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AVALIAÇÃO TRIDIMENSIONAL DAS EXTREMIDADES INFERIORES DE CRIANÇAS E ADOLESCENTES UTILIZANDO UM SISTEMA BIPLANAR DE RADIOGRAFIA DE BAIXA DOSE

Porto Alegre
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Tese de Doutorado apresentado ao curso de Pós-Graduação em Medicina/Pediatria e Saúde da Criança da Pontifícia Universidade Católica do Rio Grande do Sul, como parte dos requisitos necessários à obtenção do título de Doutor em Medicina/Pediatria.

Orientadores:

Prof. Dr. Matteo Baldisserotto

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Aprovada em: _____de_________________de_______.

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Porto Alegre

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RESUMO

Objetivos:

Avaliar as medidas tridimensionais(3D) das extremidades inferiores utilizando um sistema biplanar de baixa dose de radiação (LDX) em crianças e adolescentes.

Métodos:

Na primeira parte do estudo, medidas 3D de oito espécimes foram analisadas pelo LDX utilizando um programa estereoscópico e comparadas com medidas 3D da tomografia computadorizada (TC). Na segunda parte, 47 membros inferiores de crianças e adolescentes foram estudados utilizando medidas bi e tridimensionais. Foram avaliados: os comprimentos femoral e tibial, os ângulos mecânicos femoral e tibial, as angulações frontal e lateral do joelho e o ângulo cérvico-diafisário.

Resultados:

A comparação entre as medidas 3D pelo LDX e a TC dos espécimes não mostraram diferenças significativas:comprimento femoral (p: 0,069), comprimento tibial (p:0,059), ângulo femoral mecânico (p: 0,475), ângulo tibial mecânico (p: 0,067), angulação frontal do joelho (p: 0,198), angulação lateral do joelho (p: 0,646) e ângulo cérvico-diafisário (p: 0,068). A comparação entre as medidas bi e tridimensionais nos pacientes mostraram diferenças significativas no comprimento tibial (p: 0,003), ângulo femoral mecânico ($p<0.001$) e ângulo cérvico-diafisário (p: 0,001); os outros parâmetros não demonstraram alterações significativas.

Conclusões:

As medidas tridimensionais do LDX apresentam boa acurácia quando comparadas com as medidas tridimensionais da TC. Diferenças entre as medidas bi e tridimensionais do LDX foram observadas no comprimento tibial, ângulo femoral mecânico e ângulo cérvico-diafisário. Moderadas e boas concordâncias interobservadores foram encontradas para as medidas tridimensionais do LDX.

Palavras-chave: Tridimensional, Membros Inferiores, Medidas, Criança, Adolescente

ABSTRACT

Objectives:

To evaluate three-dimensional (3D) measurements of the lower extremity using a biplanar low-dose X-ray device in children and adolescents.

Methods:

In the first part of this study, 3D measurements of eight dried bones were analyzed by a biplanar low-dose X-ray device(LDX) using stereoscopic software and compared with 3D Computed Tomography (CT). In the second part, 47 lower limbs of children and adolescents were studied using LDX two-dimensional (2D) and 3D measurements. Both parts evaluated: femoral and tibial lengths, femoral and tibial mechanical angles, frontal and lateral knee angulations, and the femoral neck-shaft angle.

Results:

The 3D specimen comparison between LDX and CT measurements showed no significant differences: femoral length (p: 0.069), tibial length(p: 0.059), femoral mechanical angle (p: 0.475), tibial mechanical angle (p: 0.067), frontal knee angulation (p: 0.198), lateral knee angulation (p: 0.646) and femoral neck-shaft angle(p:0.068). The comparison between LDX 2D and 3D measurements in patients showed significant differences in tibial length (p: 0.003), femoral mechanical angle ($p<0.001$) and femoral neck-shaft angle (p: 0.001); other parameters were unremarkable.

Conclusions:

The 3D LDX system presented accurate measurements compared with 3D CT. Differences between LDX 2D and 3D measurements were noted in the femoral mechanical angle, femoral neck-shaft angle and tibial length. Moderate to good interobserver agreement for the 3D LDX measurements were found.

Keywords: Three-Dimensional, Lower Extremity, Measure, Children, Adolescent.

