

UNIVERSIDADE FEDERAL DO ACRE

LEONARDO KOURI ALBUQUERQUE

**MODELOS ANATÔMICOS DE LUXAÇÃO PATELAR 3D
ESTUDO RADIOLÓGICO E AVALIAÇÃO NO ENSINO
DA ANATOMIA ANIMAL APLICADA**

**RIO BRANCO
ACRE – BRASIL
ABRIL – 2018**

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Dissertação apresentada à Universidade Federal do Acre, como parte das exigências do Programa de Pós-Graduação em Sanidade e Produção Animal Sustentável na Amazônia Ocidental, para a obtenção do título de Mestre em Ciência Animal.

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APROVADA: 30 de abril de 2018.

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Ao meu pai, Aldemar Holanda Albuquerque Filho.
À minha mãe, Zenaida Kouri Albuquerque.

Dedico.

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Agradeço primeiramente a Deus, que iluminou meu caminho durante esta caminhada.

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*“Você vence. Todos os dias. Quando não
desiste, você vence. Quando levanta e
segue, você vence.”*

Ana Nunes

CERTIFICADO DO COMITÊ DE ÉTICA NO USO DE ANIMAIS –UFAC

Título do projeto: Confecção de Modelo 3D de Luxação Patelar Canina e sua Aplicação como método Alternativo no Ensino Prático da Medicina Veterinária

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RESUMO

ALBUQUERQUE. Leonardo Kouri. Universidade Federal do Acre, abril de 2018
Modelos Anatômicos de Luxação Patelar 3D: Estudo Radiológico e Avaliação no Ensino da Anatomia Animal Aplicada. Orientador: Yuri Karaccas de Carvalho. As características da impressão 3D fazem da tecnologia uma ferramenta útil no Ensino da Anatomia Animal Aplicada, favorecendo relação direta com a anatomia real e com grande potencial para fornecer materiais didáticos de alta qualidade. A finalidade do estudo foi a confecção e avaliação de Modelos Anatômicos de Luxação Patelar 3D (MALP3D) como material didático no Ensino da Anatomia Animal Aplicada. Seu desenvolvimento partiu da necessidade de representação dos diferentes graus de severidade da Luxação Patelar (LP) durante aulas práticas. Foram criados cinco MALP3D, correspondentes aos diferentes graus da doença. A criação baseou-se na digitalização por scanner 3D de ossos *In natura* correspondentes ao fêmur, tíbia, fíbula e patela, edição em software de modelagem 3D e confecção em impressora 3D. Posteriormente, foram realizadas radiografias dos MALP3D em equipamento de raio X digital para ilustrar nos diferentes posicionamentos os graus da doença. Após a criação foi realizada avaliação dos modelos e radiografias dos MALP3D em uma turma de 36 discentes distribuídos aleatoriamente em dois grupos (Tradicional e MALP3D). Todas as estruturas impressas mostraram grande semelhança com as peças naturais, os MALP3D quando radiografados e mensurados foram capazes de representar os diferentes graus da doença de forma adequada e quando aplicados em aula proporcionaram acréscimos no conhecimento dos discentes. Os MALP3D mostraram ser uma alternativa educacional importante, capazes de suprir a falta de materiais representativos para o Ensino aplicado da Luxação Patelar (LP) e contribuir para a formação dos discentes.

Palavras chaves: Impressão 3D, Prototipagem Rápida, FDM, Radiografia, Modelo didático

ABSTRACT

ALBUQUERQUE. Leonardo Kouri. Federal University of Acre, April 2018
Anatomical Models of Patellar Dislocation 3D: Radiological Study and Evaluation in the Teaching of Applied Animal Anatomy. Advisor: Yuri Karaccas de Carvalho. The characteristics of 3D printing technology make it a useful tool in the teaching of Applied Veterinary Anatomy and foster a direct relationship with real anatomy. Moreover, 3D printing has great potential as a source of high-quality teaching materials. The purpose of the present study was to design and evaluate 3D anatomical models of patellar luxation (3DAMPL) as a resource material for the teaching of Applied Veterinary Anatomy. The models were developed because there was a need to represent different grades of severity of patellar luxation (LP) during practical classes. Five 3DAMPL models were designed; they correspond to the different grades of the disease. To create the models, natural bones (corresponding to the femur, tibia, fibula and patella) were scanned in a 3D scanner, edited in 3D modeling software and printed in a 3D printer. Subsequently, the 3DAMPL models were X-rayed in a digital X-ray machine to illustrate the grades of the disease in different positions. The 3DAMPL models and their respective x-ray images were then evaluated in a class of 36 students randomly distributed into two groups (Traditional and 3DAMPL). All the printed structures were very similar to their natural counterparts; when the MALP3D models were X-rayed and measured, they were able to represent the different grades of the disease appropriately and when they were applied in the classroom, they helped students gain further knowledge of the disease. The 3DAMPL models were found to be an important alternative educational resource because they compensated for the lack of representative materials for the applied teaching of patellar luxation (PL) as well as enhanced the learning of the students.

Keywords: 3D printing, Rapid Prototyping, FDM, Radiography, Physical models for teaching

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1 ARTIGO

1 Artigo 1

3D Anatomical Models of Patellar Luxation: Radiological research and assessment
for the teaching of applied veterinary anatomy

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INTRODUCTION

Patellar luxation (PL) in dogs is a highly-prevalent orthopedic disease (Lara, It results from the development of bone abnormalities which affect hind limb ment and cause the loss of the normal anatomical relationship between the ear groove of the femur and the patella at four different grades (Piermattei et al., Thus, learning about the disease is important in the education of future ary physicians.

PL in dogs is addressed in the advanced cycle of the Veterinary Medicine Undergraduate Program through books, images, and mainly in the dependence of clinical cases (Davis et al., 2014). Although PL is commonplace in routine veterinary care, teaching about this disease is a challenging task; for example, students lack basic knowledge of anatomy; there is not enough support material for practical classes and there are not enough clinical cases covering all grades of the disease. As a result, there is a gap in veterinary education (Smith et al., 2017).

Furthermore, medical education and research institutions are currently undergoing a process of adaptation as a result of several pedagogical, ethical and economic limitations in practical teaching. Eventually, these limitations further hinder the transmission of that type of knowledge and, hence, have a direct influence on the education of students (Sugand et al, 2010; Vaccarezza and Papa, 2014).

