moves from 65 ° to 35 °, where the mechanism is in its folded position.

According to this force distribution, the force to which the spring S is subjected in the range of motion varies between 11,498 [N] and 16,125 [N] [4], for the active and folded position respectively. Therefore, the actuator spring is selected to support compression of this element and contribute to the return of the mechanism to its initial position when the dog is reinstated.

It should be noted that, during this range of motion, reactions R1 and R3 from the dog's limbs bear the greatest load, and this occurs for very short intervals of time [4]. Therefore, the dimensions of the elements are designed to withstand the loads when the dog is standing.

However, all measures of link widths are chosen taking into account the buckling criteria, since this method is the most critical. The widths of each of the links are those referred to in table 4 with a thickness of 10 mm for all.

Table IV. Link widths

Links	Resistance width [mm]	Buckling Width [mm]
L	0,608	8,978
S	0,904	6,668
P	1,848	7,212
Q	0,941	4,200
R	0,224	11,24

Source: self made.

This value is of the utmost importance, since buckling is one of the failures that tends to occur when having axial loads in the links. Note that the width values are governed by this parameter by giving much greater resistance failure, this is logical because the thickness measurement is small compared to the large length of the elements.

Table V. Results diameters nodes

Nodes	Nodes diameters [mm]
A	1,837
B	2,625
C	1,837
D	2,625

Source: self made.

Table 5 shows the pin diameters. Which are normalized to the measure of 3,175 [mm] equivalent to 1/8 of an inch and with that the safety factor that was 2 is increased according to the normalized value of the diameter, which is better for the quality of the mechanism, since it ensures a Less risk in its operation.

It should be noted that, having two different materials in contact, pin and links, it is required to use bearings, to avoid deformation of the ABS due to the difference in hardness between them.

Within the shock absorber, the screw, nut, spring and gear parameters are selected according to the torque to which the screw is subjected, since it is necessary that the system manages to compress the spring or decompress it according to the disease progression. Therefore, they were selected as found in the different catalogs [12], in such a way that they achieved the mentioned objective. Which is reflected in table 6, 7 and 8.

Table VI. Adjustment elements parameters

Elements	Lenghts [mm]	# of entry	External diameter [mm]	Thickness [mm]
Screw	250	1	10	-
Nut	19,05	1	10	-
Spring	30,2	-	15	2,2

Source: self made.

Table VII. Transmission elements parameters

Elements	Thickness [mm]	Internal diameter [mm]	External diameter [mm]
Tapered bearing	11	15	42
Balls bearing	7	8	22

Source: self made.

Tabla VIII. Parameters transmission elements

Elements	# of teeth	Preassure angle	Module [mm]
Gears	14	20	2,5

Source: self made.

The bevel gear system was designed with a 1: 1 ratio to avoid increasing the size of the mechanism. The torque found in the screw was 116 N-mm to compress the spring by means of the vertical movement of the nut, described in equation 5.

Having all the parts defined, a damping mechanism is obtained as illustrated in Figure 6, in which the operation of the bevel gears to transmit the movement to the screw axis can be appreciated.
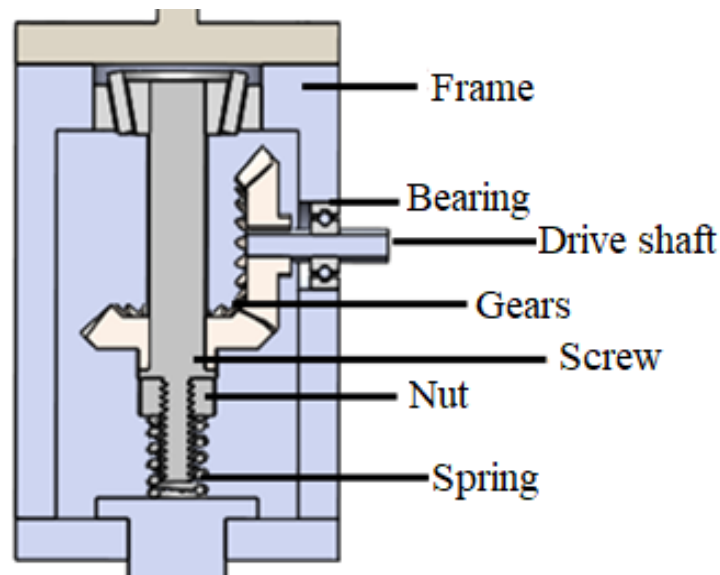

Figure 6. Shock absorber. Source: self made.

Having all the mechanism defined, the design verification is carried out by means of the FEA analysis where it is possible to see the behavior of the mechanism against the different efforts that occur in the element, so that the stresses can be located and readjusted.