RÉSUMÉ

Objectifs:

Évaluer en trois dimensions (3D) les mesures du membre inférieur avec un appareil de radiographie biplanaire à faible dose (LDX) chez les enfants et les adolescents.

Méthodes:

Dans la première partie de cette étude, des mesures 3D de huit os secs ont été analysés par le LDX en utilisant un logiciel stéréoscopique et par une tomodensitométrie (TDM). Dans la deuxième partie, 47 membres inférieurs des enfants et des adolescents ont été étudiés à l'LDX à deux dimensions (2D) et 3D. Les deux parties ont évalué: longueurs du fémur et du tibia, les angles mécaniques fémoral et tibial, les angulations frontale et latérale du genou, et l'angle du col fémoral.

Résultats:

La comparaison entre les mesures 3D LDX et 3D TDM n'a pas montré de différences significatives: longueur fémorale (p: 0,069), longueur du tibia (p: 0,059), angle fémoral mécanique (p: 0,475), angle tibial mécanique (p: 0,067), angulation frontale du genou (p: 0,198), angulation latérale du genou (p: 0,646) et angle du col fémoral (p: 0,068). La comparaison entre des mesures LDX 2D et 3D chez les patients a montré des différences significatives dans la longueur tibiale (p: 0,003), les angles fémoral mécanique ($p < 0,001$) et du col fémoral (p: 0,001); les autres paramètres étaient superposables.

Conclusions:

Le système LDX a présenté des mesures 3D concordantes par rapport à la TDM. Des différences entre les mesures LDX 2D et 3D ont été relevées dans l'angle mécanique fémoral, l'angle du col fémoral et la longueur du tibia. La concordance interobservateur pour les mesures 3D LDX est modérée à bonne.

Mots-clés: Trois Dimensions, Membre Inférieur, Mesure, Enfant, Adolescent.

SUMÁRIO

CAPÍTULO I

APRESENTAÇÃO

JUSTIFICATIVA

OBJETIVOS

REFERÊNCIAS

1.1 APRESENTAÇÃO

Na presente tese estudei uma nova tecnologia para a avaliação radiológica do sistema musculoesquelético, ainda inexistente no Brasil, chamada EOS® (Fig. 1). Ela consiste num aparelho de radiografia de baixa dose que utiliza duas fontes ortogonais de radiação lineares e detectores. Um software desenvolvido pela própria empresa permite a obtenção de medidas e reconstruções tridimensionais para os membros inferiores (1).

Fig. 1. Aparelho de radiografia biplanar com baixa dose de radiação. ®

Além disso, essa modalidade pode e tem sido utilizada no estudo de outras partes do sistema musculoesquelético, como por exemplo a coluna vertebral. A radiação empregada por esse método é cerca de 8 – 10 vezes menor que uma radiografia convencional e aproximadamente 800 – 1000 vezes menor que a radiação utilizada para uma tomografia computadorizada gerar imagens tridimensionais (1).

Por se tratar de uma tecnologia recente, não existiam estudos clínicos em crianças e adolescentes, nem mesmo comparações entre medidas bi e tridimensionais dos membros inferiores nessa população. Assim, o objetivo da minha pesquisa foi o de avaliar as características das medidas tridimensionais dos membros inferiores de crianças e adolescentes (comprimento femoral e tibial, ângulos mecânicos femoral e tibial, angulações do joelho frontal e lateral e o ângulo cervico-diafisário) e comprovar a hipótese de que elas apresentam boa acurácia e precisão (2). Ao final da pesquisa foi demonstrado que o método apresenta boa acurácia e precisão. Esse foi o primeiro trabalho clínico publicado realizado com pacientes pediátricos envolvendo essa nova tecnologia.

A tese é composta por capítulos de: introdução (apresentação, justificativa e objetivos), desenvolvimento (artigos de revisão e original) e conclusão. Os artigos são intitulados:

Assimetria dos Membros Inferiores em Crianças – Como Avaliar

Avaliação Tridimensional das Extremidades Inferiores de Crianças e Adolescentes Utilizando um Sistema Biplanar de Radiografia de Baixa Dose.