Among the innovations that have emerged to resolve this problem, 3D printing technology is seen as capable of favoring a direct relationship with real anatomy in enough detail to provide an alternative to the use of animals. Also, it has great potential to provide a source of high-quality teaching materials which, in turn, can help educational institutions cope with limitations (Mcmenamin et al., 2014; Lim et al., 2016).

27 By using this technique, students can handle 3D anatomical models regardless
28 of their location. Because digital files are easy to reproduce and distribute, they offer
29 access to models which do not exist in a particular region or educational institution,
30 thus favoring the large-scale replication and widespread use of these models.

In turn, 3D printing is characterized as an important tool to develop practical classes, as it can foster authentic and detailed understanding of the disease as well as

1 enable demonstration and experimentation in the classroom. As a result, theoretical
2 learning can be deepened (Abouhashem et al., 2015; O'Reilly et al., 2016).

3 Therefore, the objective of the present study was to design and evaluate 3D
4 anatomical models of patellar luxation (3DAMPL) as possible materials for the
5 teaching of applied veterinary anatomy.

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MATERIAL AND METHODS

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The study was developed in two steps at Federal University of Acre (UFAC), Rio Branco, AC, Brazil. The first step was performed at the Laboratory of 3D Technology. It consisted in scanning and printing the selected anatomical parts. The second step was performed during the Applied Veterinary Anatomy course. The most relevant aspects of patellar luxation (PL) were addressed and 3D anatomical models of patellar luxation (3DAMPL) were evaluated. The research was registered and approved (Protocol no. 23107.007926/2017-90) by the Animal Research Ethics Committee (CEUA- UFAC). Patent application No. xxxx.

11

12 Creation of 3D anatomical models of patellar luxation (3DAMPL)

3DAMPL models were created by scanning natural anatomical parts corresponding to the following bones: femur; tibia, fibula and patella of the left hind limb of a healthy dog. The resulting digital files were edited with 3D modeling software to produce the changes corresponding to the disease and then printed in an FDM (Fused Deposition Modeling) 3D printer (Figure 1).

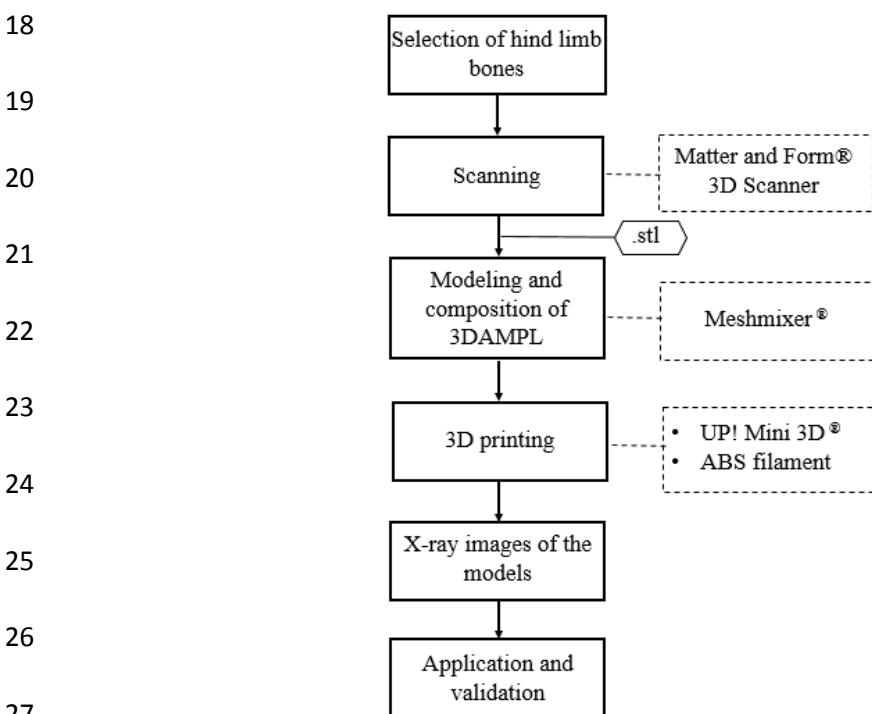


Figure 1. Flowchart for design of 3D anatomical models of patellar luxation

1 The anatomical parts were scanned in a Matter and Form[®] 3D scanner
2 (Toronto, Canada) with a CMOS HD sensor and two lasers with scanning accuracy of
3 0.43 mm (capture of small details) and capture size within ± 0.25 mm. With the aid of
4 the included software “Matter and Form Scan[®]”, each bone was scanned individually.

5 The resulting virtual models were saved in .stl format and stored in a database.
6 Later, they were imported into a 3D design software program (Autodesk Meshmixer[®],
7 version 3.1, Autodesk Inc. [®], California, United States) for modeling and composition
8 of 3DAMPL models by means of tools that have enabled the reproduction of the main
9 bone deformities corresponding to each of the four grades of PL.

10 All the characteristics of the disease reproduced in the 3DAMPL models were
11 based on studies reported by Singleton (1969); Piermattei et al., (2006); Netto et al.,
12 (2012); Oliveira and Tudury, (2016); OFA (2017) (Table 1).

13 **Table 1.** Anatomical changes visible in different grades of patellar luxation in dogs.

Grades	Characteristics
I	Tibial tubercle deviation is minimal or non-existent; Minimal changes in the patellofemoral joint.
II	Mild deformities in the patellofemoral joint; Tibial tubercle deviation from 15° to 30°.
III	Permanent patellar luxation; Tibial tubercle deviation from 30° to 60°; Shallow trochlear groove; Angular deformities of the femur and the tibia are frequent.
IV	Permanent patellar luxation; Tibial tubercle deviation from 60° to 90°; Trochlear groove commonly absent or with convex trochlear surface; Large angular deformities in the femur and the tibia.

21 **Source:** Table modified from (Piermattei et al., 2006).

22 The portions of the 3DAMPL models were constructed separately in an UP!
23 Mini[®] 3D printer (Beijing Tiertime Technology Co. Ltd. [®], Beijing, China), in high-
24 quality ABS (Acrylonitrile Butadiene Styrene) thermoplastic filament with 99% infill
25 and layer thickness of 0.2 mm. A mechanism composed of an articulating pin and hole
26 was inserted between the bones of the femur and tibia in order to enable the
27 reproduction of movements similarly to the movements of the knee joint and also allow
28 users to assemble and disassemble the parts.