However, Figure 7 shows us that the values do not exceed the yield strength of the material, validating that the mechanism works correctly when tested in an animal.
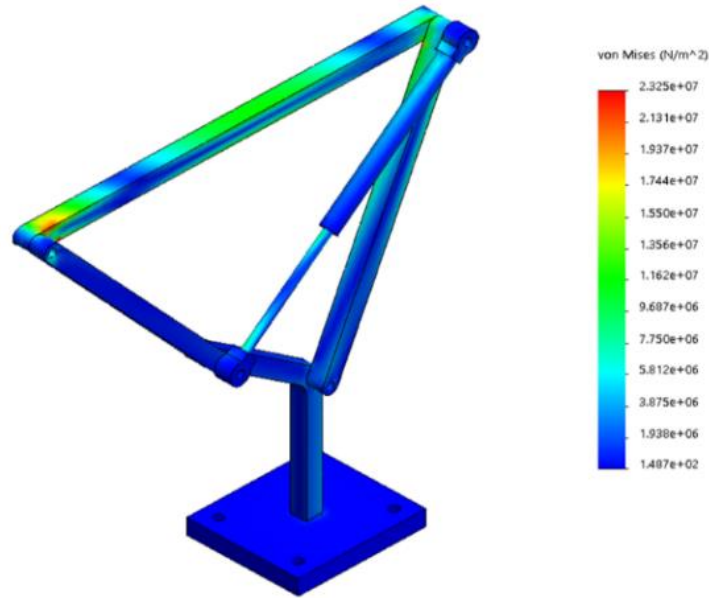
Figure 7. Finite element analysis.

Source: self made

It is important to note that the buckling does not occur to a large extent because its deformation does not exceed 2 millimeters. Likewise, it is evident that link L is the element that suffers the most effort because the weight falls mainly on it. In this way it can be said that, in a real construction, the frame would be expected to support the different loads contemplated.

Having all the variables defined and verified, these are adjusted to a support that comforts the animal (Figure 8).
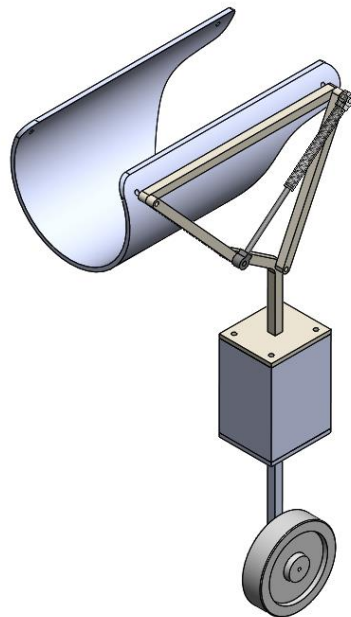

Figure 8. Final CAD design support. Source: self made.

In this way, figure 9 allows the reader of this article to give an idea of how the design is implemented in a canine, since its construction is not contemplated within the scope of this project.

Figure 9. Final design of the support in the animal. Source: self made

Economic study

Based on the results obtained in both materials and measures, an estimate of the total production cost of the product is carried out, taking into account the value per minute of the manufacturing process together with the process core is USD 0.03, together with the necessary items per catalog [12] which total a total of USD 75.7, distributed in the items shown in table 9.

Tabla IX. Cost of items according to catalog

Elements	Cost [USD]
Tapered bearing	24,2
Gears	45
Spring	6,5

Source: self made.

It should be noted that the screw and nut will be made by additive manufacturing, so it is considered in the previous value. Thus, as the approximate total value has a value of 105.7 USD

Conclusions

The design was made taking into account a theoretical and contextual framework in which a support was made for medium and large-sized dogs with hip dysplasia, so that more people had access to the solution to help the animal, as well as providing veterinarians with a new, more effective and economical medical alternative.

Bringing the design to the construction and its proper use correctly will have benefits for both humans and animals, since the former can help your pet and interact with it, because it will already have a support for your hip improving your health and comfort.

The alternative of using Grashof together with the damping system proves to be a viable option for the correction of dysplasia, which could lead to further research for its use in related diseases such as LTV (Lumbosacral Transitional Vertebrae).

When manufacturing the framework by additive manufacturing, production costs are greatly reduced, so that the manufacture of the entire corrector manages to be less than $ 110, this is of vital importance, since the reduction in price with respect to commercial correctors it is 56%, (market price of 250 USD) [13]

facilitating its acquisition.

The total weight of the corrector is approximately 2 Kg, this estimated by the computer tool in which the CAD was designed, so that a design with a relatively low weight was achieved, which facilitates the setting and transport of the mechanism.

It was possible to design an instrument that complied with the medical, financial and innovative requirements, referred to in section 2.1. Giving in response a system with the ability to adapt according to the severity of the disease and the position in which the animal is.

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