Degree in Veterinary Medicine

Final degree project

POSTURAL AND GAIT ALTERATIONS IN BULLDOGS WITH FORELIMB AMPUTATION

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ABSTRACT

The present project corresponds to the study carried out on animals of the French bulldog canine species, which underwent amputation of a forelimb, and animals of the same species and breed with the presence of all four limbs.

The objective is to obtain the results of the biomechanical adaptations generated in an animal whose gait is tripedal compared to an animal whose gait is performed on all four limbs. This is of great interest since a high compensatory effort is generated as it is forelimb, so it is important to know the changes in the redistribution of the animal´s weight both in static and dynamic.

Throughout the report, a theoretical framework is presented, where a series of concepts are presented prior to the reading of the study itself in order to facilitate its comprehension, taking into account basic terms of kinetic analysis as well as the description of the tools used.

The proyect was performed on 5 amputee dogs and 5 sound animals. For this purpose, various parameters were measured both statically and dynamically by simultaneous use of force and pressure platforms. The results were compared statistically with the help of Student´s t test. It was observed the parameters derived force and propulsive force, as well as their respective impulses, were significantly higher in the contralateral limb of the limbless group of animals. In addition, an increase in peak pressure, mean pressure and paw area was observed in these animals.

On the other hand, postural examination showed that amputee dogs achieved the same stability as sound dogs, implying an increase in strength in the contralateral limb that could lead to a potential increase in the early onset of injuries in various musculoskeletal units due to overuse.

Keywords: vertical force; pressure; amputation; equilibrium.

RESUMEN

El presente trabajo corresponde al estudio realizado sobre animales de la especie canina de raza Bulldog francés que fueron sometidos a la amputación de un miembro torácico, y sobre animales de la misma especie y raza con la presencia de las cuatro extremidades.

El objetivo es obtener los resultados de las adaptaciones biomecánicas generadas en un animal cuya marcha es tripedal en comparación con un animal cuyo paso se realiza sobre las cuatro extremidades. Esto es de gran interés ya que se genera un esfuerzo compensatorio elevado al tratarse de un miembro anterior, por lo que es importante conocer los cambios de redistribución del peso del animal tanto en estático como en dinámico.

A lo largo de la memoria se expone un marco teórico, donde se presentan una serie de conceptos previos a la lectura del propio estudio con el fin de facilitar la compresión del mismo, teniendo en cuenta términos básicos de análisis cinético así como la descripción de las herramientas utilizadas.

El estudio se realizó en 5 perros amputados y 5 animales sanos. Para ello, se midieron diversos parámetros, tanto en estático como en dinámico, mediante el uso simultáneo de plataformas de fuerza y presión. Los resultados se compararon estadísticamente con la ayuda de la prueba t de Student. Se observó que los parámetros derivados de las fuerzas de reacción del suelo tales como fuerza vertical, fuerza de frenado y fuerza de propulsión, así como sus respectivos impulsos, fueron significativamente superiores en la extremidad contralateral del grupo de animales con ausencia de un miembro. Además, se observó un aumento de la presión pico, presión media y área de la pata de dichos animales.

Por otro lado, el examen postural mostró que los perros amputados alcanzaban la misma estabilidad que los sanos, implicando un aumento de la fuerza en la extremidad contralateral que podría conducir al aumento potencial de la aparición temprana de lesiones en distintas unidades musculoesqueléticas debido al sobreuso de las mismas.

Palabras clave: fuerza vertical; presión; amputación; equilibrio.

DEDICATION

First of all, to my parents, for being the basis of everything and for the great support they have always given me. Without them, none if this would have been possible.

To my grandparents, for the love they gave me and the strength they give me. A part of them is in every achievement I make in my life.

To the friends this degree has given me, for the power and trust we have always given each other.

And last but not least, to me. For perseverance, resilience and for having achieved what I set out to do one day.

Thanks to all of you

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1. INTRODUCTION

Musculoskeletal injuries and diseases are of great importance in the veterinary field. Even more so is their resolution, as it involves an extensive research process as well as the active participation of both the veterinary clinician and the owner of the animal. To contribute to this, there are continuous and innovative advances and research in fields such as anatomy and biomechanics, the latter being somewhat neglected throughout university studies.

Biomechanics is a science that attempts to understand the movement and behaviour of the body by applying classical mechanics to biological and physiological systems. It uses physics and engineering concepts that describe the movement experienced by the various segments of the body during daily activities, which leads us to understand the importance of the interrelationship of force and movement in musculoskeletal disorders.

It is necessary to include aspects such as the principles of statics, for the analysis of the magnitudes and nature of the forces involved in joints and muscles, principles of dynamics, for the description of segmental movement, the mechanics of solids, offering utilities to evaluate the functional behaviour under different loading conditions of bones, and bases of fluid mechanics, thus understanding the blood flow in the circulatory system, air in the lungs and the lubrication of joints.

The focal point of biomechanics is the recruitment by the organism of sensory information from the physical environment and the orientation of the body and joints, with which the central nervous system will plan a strategy to execute an action. Once a strategy has been adopted, muscles are recruited to provide forces and moments required for movement and balance of the system, whereby forces will be modified and soft tissues will experience different loading conditions.

The importance of this science lies in the study of the different simple and complex movements of animals using mechanical methods to solve problems caused by various conditions. Research related to this field has focused on the analysis of the different dynamic and static parameters of the patient in order to design orthopaedic devices that facilitate the daily movement of the animal and improve its quality of life (Rodríguez, 2022).

In both human and veterinary medicine, biomechanical studies are used in the field of sports in order to gain insight into the mechanisms that cause movements and how, through their study, better performance and fewer injuries can be achieved. In the veterinary field, examinations mostly involve characterising and establishing kinematic standards in dogs and racehorses.

On the other hand, the role of this science has been studied in degenerative diseases of the locomotor system with the evaluation of the efficacy of platelet-rich plasma (López, 2019) or the assessment of surgical recovery. Another aspect to highlight is cranial cruciate ligament rupture, which is relevant as it has a high prevalence and is also being focused on in biomechanical studies.

Also, and more related to the topic at hand, there are articles that show the analysis of gait in sound (Mclaughlin, 2001) and elderly dogs (Lorke *et al*., 2017) as well as in dogs with pathologies such as hip dysplasia (Bennett *et al*., 1996), osteoarthritis (Beraud *et al*., 2010), neurological diseases or dogs with dystrophin deficiency (Barthélémy *et al*., 2009). In contrast, there have been no articles to date that have focused on dogs with limb amputation.