1.2 JUSTIFICATIVA

A assimetria dos membros inferiores em crianças e adolescentes é uma das queixas mais comuns encontradas na prática ortopédica diária, seja ela estrutural ou funcional (3-5). O manejo terapêutico pode ser conservador ou cirúrgico, dependendo da etiologia e da predição do potencial de crescimento dos membros inferiores (6,7). Embora assimetrias pequenas não sejam clinicamente significativas, as maiores podem causar mudanças na marcha, mecanismos compensatórios e favorecer o surgimento de doenças degenerativas.

Além da busca por um método que apresente uma alta acurácia e precisão, em pacientes pediátricos é de fundamental importância a utilização de uma técnica que apresente baixa ou nenhuma radiação em virtude dos potenciais efeitos nocivos da radiação ionizante (8).

Até o presente estudo não havia na literatura estudos com pacientes pediátricos que comparassem medidas bi e tridimensionais na avaliação dos membros inferiores (2,4,9).

1.3 OBJETIVOS

Estudar membros inferiores de crianças e adolescentes para avaliar a acurácia e precisão das medidas tridimensionais.

Comparar as diferenças entre as medidas bi e tridimensionais em membros inferiores de crianças e adolescentes.

Avaliar a concordância interobservador no estudo das medidas tridimensionais.

1.4 REFERÊNCIAS

1. Dubousset J, Charpak G, Dorion I, Skalli W, Lavaste F, Deguise J, et al. [A new 2D and 3D imaging approach to musculoskeletal physiology and pathology with low-dose radiation and the standing position: the EOS system]. Bull. Acad. Natl. Med. 2005 fev;189(2):287–297; discussion 297–300.

2. Paley D, Pfeil J. [Principles of deformity correction around the knee]. Orthopade. 2000 jan;29(1):18–38.

3. Gurney B. Leg length discrepancy. Gait Posture. 2002 abr;15(2):195–206.

4. Knutson GA. Anatomic and functional leg-length inequality: a review and recommendation for clinical decision-making. Part I, anatomic leg-length inequality: prevalence, magnitude, effects and clinical significance. Chiropr Osteopat. 2005 jul 20;13:11.

5. Song KM, Halliday SE, Little DG. The effect of limb-length discrepancy on gait. J Bone Joint Surg Am. 1997 nov;79(11):1690–8.

6. Reynolds DA. Growth changes in fractured long-bones: a study of 126 children. J Bone Joint Surg Br. 1981 fev;63-B(1):83–8.

7. Shapiro F. Developmental patterns in lower-extremity length discrepancies. J Bone Joint Surg Am. 1982 jun;64(5):639–51.

8. Brink JA, Amis ES. Image Wisely: a campaign to increase awareness about adult radiation protection. Radiology. 2010 dez;257(3):601–2.

9. Sabharwal S, Kumar A. Methods for assessing leg length discrepancy. Clin. Orthop. Relat. Res. 2008 dez;466(12):2910–22.

CAPÍTULO II

ARTIGO DE REVISÃO

Lower Extremity discrepancy in Children – How to Evaluate

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Abstract

Evaluation of lower extremity discrepancy is of paramount importance when clinically significant, specially in children. Several approaches are found to perform these measures and each one presents its strong and weak points. The objective of this paper is to review the most significant methods for leg length measurement.

Introduction

Lower extremity discrepancies(LED) in the childhood are related to congenital malformations, growing disturbances, and trauma (1,2). When clinically relevant, they are associated with gait abnormalities and predisposition of degenerative diseases by affecting gait and running mechanics (3–7). A proper examination is fundamental for diagnosis, follow-up, and treatment (8).

Besides clinical examination, the assistant physician has a wide range of radiological methods to study this abnormality, such as conventional radiography, microdose radiography, computed tomography, ultrasound, magnetic resonance imaging, and low dose x-rays machines (2,4,9,10). To the best of our knowledge there are no reports dealing with a comprehensive review of the many radiological techniques available to evaluate lower extremity discrepancy focusing in children. The objective of this article is to describe and discuss the most significant imaging techniques for evaluating the lower limb in children, regarding mainly its accuracy, precision, and radiation dose.

Search Criteria

The Medline database was used to search all the articles. We used the following terms and combinations: lower limb, lower extremity, leg, discrepancy, evaluation, children, pediatric, tape measure, radiographic, orthoroentgenogram, teleoroentgenogram, scanogram, computed tomography, ultrasound, magnetic resonance. Articles focusing on etiology and treatment were excluded, as well as articles without english abstracts.