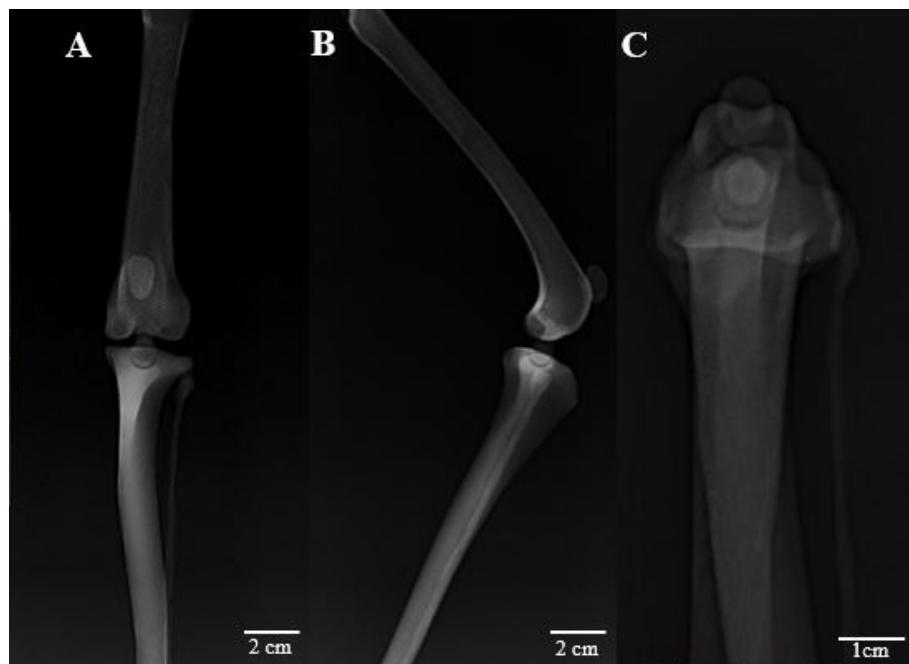
29

1 **Radiographic study of 3DAMPL models**

2 After the 3DAMPL models had been constructed, they were brought to the
3 Center for Diagnostic Imaging for the purpose of x-ray imaging. In case the desired
4 measurements had not been achieved, the original files were modeled again to provide
5 the correct measurement.

6 All the 3DAMPL models were X-rayed in a General Electric DR-F digital X-
7 ray machine (General Electric Company®, United States), with exposures of 50
8 Kilovolts (kV) for radiation intensity and exposure time of 6.3 milliamperes per second
9 (mAs).

10 Each 3DAMPL model was X-rayed in three radiographic positions, namely:
11 Mediolateral; Craniocaudal; Tangential (Skyline), as recommended in the diagnosis of
12 PL (Connie and Cheryl, 2007) (Figure 2). The X-ray images were subsequently
13 measured through the use of the software RadiAnt DICOM Viewer® (2009-2017
14 Medixant ©, Poznan, Poland).



24 **Figure 2.** X-ray images of 3D anatomical models of patellar luxation. Radiographic positions for diagnosis of
25 medial patellar luxation. **A.** Craniocaudal. **B.** Mediolateral. **C.** Tangential (Skyline).

1 By means of tangential (Skyline) projection, depth, width and angle of the
2 trochlear groove were measured, taking as a basis the higher areas of the crests of the
3 femoral trochlea (Figure 3). After these values were determined, the results were
4 compared to the findings of studies that highlight this type of measurement as well as
5 studies which are focused on tibial tubercle deviation and bone conformations of the
6 tibiofemoral and the femoropatellar joints (Singleton, 1969; Netto et al., 2012; Oliveira
7 and Tudury, 2016; Yasukawa, 2016)



Figure 3. Measurements of the trochlear groove. **A.** Depth. **B.** Width. **C.** Angle of the trochlear groove.

8

9 Students and educational setting

10 All students who agreed to take part in the study were second-year students of
11 the undergraduate program in Veterinary Medicine. At this stage, it was assumed that
12 they had little or no previous knowledge about patellar luxation. However, because
13 they had already taken courses on descriptive veterinary anatomy, it was assumed that
14 all of them had satisfactory knowledge of the anatomical structures that compose the
15 knee joint.

16

17 Groups

18 After signing an Informed Consent Form, the students were randomly
19 distributed into two groups: Traditional group ($n= 18$) and 3DAMPL Group ($n= 18$).
20 Soon afterwards, they attended a theoretical-practical class and were subsequently
21 evaluated at two moments: 1. Before the class (Pre-test) and 2. After the class (Post-
22 test). Both groups (Traditional and 3DAMPL) used traditional X-ray images to answer
23 the questionnaire during the Pre-test and Post-test (Figure 4).

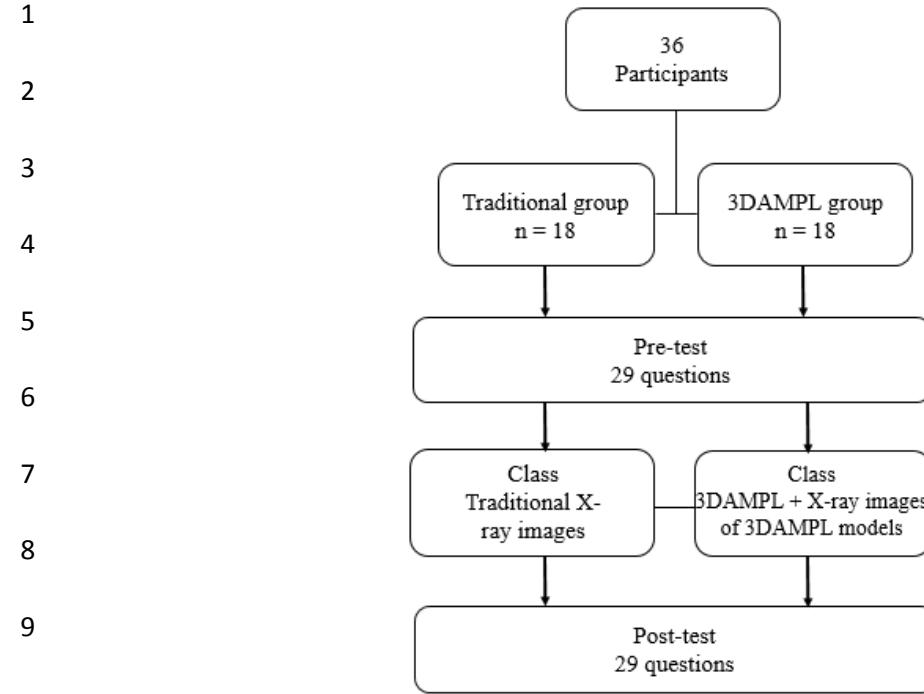


Figure 4. Flowchart for assessment of the 3D anatomical models of patellar luxation.