Amputation of limbs in the canine species is often the only treatment option for pathological conditions such as severe trauma affecting the nervous system, congenital disorders or highly malignant neoplasms. In these cases, the contralateral limb will have to fulfil support and balance functions so that the animal can remain stationary as well as redistributing the weight of the body on the remaining limbs and compensating the loads. Therefore, this situation generates an increase in the force used by the contralateral limb, producing a greater predisposition to the early appearance of injuries due to musculoskeletal overload.

In this project, a biomechanical study is carried out, by means of dynamic (gait) and static (posture) analyses, of animals with amputation of a forelimb and it is compared with others whose limbs are complete. For this purpose, different parameters are obtained through the simultaneous use of force and pressure platforms. The aim is to observe how the body itself compensates mechanically for the loss of a limb in order to best adapt to walking. In addition, it provides an objective analysis of the functional state of the limbs after surgical treatment.

2. BACKGROUND CONCEPTS AND TOOLS

2.1. Background concepts

Biomechanical gait analysis includes the measurement of different parameters that help us to facilitate the study of this science. For this reason, some of them are defined and simplified in this section in order to improve the understanding of later explanations. The concepts are related to the kinetic and kinematic analysis of animal gaits.

2.1.1 Ground Reaction Forces (GRF)

These types of forces are included in kinetics, which is responsible for analysing movement and, more specifically, the forces that produce it. The ground reaction forces are the most important and are those generated by the ground on a body that is in contact with it, such as the lateral force, medial force, propulsive force, braking force and vertical reaction force (Fig1). These are used with the aim of estimating the movements of joints and muscles as well as their possible alterations in the musculoskeletal system by means of the force platform, demonstrating that, depending on the pathology, some of them may be altered.

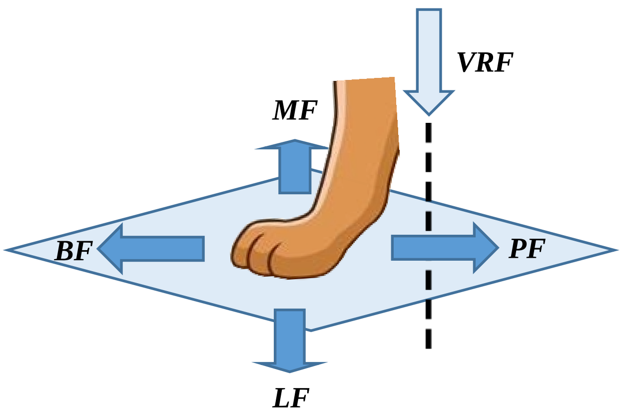

***Figure 1**. Representation of the forces exerted during an animal's footfall: Lateral force (**LF**), Medial force (**MF**), Braking force (**BF**), Propulsive force (**PF**) and Vertical reaction force (**VRF**)*

GRF can be measured both at walk and trot and the values will be modified by the speed of the animal. In addition, a value that will determine this type of forces is the body weight of the individual, so the results of the analysis shall be expressed as a percentage.

2.1.2 Vertical force peaks (PVFs) and vertical impulse (VIs)

The vertical peak force is the most analysed and used parameter of the GRF in kinetic analysis. It is the highest value of force exerted against the ground when the limb is supported during gait because it is vertical and includes the animal's body weight.

On the other hand, the vertical impulse is the product of the force times the time the limb is supported and is represented graphically as the area under the curve. This parameter takes into account not only the magnitude of the force, but also the duration of its application (Placzek *et al*., 2023).

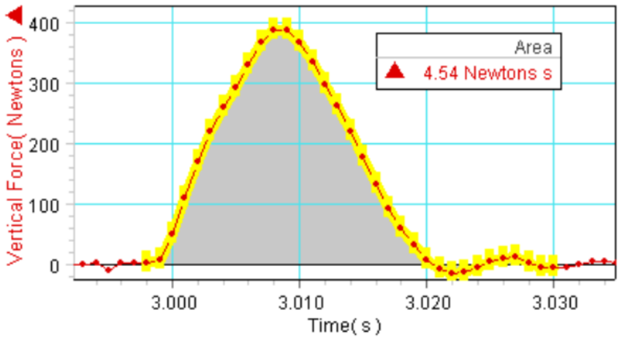

***Fig 2**. Graphical representation of the vertical impulse (Area under the curve) (Pasco scientific)*

2.1.3. Centre of masses (COM) or centre of gravity (CG)

The centre of mass is the sum of the trajectory of all body segments in the cranio-caudal and latero-medial planes, that is to say, is the point at which the total force of gravity acts. In order to calculate this parameter, the sum of the position vectors that are directed to the centre of mass of the objects in a system is calculated. The result will vary depending on the individual and its location will vary during the movement.

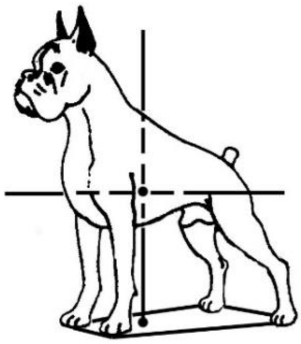

***Fig 3**. Graphical representation of the static location of the centre of mass (TowerBoxer)*

2.1.4. Centre of pressure (COP)

The centre of pressure is the sum of all the pressures exerted by an object that are transmitted from the support base of the system in question. In this case, it refers to the average of the various pressures exerted by the animal on the ground. This parameter represents the vertical projection of the centre of mass; although they are independent measurements.

The study of balance is included in stabilometry, which allows the analysis of postural control and its relation to stability. This makes it possible to measure this parameter quantitatively, taking into account the centre of gravity, which in turn is determined by the distribution of the different pressures. The results are represented graphically by means of statokinesiograms and stabilograms, whose comparative measurements between sound dogs and dogs with musculoskeletal pathologies have revealed the body variations that are generated when an animal has undergone treatment or is subject to an ailment.