Diagnostic Methods

Clinical Methods

The tape measure is a clinical method to evaluate lower extremity discrepancy. The length of the lower limb, called true lower limb length, is measured between the anterior superior iliac spine and the medial malleolus. A variation of this technique, called apparent leg length, is measured from the pelvis to the bottom of the heel (4). Another method, called indirect, is the Standing on Blocks. It consists in measure an erect patient by placing blocks of known height under the short limb (4).

Radiological Methods

Plain Films/Digital Radiography

Conventional radiography was the first radiological method to evaluate the LED. It can be divided in three main techniques: orthoroentogenogram, scanogram and teleroentgenogram (Figure 1). The first one is obtained with 3 distinct AP (Anteroposterior) radiographic incidences centered in the hip, knee and ankle with one cassette, in order to minimize the effects of magnification. Scanogram, despite some controversies regarding the name, consists of three separate images, AP, centered in the hip, knee and ankle using three different cassettes, a radiopaque ruler between the limbs is used. Although these two previous techniques present low magnification, they are associated with a greater radiation dose (TBV). The last one, teleroentgenogram, is a single AP radiographic exposure, centered in the knee, of both lower limbs, using a single cassette. Even though this method uses a single exposure and have the potential of revealing more clinical information, it presents a considerable magnification error, around 4,5% (4).

In the last years computed radiography is gaining popularity. One of the advantages are the potentially dose reduction with fixed or automatically exposure control, the latter maintaining high image quality for the given technique. A similar approach is used in the scanogram (3 cassettes) and teleroentgenogram (1 cassette), with differences in the number of cassettes and exposures, three and one, respectively, and related to the electronic stitching. Besides, after the image acquisition the software is able to produce good quality images with a less radiation dose due to the electronic image enhancement, making this a valuable tool for pediatric patients (11,12).

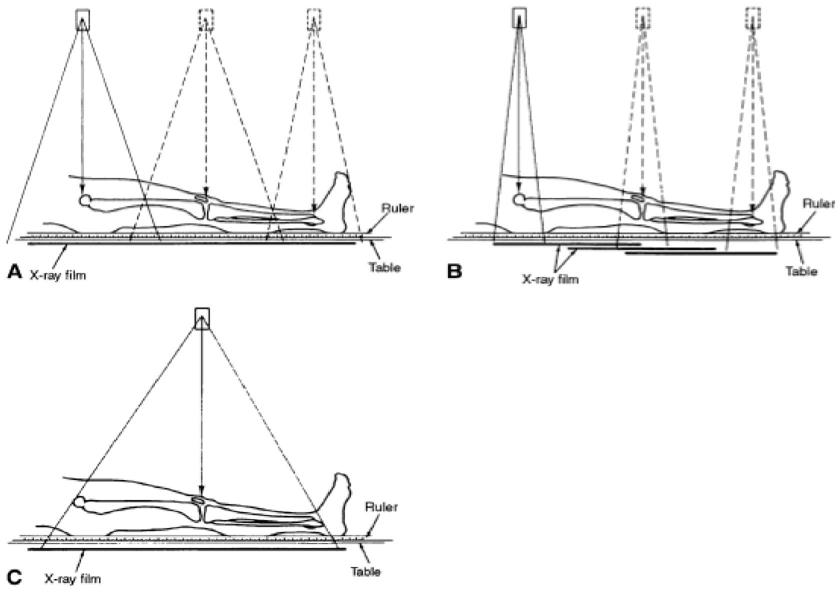

Figure 1. Three exemples of radiological methods described by Sabharwal *et al*. A: Orthoroentgenogram, B: Escanogram, C: Teleoroentgenogram.

Computed Tomography

Digital AP scout can also be used to evaluate bilaterally the femur and tibia. The cursor is measured from the top of the femoral head to the distal part of the medial femoral condyle and for the tibia, from the medial tibial plateau to the distal tibial plafond (Figure 3) (10). The scout image is a fast method to be obtained and evaluated and presents a low radiation dose, being specially indicated for children (4,10).