Application and assessment of the 3DAMPL models

The lessons were taught by the same lecturer and lasted for 40 minutes. At that time, the lecturer explained the most important anatomical and radiographic aspects of PL and its main measurements as a tool for classification of the disease. The first group (Traditional) received the lesson in a conventional form, i.e., using X-ray images of clinical cases, while the second group (3DAMPL) was taught with the use of the 3DAMPL models and the respective X-ray images. At the end of each lesson, the students were given 10 minutes to discuss the subject and to evaluate the specimens by comparing them to the contents that had been taught.

The test for evaluation of the 3DAMPL models was composed of an anonymous questionnaire with 29 affirmative questions, whose possible answer choices were true or false (T or F). The questionnaire was divided into three sections linked to specific knowledge of the disease, namely: 1. Radiographic anatomy of the knee joint; 2. Radiographic findings for patellar luxation; 3. Classification of patellar luxation.

1 **Statistical Analysis**

2 To check if the groups had the same level of knowledge, an analysis was
3 performed of the answers given in the Pre-test by the groups that were taught the
4 traditional lesson in comparison with the lesson taught with the 3DAMPL models. To
5 check what students had learned when using the models, the correct answers of the
6 Post-test were submitted to the non-paired t-test with a significance level of 5% ($p <$
7 0.05). To assess improvements in learning after use of the 3DAMPL models, the
8 answers were tested separately between the three topics covered in the questionnaire
9 (Radiographic anatomy of the knee joint, Radiographic findings for patellar luxation
10 and Classification of patellar luxation).

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RESULTS

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Evaluation of the 3DAMPL models

The 3DAMPL models showed great accuracy in the replication of all the bone structures involved. The printed models maintained the same length, width and depth of the bones. Also, each part of the bones was represented in detail (Figure 5).



Figure 5. Natural bones (Left) and 3D-printed bones (Right) that compose the tibiofemoral and femoropatellar joints. **A.** Femoral Head (FH), Femur (Fe), Medial trochlear crest (MTC), Lateral trochlear crest (LTC), Trochlear Groove (TG), Patella (Pa). **B.** Tibial tubercle (TB), Tibia (Ti), Fibula (Fi).

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The digital file which resulted from scanning of natural bones was used as the basis for the creation of all other 3DAMPL models. It was named Grade 0, because it did not have signs of anatomical deformities. The 3D-printed replica showed perfectly visible femur and trochlear crest of the femur and similar conformation to that of the original bone; the oval shape, width and thickness of the patella have been preserved and followed the original aspect ratio; the tibia retained the same smooth and defined lines that delimit tibial tuberosity.

The presence of the articulated mechanism between the bones of the femur and tibia gave the 3DAMPL models the ability to reproduce movements of extension, flexion and rotation similarly to the movements of the knee joint. Thus, radiographic

1 positions suitable for the study could be replicated, and the users could assemble and
2 disassemble the parts.

3 Four 3DAMPL models were printed, each representing one of the different
4 grades of the disease. Each model was composed of four structures, namely: femur
5 (femur + articulating pin); tibia, fibula and patella. The structures were printed
6 separately in ABS thermoplastic material with 99% infill, layer thickness of 0.2 mm
7 and fine quality that ensures reduced print speed, in order to offer good quality of the
8 final product.

9 At the end of the production of all the 3DAMPL models, approximate values
10 were estimated for development time, printing time, material expenditure and cost per
11 anatomical structure and per printed 3DAMPL model. The values are shown in Table
12 1.

13

14 **Table 1.** Values for creation and printing of 3D anatomical models of patellar luxation. Time (Hours), Material
15 expenditure (grams) and cost (US dollar) per part and MALP3D model.

Anatomical structures	Development time (h)	Printing time (h)	Material expenditure (g)	Cost (US\$)
Femur	2.5	3.5	28.8	0.87
Tibia	1.5	2.0	23.3	0.70
Fibula	0.33	0.45	2.8	0.08
Patella	0.16	0.13	0.7	0.02
3DAMPL				
1 Unit	4.49	6.08	55.6	1.67
4 Units	6.49	24.32	222.4	6.68

*Value of the dollar = BRL 3.30

*ABS Filament Value = \$30.30

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17 For Grade I, small changes were made on the surface of the femoral trochlea
18 to achieve the anatomical incongruence which is compatible with the grade. For
19 Grades II, III and IV, bigger changes were made with the purpose of replicating the
20 corresponding signs of osteoarthritis. The deformations significantly affected the
21 femoral trochlea and the trochlear groove and were necessary to achieve the

1 measurements equivalent to each grade of the disease, and to allow a macroscopic
2 view of the anatomical changes (Figure 6).

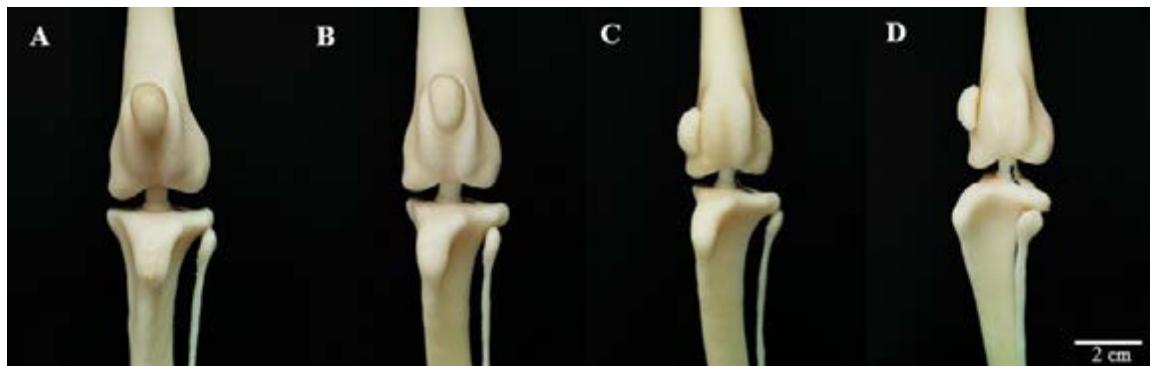


Figure 6. 3D Anatomical Models of Patellar Luxation. Detail of the deformities produced in the trochlear groove, tibial tubercle deviation and patellar luxation. **A.** Grade I; **B.** Grade II; **C.** Grade III; **D.** Grade IV.