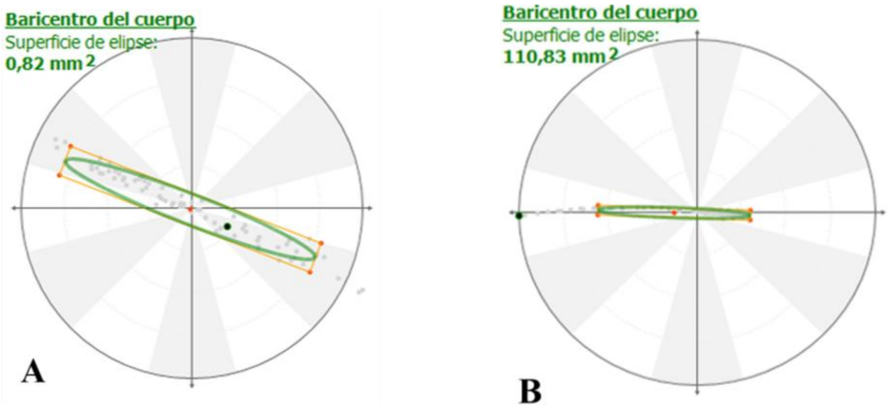

Fig 4. *Graphical representation of a statokinesiogram in a sound (A) and lame (B) dogs (Manera et al., 2017)*

2.2. Tools

Biomechanical gait studies use various parameters and software that contribute significantly to the research. In addition, the use of technological devices for the measurement of different force and pressure parameters should be highlighted. These correspond to force and pressure platforms, respectively.

2.2.1 Pressure platform

The pressure platform, in gait analysis, is able to measure and provide data related to pressure distribution within the limb as well as podobarographic and postural parameters. Some studies have used it for the purpose of measuring force distribution in the pads during stance phase in sound dogs (Marghitu *et al*., 2003) or with pathologies such as cranial cruciate ligament rupture (Souza *et al*., 2014) or hip fractures (Vassalo *et al*., 2015). Recently, a study has been published on animals with the presence of lameness using this platform (López *et al*., 2019), which leads us to verify the functionality of this technology in the evaluation of stability in patients with this type of ailment, which in turn would lead to an improvement in the therapeutic protocol.

On the other hand, this type of platform is not capable of measuring mediolateral and cranio-caudal forces during locomotion, which the force platform is capable of. Anyway, they are suitable for the measurement of parameters at different foot strikes on each limb during a single pass, on the speed of each limb as well as the static weight distribution on each limb. In addition, it is able to perform evaluations on animals of different sizes and measurements of individual foot strikes with several feet on the surface at the same time.

Fig 5. *Examples of pressure platforms used in kinetic analysis*

2.2.2 Force platform

The first studies accompanied by the force platform originated in the human species in the 20th century (Elftman, 1938) and worked mechanically with springs and levers.

In veterinary medicine, it was not until the late 1970s that they began to be used to measure ground reaction forces (GRF) in the canine species during walking, trotting and jumping. Notably, among other things, their use has been successful in evaluating the efficacy of analgesics in the treatment of preoperative limb pain (Soutas-Little, Am J, 1988) and in alleviating chronic pain associated with osteoarthritis (Hoelzler *et al*., 2004). However, it has some disadvantages compared to the pressure platform, such as not being able to measure successive events during locomotion or related to stride length, as it makes data collection difficult for small dogs.

The force platform has its emphasis on the assessment of vertical peak forces (PVF) and vertical impulses (VI), as it measures the vertical forces that are generated during the time interval in which the animal keeps the limb in contact with the ground. In addition, it provides information on ground reaction force that can be used to study limbs with normal or abnormal function. When combined, the interrelated variables of ground reaction forces give a more complete description of gait than when used individually (Martín, 2019). This type of platform provides objective measurements to be able to detect different degrees of lameness as well as gait disturbances that may be caused by other pathologies that we cannot observe with the naked eye.

One of the advantages of this type of instrument is that, due to its design, it is possible to obtain data from several consecutive footprints. Therefore, it is possible to study the characteristics of the centre of pressures (COP) and its modifications when an animal presents a pathology that alters its balance.

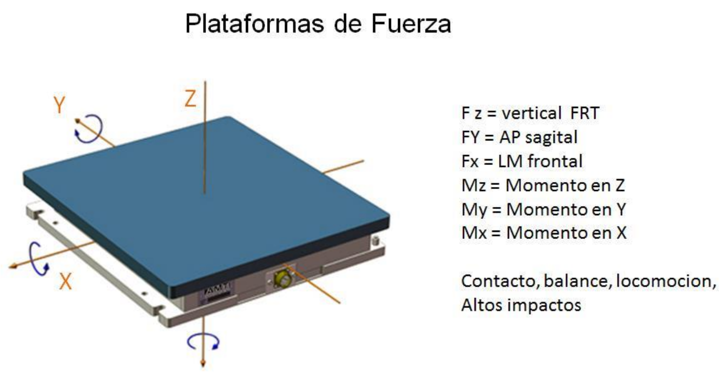

Fig 6. *Force platform and its respective measurements*

The force platforms consist of 4 sensors located at the corners of the platform. During the stance phase, the force exerted is recorded by the sensors and transmitted directly to the computer or electronic device used to display the data.

2.2.3 Software

Once the information has been collected through the various platforms, it is transmitted directly to the electronic device being used. The accompanying software is capable of measuring and recording the forces acting between the foot and the ground in real time as well as their directions, friction forces, centre of pressure, torques, performance and energy used.

This type of instrument has its justification in Newton's third law, which indicates that the value of the external force on a surface can be obtained by establishing the original degree of force but in the opposite direction, that is to say, the force on the platform will generate an electrical signal proportional to the force that has been applied and will be projected on the three axes of space (X, Y, Z).

The vertical component (X) is presented in relation to the weight of the animal's body exerted on the animal's foot and the cranio-caudal (Y) and mid-lateral (Z) correspond to the frictional forces between the foot and the ground. In addition, the anteroposterior component, related to the deceleration or braking of the heel strike, the mid-lateral component, which indicates the lateral deviations of the foot, and the torsional forces, which show the internal and external rotational movements of the limbs during gait, are presented. Represented on a graph, the three components would be projected as follows:

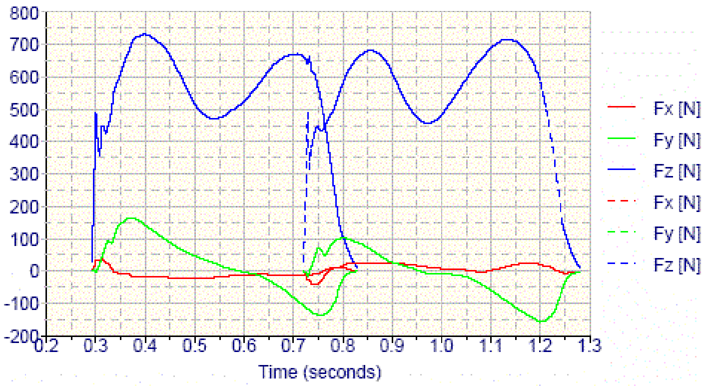

Fig 7. *Representation of the three types of force analysed during gait. Vertical forces are shown in blue, cranio-caudal forces in green and mediolateral forces in red (Campana and Aranda, 2007)*

3. GAIT ANALYSIS

The analysis of gait in a quadrupedal animal encompasses the study of its locomotion. Specifically, it focuses on aspects such as synchronisation, harmony and balance of the locomotor apparatus and nervous system.

3.1. Zoometry

In order to understand how the gait of a four-legged animal is formed, it is necessary to take into account aspects such as its morphology and normal anatomy. Zoometry is the science that studies the morphology of animals by means of specific body measurements such as height measurements, which determine the height of the animal in the higher regions, length measurements, which try to measure the distance between body points in the longitudinal direction, width measurements, which determine the distance between body points in the transverse direction of the longitudinal axis of the body, and girth, which determines the contour of certain body regions.

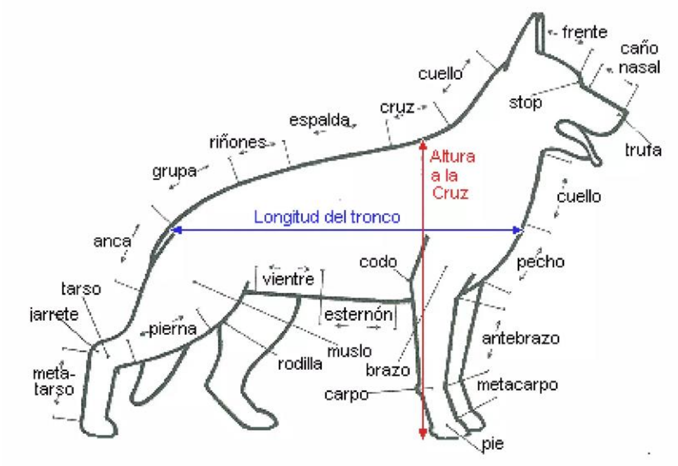

Fig 8. *Anatomic division of the dog. Canine zoometry (Augusto, 2021)*

3.2. Body weight distribution

Quadruped animals usually distribute their body weight asymmetrically, with 60% of it is in the front part of the animal and the remaining 40% in the rear part (Sabater, 2019).

With this in mind, changes in forces following limb amputation can be more easily identified, for example reaction forces, which tend to increase following the loss of a forelimb compared to the loss of a hind limb. Also, ground contact time tends to be longer for the remaining limbs as balance will be required in the absence of one of them.

However, this redistribution of loads is irregular, as is the movement of the animal itself, which can lead to a reduction in the quality of life and a shortening of life expectancy over time.

3.3. Zookinesis examination

This type of study is based on the observation and evaluation of the anatomical and functional elements of the locomotor apparatus. For this purpose, neuromuscular and skeletal components are taken into account, evaluated both statically and dynamically.

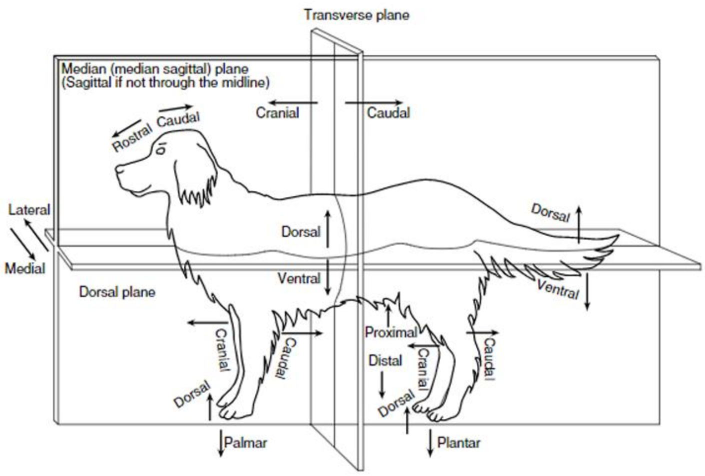

Fig 9. Orientation and planes of movement and directional terms for the dog (Riegger-Krugh et al., 2004)

3.3.1 Static assessment

In addition to the dynamic study of an animal, it is highly relevant to take into account the possible static alterations of the animal. For this purpose, aspects such as posture, attitude to the environment, muscular development and atrophies and joint angles are observed.

The ideal angulation of the scapula is around 30º; if it is greater, there are no significant disadvantages, as the stride would be longer and would lead to an increase in muscle development. In any case, there would be less shoulder contusion when jumping due to the increase in flexion and impact absorption. In the event that this angulation is less, the shoulder would be predisposed to the appearance of wear and tear pathologies due to greater suffering. On the other hand, the length of the shoulder is taken into account, as it must coincide with the scapula and the radius and ulna must be below the body.

As for the hind limbs and, taking the image (Fig 10) as a reference, the longer the distance between both lines perpendicular to the ground, the greater the angulation. This would cause an increase in stride with a consequent decrease in energy expenditure, while, anyway, it would generate greater instability, which would require greater muscular strength and coordination.