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4 The x-ray images made of the 3DAMPL models were very similar to traditional
5 ones, clearly revealing radiopaque and radiolucent areas. In the X-ray images, each
6 one of the bones and their corresponding anatomical structures could be observed and
7 determined. As a result of the addition of the articulating mechanism between the
8 bones of the femur and tibia, the presence of the socket pin was clearly visible in the
9 X-ray images made for the study. However, their presence did not influence the
10 evaluation of the pathological aspects of the disease (Figure 7).

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FIGURE 7. X-ray images of the knee joint. Craniocaudal and tangential (Skyline) projection. **1.** Femur; **2.** Tibia; **3.** Fibula; **4.** Patella; **5.** Femoral trochlea; **6.** Tibial tubercle; **7.** Trochlear groove. **8.** Socket pin.

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1 In the X-ray images of Grade I, there were no evident anatomical deformities
2 in the patellofemoral joint or changes that simulated osteoarthritis. There was no
3 noticeable evidence of patellar luxation and the femoral trochlea showed almost
4 imperceptible incongruity, similarly to Grade 0, whose measurements of the trochlear
5 groove were virtually unchanged; in the tibiofemoral joint, there is only a slight medial
6 rotation of the tibial tubercle (Figure 8A).

7 In the X-ray images of Grade II, there were mild deformities in the femur,
8 which simulated slight osteoarthritis, with incongruity of the crests of the femoral
9 trochlea that caused a slight reduction of the depth and width of the trochlear groove
10 as well as changes to its angulation; the patella does not seem to be luxated in the
11 image; and the tibial tubercle presents medial rotation of 20° (Figure 8B).

12 In the X-ray images of Grade III, anatomical deformities were noticeable both
13 on the femur and the tibia: the femur presented incongruity of the trochlear crests, as
14 shown by accentuated flattening of the trochlear groove, which resulted in a significant
15 difference in the measurements of its angle, depth and width; the patella showed
16 evident medial luxation; and the tibia showed sharp angular deformity that caused
17 medial rotation of the tibia tubercle at 35° (Figure 8C).

18 In the x-ray images of Grade IV, anatomical deformities were severe and could
19 be easily observed: the femur presented incongruity of the trochlear crests, as shown
20 by accentuated flattening or virtual disappearance of the trochlear groove, which
21 resulted in a significant difference in the measurements of its angle, depth and width;
22 the patella showed evident medial luxation; and the tibia showed sharp angular
23 deformity that caused medial rotation of the tibia tubercle at 70° (Figure 8D).

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Figure 8. X-ray images of 3D anatomical models of patellar luxation, Craniocaudal and tangential projections, respectively. **A.** Grade I; **B.** Grade II; **C.** Grade III; **D.** Grade IV.

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1 Table 2 shows the measurements made of the 3DAMPL models for width, depth
2 and angle of the trochlear groove, as well as the values of tibial tuberosity deviation.

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	Depth	Width	Angle	TTD
Grade 0	1.97	9.95	128.8°	-
Grade I	1.95	9.95	130.3°	-
Grade II	1.87	9.22	132.6°	20°
Grade III	1.13	8.98	149.1°	35°
Grade IV	-	8.67	155.7°	70°

4 **Table 2.** Measurements of the trochlear groove (depth and width in millimeters) and tibial tubercle deviation (TTD) in
5 different grades of the 3DAMPL models.

6

5 Evaluation of learning with the 3DAMPL models

6 The general analysis of the questionnaires showed that the mean number of
7 correct answers between the two groups (Traditional and 3DAMPL) was statistically
8 similar in both the Pre-test ($p= 0.148$) and the Post-test ($p= 0.529$). When analyzing
9 the means (Pre-test and Post-test) within the same group, a significant difference ($p<$
10 0.05) was found in both groups (Figure 9A).

11 In the comparative analysis between the groups (Traditional and 3DAMPL) in
12 the Pre-test of the item “Radiographic anatomy of the knee Joint”, it was found that
13 the mean number of correct answers of the 3DAMPL group was higher than the mean
14 of correct answers in the traditional group, hence there was a significant difference for
15 this test. By contrast, in the Post-test for the same item, no significant results were
16 found ($p= 0.643$). To analyze the means for correct answers in the questionnaire (Pre-
17 test and Post-test) within the same group, there was a significant increase in the number
18 of correct answers for both the Traditional group and the 3DAMPL group (Figure 9B).

19 For the item “Radiographic findings for patellar luxation”, no significant
20 differences were found between the groups (Traditional and 3DAMPL) in the Pre-test
21 ($p= 0.916$) and the Post-test ($p= 0.645$). When analyzing each individual group, despite
22 the increase in the mean number of correct answers for this item in both groups, the
23 difference between the Pre-test and the Post-test was not significant ($p>0.05$) (Figure
24 9C).

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1 For the item “Classification of patellar luxation”, there were no significant
 2 differences in the analysis of the Pre-test ($p= 0.644$) and the Post-test ($p= 0.843$) when
 3 comparing the means of the groups (Traditional and 3DAMPL). In the individual
 4 analysis per group, despite the increase in the means, there were no significant
 5 differences ($p>0.05$) (Figure 9D).