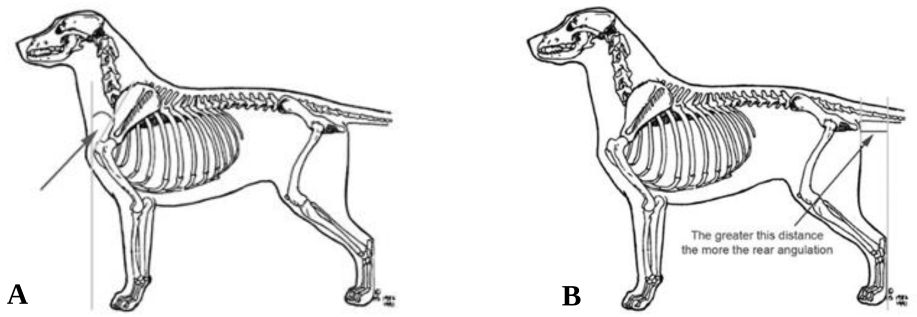

***Fig 10**. Forelimb (A) and hind limb (B) angulation lines (Lascelles, 2006)*

In order to visualise the static and dynamic analysis subjectively, the Dempster Diagram is used. This diagram divides the animal's body into functional anatomical units and then evaluates the maximum flexion and extension angle of each joint with the aid of a goniometer.

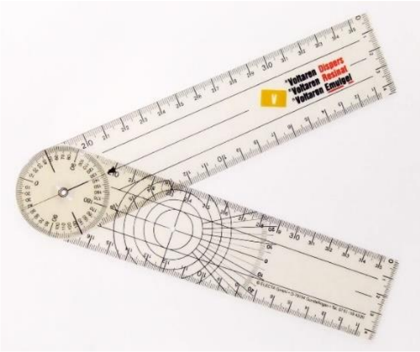

***Fig 11**. Goniometer (Zapata, 2019)*

The main function of this analysis is the measurement of angles, essentially those formed by the intersection of the longitudinal axes of the bones at the joint level. This is useful in the veterinary field as it provides information on the functionality of the joints in addition to the evaluation of the efficacy of surgical, pharmacological and physiotherapeutic treatments (Catelotti, 2020).

Goniometry is intended to assess joint mobility limitations, the existence of loss of flexion and extension and the presence of pain during the assessment. In addition, the functional value does not always correlate with the complementary radiological findings, so the functional examination is essential to know the state of the osteoarticular system and its evolution.

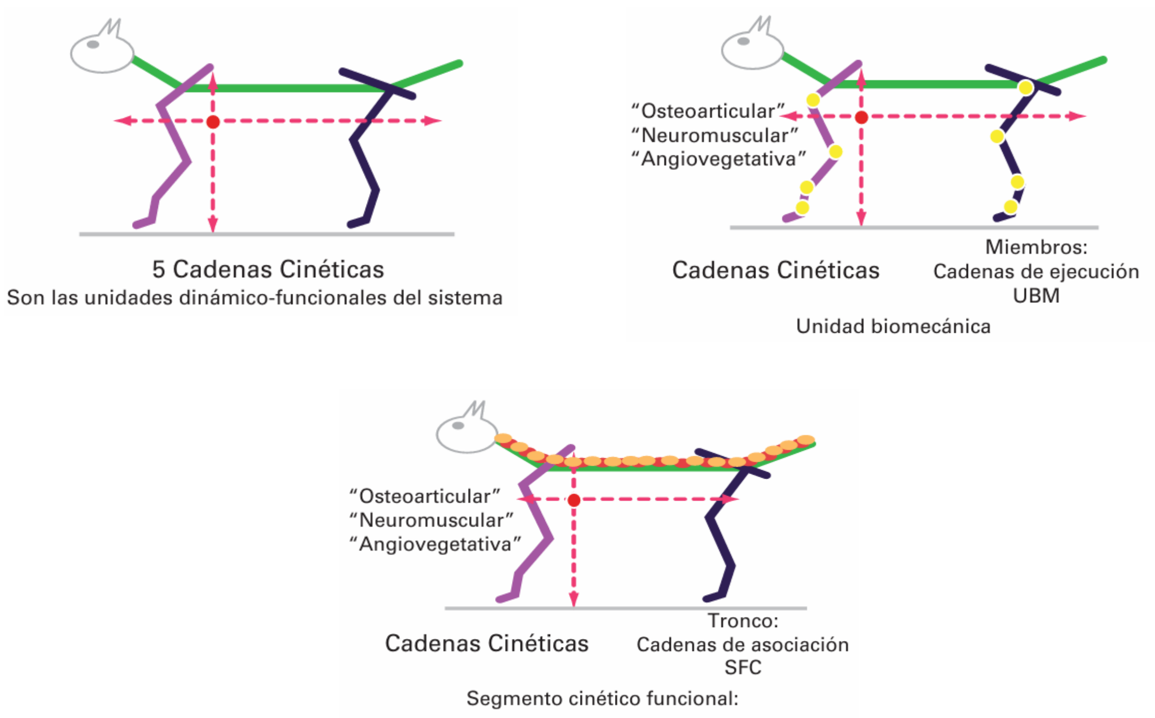

***Fig 12**. Included in the Dempster Diagram are the Kinematic Chains, which comprise the four limbs and the spine. These, in turn, are made up of successive Bone Chains linked together by Biomechanical Units, corresponding to the joints. Likewise, the vertebrae of the spine are united by Functional Kinetic Segments, corresponding to the invertebral joints (Sterin, 2008)*

Finally, it should be noted that limb angulations may vary throughout the animal's life due to injury or fitness level.

3.4. Basic dynamic analysis of a dog

In the dynamic analysis a study is made of several parameters such as the animal's mobility, flexibility, coordination, balance, functional capacity and use of musculature and the presence of lameness**.**

During locomotion, a combination of forces is generated, mainly those exerted by gravity on the body (passive forces) and active forces, which are generated by the body itself. In the canine species, it is the forelimbs that are closest to the centre of gravity, which is why they are established as the supporting limbs.

Furthermore, the hind limbs are the ones that generate the force and impulse, so there is a difference in loads between the two pairs of limbs. This means that in the analyses carried out there is an asymmetry in the ground reaction forces when comparing both limbs, which means that, in the absence of this asymmetry, pathologies related to gait can be identified thanks to the tests carried out on the strength platform.

After that, it is necessary to consider what a dog's normal gait looks like as assessed in a locomotion analysis. Locomotion is known as the result of the execution of movement patterns, which are coordinated and involve the activation of muscles and phases of the movement cycle by commands sent from the nervous system (Cabej, 2019).

The canine species can gait in four forms (walk, trot, canter and gallop). During the gait, it is normal to find three of the animal's legs on the ground at the same time. In this case, the gait of the animal is slower and the first movements are made by the pelvic limbs followed by the forelimbs on the same side. In trotting, the legs move diagonally and in pairs. That is to say, the left thoracic and right pelvic will move at the same time, followed by the right thoracic and left pelvic in the same way. In addition, during the trot, the pelvic limb in its movement will step on the same place where the front limb previously stepped on.

When galloping, the dog uses the power generated by the musculature of the spine and abdomen to produce two moments of suspension in the air, each followed alternately by the forelegs and hind legs hitting the ground (Sabater, 2019). It is represented more graphically in the following diagrams:

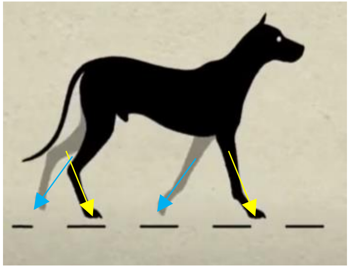 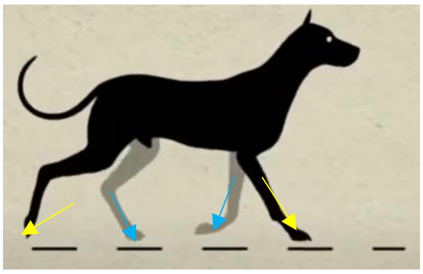

Fig 13. Walking (A) and trotting (B). Animal gait animators

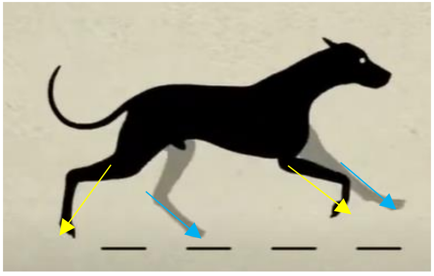 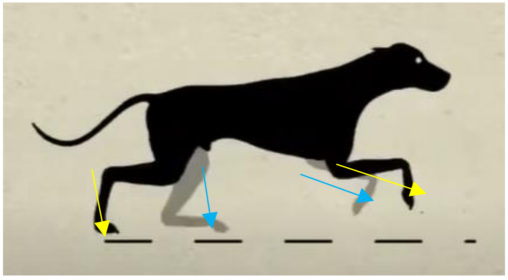

Fig 14. Sustained gallop (A) and gallop (B). Animal gait animators

3.5. Systems involved in gait

As can be seen, a good study of canine gait implies the need to know correctly each of the parts of the musculoskeletal system and its main function. Therefore, in addition to the joints and bones, the muscular movement involved in the gait of a quadrupedal animal must be taken into account in order to identify and correct the pathologies associated with gait, as well as the techniques for preventing possible biomechanical alterations. For this purpose, muscle activity is measured using electromyography, which is responsible for graphically recording the electrical activity produced by the muscles.

Therefore, the muscle groups to be taken into consideration are described below (Table 1).

MUSCLE	FUNCTION
SUPRASPINATUS	Extension of the shoulder and advancement of the limb forward. Prevents shoulder locking when bearing weight on the limb.
TRICEPS BRACHII	Elbow extension and prevention of elbow locking during gait. Propulsion during trotting
LATISSIMUS DORSI	Lifting of the trunk and deceleration of the forward movement of the limb
BICEPS BRACHII	Stabilising and preventing shoulder locking when weight bearing the limb
BRACHIALIS	Elbow flexion and maintenance of flexion before extension
VASTUS LATERALIS	Knee extension and flexion control
GASTROCNEMIUS	Maintenance of static ankle posture
SARTORIUS	Hip flexion
BICEPS FEMORIS	Deceleration of limb movement prior to ground contact and extension of the hip after the footfall
GLUTEUS MEDIUS	Hip extensión

Table 1. *Muscles involved in canine gait and their functions (Own elaboration)*

In addition, the main systems involved in movement are:

- Osteo-articular and ligamentous system. Which is responsible for facilitating the range of motion and allowing all the degrees that can occur during kinematics.
- Muscular system. It comprises agonist muscles, responsible for muscle contraction, and synergist muscles, responsible for relaxation. Their interaction allows the correct production of movement.

- Nervous system. Capable of controlling and regulating movements and their strength, speed and coordination, producing range of motion.

3.6. Pathologies associated with the absence of a forelimb

As will be mentioned in the conclusions of this proyect and with reference to previous studies (Ben-amotz, 2020), it has been demonstrated that the changes that the animal must make in order to adapt to this new situation can generate a greater predisposition to the appearance of osteoarticular and muscular pathologies in the long term.

In such cases, there is an increase in ground reaction forces and ground contact times, with a higher incidence in forelimb amputations than in pelvic limb amputations (Fuchs, 2014).

This leads to a decrease in the quality of life of the pet, which in turn leads to a lower level of owner satisfaction and may increase the percentage of abandonment and even euthanasia due to the inability to adapt to being in charge of a pet in such circumstances.

Therefore, the most frequent pathologies associated with this adaptation must be taken into account in order to reduce or delay their appearance as much as possible, as well as to advance in the study of prostheses adapted to each animal and its primary ailment.

3.6.1. Osteoarthritis

This disease is commonly caused by cartilage degeneration leading to inflammation and chronic lameness. One of the main causes of presentation is due to the chronic increase in the force exerted on the joints, which can occur in an animal with resection of a limb due to redistribution of weight on the remaining limbs.

3.6.2. Tendinitis

It is referred to as inflammation of the tendons, mainly affecting the biceps brachii tendon and the supraspinatus tendon. It is caused by trauma to the tendon or possible degradation due to overuse as well as calcification. The animal will present a lameness that is accentuated by exercise as well as pain and inflammation of the affected area.

In animals that have had one of their forelimbs amputated, there is an increased action of the supraspinatus and biceps brachii muscles, so tendonitis can be a common occurrence.

3.6.3. Muscle strain

Muscle function will be affected in one way or another in dogs with tripedal gait, resulting in chronic muscle tension. This results in signs of muscle tension in these animals having to compensate for the additional workload, with the supraspinatus and biceps brachii muscles of the forelimb and the gastrocnemius muscles of the hind limb being most affected.

4. MATERIALS AND METHODS

4.1. Animals and control group

Ten adult French bulldogs participated in the present study. Of the total, 5 were forelimb amputees and the remaining 5 were sound dogs that were used as a control group.