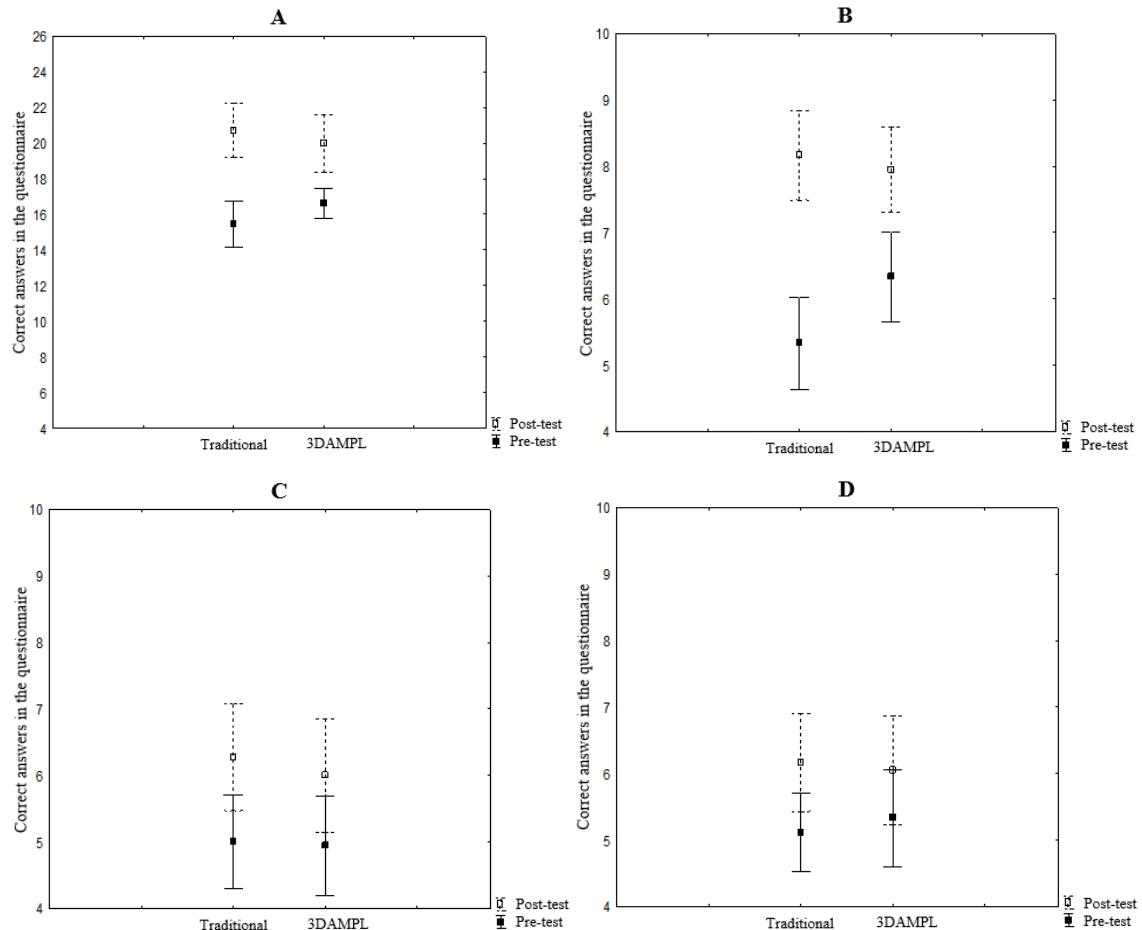


Figure 9. Graphs of the mean number of correct answers in the questionnaire. **A.** General Results. **B.** Radiographic anatomy of the knee joint. **C.** Radiographic findings for patellar luxation. **D.** Classification of patellar luxation.

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DISCUSSION

In several studies, 3D printing has been described as a useful complement in medical and veterinary medical education and particularly associated with issues such as surgery (Castilho et al., 2014; Harrysson et al., 2015; Kim et al., 2018) and anatomy (Lee et al., 2013; Thomas et al., 2016; Lim et al., 2016; Adams et al., 2016; Li et al., 2016).

The development of 3DAMPL models arose from the need to represent different grades of severity of PL during practical classes. Although it is a highly prevalent disease in veterinary clinical practice, it is often addressed in the classroom in a limited manner. There are not enough medical centers and few cases of this disease are treated in educational institutions; therefore, students do not have enough clinical experience about the disease or have fewer possibilities of visualizing the different grades of severity of the disease during their undergraduate education.

The initial scanning of natural bones with the 3D scanner was a fundamental step in the development of the research, since it provided digital files with excellent quality and resolution that were used for the design of the 3DAMPL models. This corroborated other studies that also reported the accuracy of 3D scanning in the process of development of anatomical models (Cantín; Muños and Olate, 2015; Thomas et al., 2016; Li et al., 2018).

The stage of design of the 3DAMPL models required a total time estimated at approximately 6.49 hours. It should be noted that prior knowledge of details during reproduction of the models and, especially, mastery of the tools used in the 3D modeling software were crucial to replicate bone deformities accurately and to achieve the desired results in a shorter time frame.

When a comparison was made of the time spent in the design of the 3DAMPL models based on the use of diagnostic imaging equipment, it was found that the two techniques have a similar length. However, if an analysis is made of the advantages and the cost of each method, 3D printing is more feasible for use in places that do not have financial resources to rely on medical equipment (Mcmenamin et al., 2014; Mitsopoulou et al., 2015).

1 The scanned structures that served as a basis (Grade 0) for the design of the
2 3DAMPL models showed great precision when printed. They represent the bone
3 conformations and the main anatomical structures of the natural bones with great
4 similarity. This was an important factor for the modeling process, because it was an
5 anatomical reference during reproduction of the deformities corresponding to each of
6 the grades of PL.

7 As shown in a study by Chung et al., (2018), the settings of the print parameters
8 in use (such as infill of the model, layer thickness, temperature and speed of printing)
9 are critical factors to ensure accuracy and good print quality. These aspects are also
10 closely related to the quantity of material used in the process, which directly affects
11 the cost and time of printing.

12 When the values of time and cost of printing of 3DAMPL models were
13 compared with those of similar studies that also used printers for extrusion of plastic
14 material (Li et al., 2018; Chung et al., 2018), it was found that the values were similar
15 in structures which have similar proportions, whereas there was a slight variation of
16 values in larger structures. This may be explained by the size ratio of the object being
17 printed, position on the printing surface, quantity of support filament, print parameters
18 in use or even type of printer in use (Aguiar and Yonezawa, 2014).

19 As pointed out, the use of 3D-printed replicas has the potential to provide a
20 readily available source of high-quality teaching materials. As shown in other studies
21 (Liew et al., 2015), the use of technology allows a better assessment of pathological
22 aspects of a disease when they are examined in tangible models of bone anatomy,
23 allowing manipulation and visualization in different perspectives, a fact that provides
24 learners with greater accessibility to different forms of learning.

25 The digital files of the 3DAMPL models as well as those of other studies may
26 contribute to the creation of databases, thus favoring the universalization of models,
27 i.e., any person or institution can have access to these models regardless of where they
28 are. Also, students can learn at their own pace and review the materials as many times
29 as necessary (Abouhashem et al., 2015; O'Reilly et al., 2016).

30 However, in order for models to appropriately contribute to the education of
31 professionals, experimental evidence is required to prove the efficiency of their
32 application (Mcmenamin et al., 2014; Abudayyeh et al., 2017). Thus, in the present

1 study, 3DAMPL models and their X-ray images were applied in order to prove that
2 they are a reliable source of teaching material for the proposed theme.