The amputation of the animals was the result of canine sarcoma (n=3) and trauma (n=2), which were clinical cases belonging to the Clinical Veterinary Hospital of the University of Las Palmas de Gran Canaria in a period between February 2021 and June 2023. The choice of these animals for the study was based on their ability to walk comfortably or the absence of orthopaedic or neurological findings in any of the remaining limbs during a previous clinical examination.
On the other hand, the control group consisted of sound animals, with no current history of previous orthopaedic and/or neurological diseases.

4.2. Platforms

The force platform used consisted of 4 force sensors of 35 x 35 cm and 250 Hz sampling rate. It was placed in a hole in the floor of a 10-metre long corridor. The hole was arranged in such a way that the surface of the platform and the floor were at the same level.

Anyway, the software used (DataStudio, Pasco, California) measured parameters such as maximum vertical forces (Fvmax), cranial or braking forces (Fcrmax) and flow or propulsion forces (Fcamax) from three valid trials. Vertical impulse (VI) parameters in vertical, cranial and flow directions (VIv, VIcr and VIca, respectively) were also obtained.

Tests were considered valid when there was no movement of the limbs, head and/or neck, and the owner had no physical contact to hold the animal during the measurement. In addition, mean values were adapted to body weight (% BW).

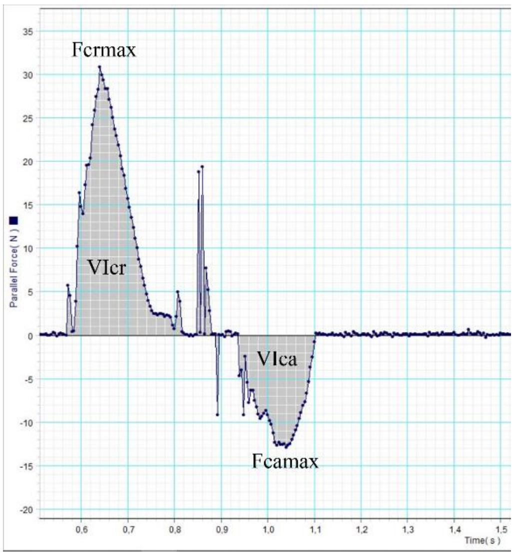

Fig 15. *Representation of horizontal forces and impulses by force platform recording*

The pressure platform used is EPS/R1, Loran Engineering, Bologna, Italy, with Biomech software (Loran Engineering). It consists of 2096 pressure sensors (density 1, sensor /cm2) evenly distributed in a quadrangular frame.

The acquisition frequency was 100 Hz and the pressure measurement range was 30-400 kg. This platform was placed in another hole that kept it level with the ground and adjacent to the force platform in order to ensure that the recordings were made in the same test.

For the postural examination (posturography), the animals were placed with both forelimbs on the platform and remained motionless for 10 seconds. In this case, the owner stood directly in front of the animal to ensure that the animal's head and neck were presented facing forward and without turning during the examination.

Fig 16.*Example of animal positioning during the study (Manera, 2019)*

Three tests were obtained from each animal and, in order to consider them valid, the same conditions were taken into account as for the force platform.

The posturographic data obtained corresponded to the statokinesiogram (Stat, mm^2), peak and mean pressures (PP, MP, Kpa) and paw area (PA, cm^2). In order to analyse the characteristics of the COP pathway, dogs were walked on a leash in the same way as for the strength platform.

4.3. Statistical analysis

For this study, the data for strength and postural pressure, obtained from both amputees and sound dogs, were compared using Student's t-test. In interpreting the results, differences with a p-value of less than 0.05 were considered statistically significant.

5. RESULTS

The mean ± SD (standard deviation) and p-value for both groups of animals tested are shown in the following table (Table 2):

	Sound	Amputee	P-value
Force Values			
Fvmax	99.4 ± 0.04	182.8 ± 0.11	0.0002
VIv	15.9 ± 0.02	28.1o ± 0.00	0.0004
Fcrmax	9.60 ± 1.68	25.31 ± 0.75	<.0001
VIcr	0.74 ± 0.31	2.50 ± 0.150	0.0003
Fcamax	5.21 ± 0.87	12.11 ± 2.21	0.0230
VIca	1.0 ± 0.20	1.20 ± 0.160	0.2836
Pressure values			
Stat	0.230 ± 0.03	0.227 ± 0.05	0.9267
PP	215.8 ± 5.07	292.4 ± 10.16	0.003
MP	78 ± 0.71	82.50 ± 3.26	0.0185
PA	14.5 ± 2.4	20 ± 1.00	0.0126

Table 2. *Statistical results of the study. Units: Fvmax, Fcrmax, Fcamax: N (%BW); VIv, VIcr, VIca: N.s (%BW); Stat: mm2; PP, MP: KPa; PA: cm2*

Taking stock of the results obtained, it can be seen that the Fvmax, VIv, Fcrmax, VIcr and Fcamax values were significantly higher in relation to the amputee group, while VIca showed no significant differences.

On the other hand, in terms of pressure data, the statokinesiogram revealed no differences between amputated and sound dogs. Notably, the orientation of the ellipse was positioned sagittally instead of horizontally (Fig 18) in the amputee group. In addition, static data such as PP, MP and PA were significantly higher in these animals.

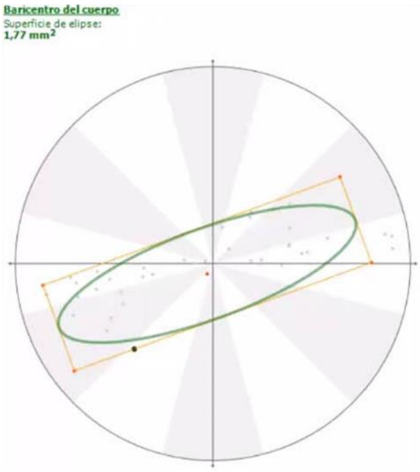

Fig 17. *Statatokinesiogram of one of the sound dogs*

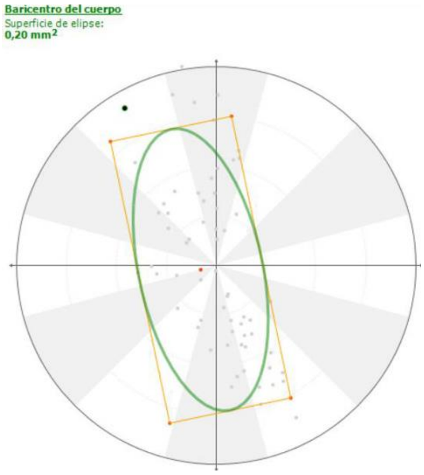

Fig 18. *Statatokinesiogram of one of the amputees*

As for the study of the COP path, during the gait of sound dogs, it can be seen that they initiate contact with the ground in the centre of the paw and their path is cranial during the stance phase of gait. In contrast, amputees present their COP more caudally, at the level of the metacarpal pad (Fig 20).