3 The x-ray images of the 3DAMPL models were very similar to traditional x-
4 ray images; they showed each of the bones and their corresponding anatomical
5 structures, as well as changes that simulated osteoarthritis and anatomical deformities
6 in the patellofemoral joint, caused by the disease (Piermattei et al., 2006; Oliveira and
7 Tudury, 2016). This was extremely important for measurements and validation of the
8 models.

9 The presence of an articulated mechanism between the bones of the femur and
10 tibia made the 3DAMPL models more realistic and interesting for learners, because
11 their parts could be assembled and disassembled as well as handled to take different
12 positions. This mechanism was also essential at the time of reproduction of X-ray
13 images, because the ability of motion (extension, flexion and rotation) allowed the
14 3DAMPL models to take the most appropriate positions for X-ray imaging.

15 There are no studies to date that have cited X-ray imaging of 3D anatomical
16 models. Therefore, this study proposed the use of 3DAMPL models for the creation of
17 X-ray images, and this is a valuable step in the demonstration of pathological aspects
18 that are usually not often addressed in Applied Veterinary Anatomy classes.

19 It should be noted that the procedure in use has a distinctive approach, because
20 it takes the opposite path as advocated in most studies published previously, i.e., most
21 of them have reported the use of medical images for the production of 3D-printed
22 models (Ebert et al., 2011; Haspel et al., 2014; Kondo et al., 2015). Moreover, the
23 procedures described in the present study can be used as a valuable resource for
24 creating collections of teaching materials and, thus, provide educational institutions
25 with the possibility of compensating for possible deficiencies, or use them as an
26 additional resource in the classroom, hence improving the education of students and
27 the study of different diseases.

28 As cited by Preece et al. (2013), in several studies that have focused on the
29 development of new models for teaching, evaluations are usually based only on the
30 satisfaction of end users, but they do not present quantitative evidence to support the
31 real effectiveness of new models in the improvement of knowledge.

1 The general results of the evaluation provided evidence that the printed
2 3DAMPL models can be used as a complementary resource to teach Applied
3 Veterinary Anatomy effectively and increase the knowledge of learners, thus
4 corroborating the findings of the study by Lim et al. (2016), who also found a
5 significant effect on learning in a group of students who used 3D-printed materials.

6 Because students had already taken descriptive veterinary anatomy classes but
7 had not been, so far, acquainted with clinical medicine courses, they were expected to
8 have little or no previous knowledge about patellar luxation during the application of
9 the Pre-test and satisfactory knowledge of the anatomical structures that compose the
10 knee joint. However, the assumption about the students' knowledge of anatomy was
11 not confirmed, because the analysis showed a significant difference between the
12 groups during the Pre-test.

13 However, such difference may be due to the fact that the students had never
14 seen X-ray images and, therefore, they did not feel confident to identify anatomical
15 structures. This became clear because of the significant increase in the average number
16 of correct answers in the questionnaire and the balance represented by the similarity
17 of results between the groups after the classes.

18 The low mean number of correct answers for the items of radiographic findings
19 and classification of PL in both groups during the Pre-test confirmed the fact that the
20 students had little knowledge about the disease. This inference was further reinforced
21 during a survey carried out at the time of class, when most learners reported that they
22 were unaware of the disease.

23 After the classes were taught, it was found that the students gained some
24 knowledge about the disease, although not significantly. However, this was indicative
25 of increased knowledge about the subject. Therefore, it can be stated that the students
26 learned the content in a similar manner in the two groups.

27 The replacement of traditional X-ray images with 3DAMPL images did not
28 interfere in the way that the students learned about the subject. After the classes, there
29 were no significant differences between the groups, i.e., the students can study the
30 subject by looking at 3DAMPL images and then identify the disease in traditional X-
31 ray images.

1 The present results highlight the importance of the experiment conducted in
2 this study for the teaching and learning of Applied Veterinary Anatomy. It can be
3 concluded that highly-accurate teaching materials can be developed to bridge the gaps
4 found in medical and veterinary education which may make it difficult to explain
5 certain diseases. These materials can help students enter the labor market with a better
6 understanding of the morphological and functional aspects relative to the conditions
7 and organic abnormalities of the disease.

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CONCLUSION

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3 The development of the 3DAMPL models showed that economically viable
4 teaching materials can be designed for educational institutions, and they can represent
5 the main pathological aspects of a disease in a similar manner to traditional materials.
6 This radiological study and the 3DAMPL models provide an important educational
7 alternative, because they not only compensate for the lack of suitable physical models
8 for applied teaching but also ensure greater accessibility to different individuals, who
9 have their own way of perceiving and storing new information. Thus, better results are
10 achieved during the learning process.

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APÊNDICES

Apêndice A – Termo de consentimento livre e esclarecido – TCLE. modelos anatômicos 3D de luxação patelar e sua aplicação no ensino da medicina veterinária.

1. Apresentação

A pesquisa “**Modelos Anatômicos 3D de Luxação Patelar e sua Aplicação no Ensino da Medicina Veterinária**”, tem por objetivo “avaliar a utilização dos modelos anatômicos 3D da Luxação Patelar no processo de Ensino e aprendizagem em substituição aos métodos tradicionais utilizados nas disciplinas de Anatomia Patológica, Diagnóstico por Imagem e Clínica Cirúrgica do curso de Medicina Veterinária”. A população alvo é constituída por alunos de ambos os sexos, do Curso de Medicina Veterinária da Universidade Federal do Acre do município de Rio Branco, estado do Acre. Trata-se de uma pesquisa em nível de Dissertação de Mestrado, realizado pelo pesquisador Leonardo Kouri Albuquerque e seu orientador Professor Doutor Yuri Karaccas de Carvalho.

2. Esclarecimento

Esclarecemos que a sua participação, na pesquisa “Modelos Anatômicos 3D de Luxação Patelar e sua Aplicação no Ensino da Medicina Veterinária”, consiste em participar de aula teórico-prática e responder questionário pré e pós aula teórico-prática sobre a Luxação Patelar.

A participação do (a) aluno (a) é voluntária podendo desistir a qualquer momento, não havendo custos materiais ou financeiros para você ou para o (a) aluno (a), bem como não haverá remuneração pela participação do (a) aluno (a). Você poderá retirar seu consentimento em qualquer momento da realização da pesquisa, sem ter que justificar sua desistência e sem que sofra quaisquer tipos de coação ou penalidade por parte de seu professor e/ou dos pesquisadores.