The figure below (Fig 19) shows the pressure recording during the stance phase in a sound dog. The consecutive pink dots correspond to the COP pathway. It can be seen how the tracing starts at the centre of the paw and transits cranially.

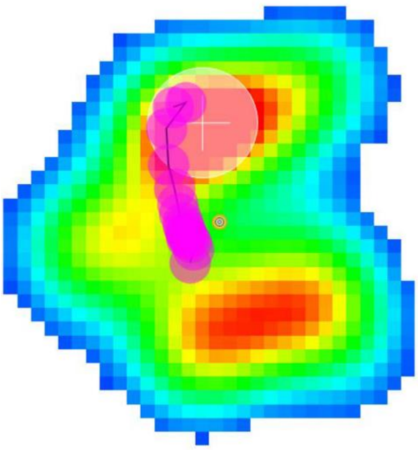

Fig 19. *Colour scale chart in sound dog.*

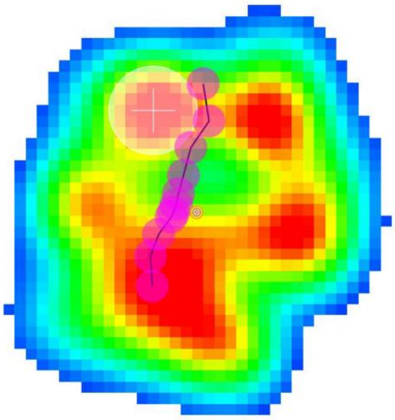

***Fig 20**. Colour scale chart in lame dog*

In this case (Fig 20) the pressure during the stance phase of an amputated dog is recorded. The pink dots correspond to the COP pathway. Note how the tracing starts more caudally, at the level of the metacarpal pad and transits cranially. This shows that the limb, on contact with the ground, is positioned more cranially than the sound limb.

6. DISCUSSION

In this study, different kinetic parameters obtained from the use of force and pressure platforms were compared in a group of 5 French bulldogs with a forelimb amputation and a group of 5 sound animals of the same breed.

Prior to the biomechanical evaluation, it was ensured that the amputees were fully adapted to the tripedal gait. Also, most dogs adapt within one month to this type of gait (Galindo, 2016), especially if it involves the forelimbs (Vassalo *et al*., 2015). However, there are several factors that vary the adaptation time, such as the animal's body weight, age and breed (Weiget, 2003). In this study, the dogs were fully adapted as they all underwent surgery four months in advance.

On the other hand, analysing the results, it can be observed that most of the force parameters (Fvmax, Fcrmax, Fcamax) as well as their respective impulses (VIv, VIcr) showed higher values. This demonstrates a redistribution of weight to the contralateral forelimb. These data are not only reflected in terms of force, but also in the braking phase, showing that amputated dogs are in this phase longer than sound dogs. In contrast, the VIca value remained the same, suggesting that the propulsion phase is shorter in the amputee group.

It is believed, therefore, that while it is the contralateral limb that has to assume the braking force, there is a very important contribution from the hind limbs during the propulsion phase, where the inverse relationship between force and duration of the phase has been pointed out by other authors (Mclaughlin, 2001).

Regarding the analysis of posture, it has been proposed that animals with amputated forelimbs have more difficulties in maintaining body balance (Cole *et al*., 2017). However, the results of our study obtained during the statokinesiogram show that the group of amputees manages to maintain balance as well as the group of sound dogs, so it can be certified that the tripedal support for the first group is as effective as the quadrupedal support, as far as balance is concerned.

In addition, it has been found previously that the ellipse in both types of dogs is maintained in a transverse orientation, which means that they have greater stability in the sagittal plane, as the longitudinal axis is longer than the horizontal axis. However, in our case, the ellipse changed to a sagittal plane, so that, although the maintenance of balance does not change, the vertical axis of the COP changes from transverse to parallel to the longitudinal axis of the animal.

Similarly to the case of forces, the amputee group exerts more pressure during contact of their limbs with the ground, again reflecting the redistribution of weight on the sound forelimb in cases of painful limping (Bockstahler et al., 2009)

Leg extension is due to the pressure exerted by the limb on the ground due to the elastic nature of the metacarpal and digital pads. In this study, an increase in this extension is shown in amputated animals. However, it does not appear to be proportional to the increase in pressure.

Finally, it was observed that the COP trajectory of the limb started more caudally in the tripedal stance dogs, which suggests that the forelimb moves more cranially than in sound dogs when initiating the stance. This makes it clearer to understand that the increase in both force and pressure, as well as the variability in limb position during stance, leads to increased stress on the contralateral forelimb, primarily on the structures involved in supporting the animal's body. Previous studies relate these changes to the predisposing appearance of pathologies such as osteoarthritis, tendinitis or muscle contractures (Gimeno Ponce, 2022). It is considered that the results shown in this study contribute to the knowledge of the dynamic and postural adaptations of dogs with a forelimb amputation.

Moreover, there are some limitations such as: the small number of animals used for the study, although belonging to the same breed allows us to obtain more homogeneous data and, thanks to this, to reinforce the solidity of the conclusions. In addition, the fact, already reported, of weight redistribution towards the hind limbs in forelimb amputees has not been taken into account, which could be the subject of future research.

7. CONCLUSIONS

The amputation of a limb in dogs and its consequent tripedal stance does not mean that there is a loss of balance in quantitative terms. On the other hand, there is an increase in the pressure and ground reaction force of the remaining limb during the stance phase and a prolongation of the braking phase. This reflects the animal's adaptation to the absence of one of its limbs by redistributing the forces.

Furthermore, these events predispose to the early onset of injuries caused by overuse of the different musculoskeletal units, which leads to a further deepening of preventive and curative studies in this science with the aim of improving the duration and quality of life of affected patients.

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