Os riscos da pesquisa são mínimos, podendo ocorrer possíveis desconfortos emocionais por parte do (a) aluno (a). Esses desconfortos poderão ocorrer por ocasião da emissão das respostas às questões dos questionários ou em decorrência da participação na aplicação dos modelos, visto que podem sentir receio de externar suas percepções sobre a funcionalidade do modelo, utilizado como recursos didáticos durante os processos de ensino e aprendizagem dos conteúdos para os quais foram produzidos. Para minimizar e/ou excluir tais desconfortos, será solicitado ao (a) aluno (a) que não responda o questionário na sala de aula, leve-o para casa, não se identifique ao responder o questionário para garantir o anonimato da resposta e deposite o questionário respondido numa urna deixada no laboratório da pesquisa. Garantimos manter o mais amplo, absoluto e irrestrito sigilo profissional sobre a identidade do (a) aluno (a), durante e após o término da pesquisa. Desse modo, a identidade pessoal do (a) aluno (a) será excluída de todos e quaisquer produtos da pesquisa para fins de publicação científica.

Os possíveis benefícios o que o (a) aluno (a), terá com a pesquisa são que, ao utilizar o modelo anatômico experimentalmente, desenvolva aprendizagens significativas dos conteúdos curriculares para os quais o modelo anatômico foi elaborado.

Esclarecemos que os dados coletados por meio do questionário serão utilizados única e exclusivamente para produção do Relatório de Pesquisa e seus resultados serão publicados em meios de comunicação científica, tais como eventos científicos, livro e/ou revista acadêmica, sempre resguardando sua identidade.

Você receberá uma via deste Termo de Consentimento Livre e Esclarecido (TCLE), o qual terá as duas primeiras páginas rubricadas pelo pesquisador responsável e por você e a última página será assinada pelo pesquisador responsável e por você.

Para maiores informações e esclarecimentos sobre a pesquisa e/ou seus procedimentos, você poderá entrar em contato com o pesquisador responsável Leonardo Kouri Albuquerque, pelo telefone nº (68) 99220 4145 e e-mail leonardo_kouri@hotmail.com.

Por fim, eu, Leonardo Kouri Albuquerque, pesquisador responsável, declaro cumprir todas as exigências éticas contidas nos itens IV. 3, da Resolução CNS Nº 466/2012, durante e após a realização da pesquisa.

3. Consentimento

Eu,

RG Nº _____, CPF Nº _____._____._____-_____, declaro que: (a) li e compreendi o Termo de Consentimento Livre e Esclarecido (TCLE); (b) que a minha participação na pesquisa “**Modelos Anatômicos 3D de Luxação Patelar e sua Aplicação no Ensino da Medicina Veterinária**” é livre e espontânea; (c), não terei nenhum custo e nem serei remunerado pela participação; (d) posso retirar o consentimento e desistir a qualquer momento como participante da pesquisa, sem ter que justificar minha desistência e não sofrer qualquer tipo de coação ou punição. Diante do exposto, aponho minha rubrica nas duas primeiras páginas do TCLE e minha assinatura abaixo, como prova do meu Consentimento Livre e Esclarecido em permitir minha participação na pesquisa.

Rio Branco - Acre, _____ de _____ 2017.

Participante da Pesquisa

Leonardo Kouri Albuquerque
Pesquisador Responsável

Apêndice B – Avaliação da aplicação do modelo anatômico de luxação patelar.

Assinale (V) para afirmações verdadeiras e (F) para afirmações falsas:

ANATOMIA E ASPECTOS RADIOGRÁFICOS DO JOELHO

1. Na imagem radiográfica A há o mau alinhamento de uma ou mais estruturas ósseas da articulação do joelho.
2. Na imagem radiográfica E não é possível visualizar a Patela.
3. A imagem radiográfica B corresponde ao posicionamento Craniocaudal.
4. Na imagem radiográfica A é possível visualizar a Tuberossidade da Tíbia.
5. A imagem radiográfica D corresponde ao posicionamento Tangencial (Skyline).
6. A imagem radiográfica F corresponde ao membro pélvico esquerdo.
7. Na imagem radiográfica C é possível visualizar o Sulco Troclear.
8. A imagem radiográfica C corresponde ao posicionamento Médio-lateral.
9. A imagem radiográfica A corresponde ao membro pélvico direito.
10. A imagem radiográfica F apresenta a Tuberossidade da Tíbia em seu posicionamento anatômico normal.

ACHADOS RADIOGRÁFICOS DA LUXAÇÃO PATELAR

11. Na imagem radiográfica D é possível visualizar a Patela luxada.
12. Na imagem radiográfica B é possível visualizar grave deformidade no Sulco Troclear.
13. As imagens radiográficas B e E apresentam alterações anatômicas evidentes.
14. A imagem radiográfica A apresenta Luxação Patelar Lateral.
15. As imagens radiográficas A e D indicam Luxações reduzíveis.
16. A imagem radiográfica B apresenta Sulco Troclear pouco profundo.
17. As imagens radiográficas B e F indicam Luxações permanentes.
18. A imagem radiográfica B apresenta Sulco Troclear com deformidades leves.
19. A imagem radiográfica F apresenta Luxação Patelar Medial.

CLASSIFICAÇÃO DA LUXAÇÃO PATELAR

20. Na imagem radiográfica D o desvio da Tuberossidade da Tíbia pode estar entre 30° e 60°.
21. A imagem radiográfica C permite avaliar a profundidade do Sulco Troclear.
22. A imagem radiográfica B permite avaliar a largura do Sulco Troclear.
23. Na imagem radiográfica A o desvio da Tuberossidade da Tíbia pode estar entre 60° e 90°.
24. A imagem radiográfica C permite avaliar a angulação do Sulco Troclear.
25. As alterações anatômicas apresentadas na imagem radiográfica D corresponde ao Grau I da Luxação Patelar.
26. O desvio da Tuberossidade da Tíbia apresentado na imagem radiográfica F corresponde ao Grau III da Luxação Patelar.
27. Na imagem radiográfica A o desvio da Tuberossidade da Tíbia pode estar entre 15° e 30°.
28. A imagem radiográfica F corresponde ao Grau IV da Luxação Patelar.
29. A imagem radiográfica A corresponde ao Grau II da Luxação Patelar