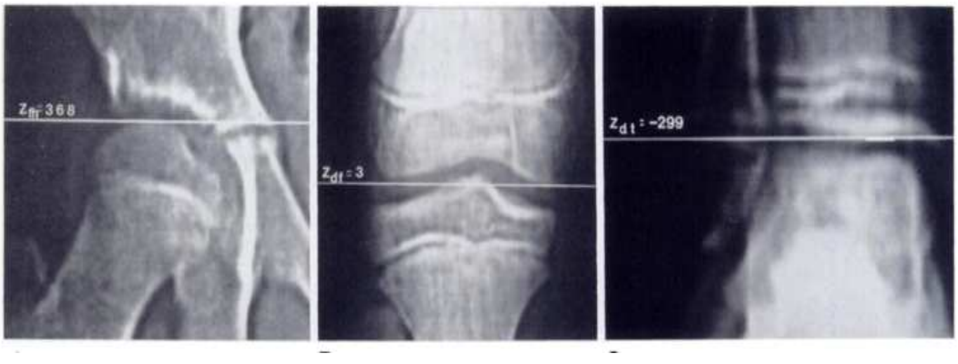

Figure 3: CT scout measurements, recommended by Aitken *et al*.

Biplanar x-ray device

In the past decade, another x-ray device was created to produce two and three dimensional images of bone structures and its measurements in a standing patient. It consists of a biplanar collimated horizontal beam, that moves from the feet to the head of the patient (13). A special software is used to obtain three dimensional reconstructions using modeling techniques, giving to the surgeons a more accurate evaluation of the lower limb, specially in flexion knee deformities (5,9). Besides, a different detector chamber allows the machine to use a very low radiation dose, about 8 to 10 times less than a conventional radiography (13).

Ultrasound

Ultrasound, with some specific accessories, can also be used to measure the lower limbs by identifying bony landmarks, such as the hip, knee and ankle joint (Figure 2) (14,15). This technique is free of ionizing radiation and can be performed in supine or upright position (14,15). With specialized softwares it is also possible to study torsion deformities (14,15).

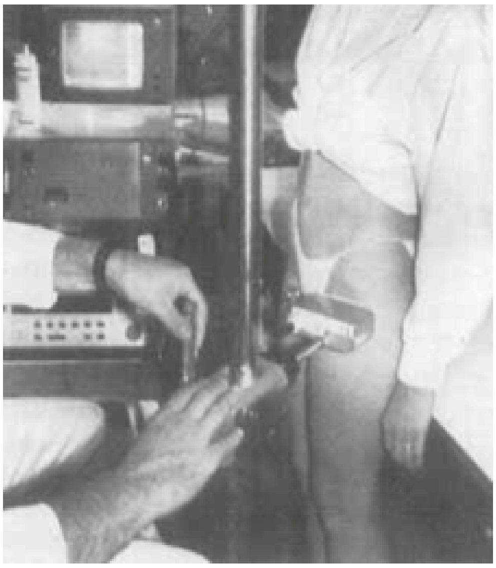

Figure 2: US method described by Terjersen *et al*.

Magnetic Resonance Imaging

Magnetic resonance imaging is another non-ionizing method that can be used to evaluate the LED. Using the same landmarks as the CT, the T1 sequence in the coronal plane is sufficient to perform the measurements (16). The majority of the commercially available machines were designed to work with a patient in supine position, creating some problems with the limb measurement, even with stitched softwares. Nevertheless, some new special models are capable of upright examinations (17).

Discussion

It is general agreement that the best choice for evaluating the lower limb in children is based in the accuracy, precision, radiation dose, machine characteristics, and patient limitations (18–20).

The tape measure is considered a quick and easy method for LED evaluation. Even though some studies presented a good concordance with the tape measure and the scout CT (ICC of 0.805 in a pediatric and adult population), problems can be seen in the differences between the girth of the lower limbs, identification of the bony prominences, angular deformities, anomalies concerning the foot, and muscular contractures around the hip and knee (4). In a study involving adults, considering the ICC, the interobserver agreement varied between 0.88 to 0.99, and the comparison with radiographic examination between 0.8 and 0.75, for the true and apparent lower limb length, respectively (4). Another study with adult subjects comparing the tape measure with radiography, using one and two clinical measurements found a correlation of 0.683 and 0.793, respectively, demonstrating the variation between the clinical measurements. However it should be noted that just 19 subjects were enrolled in this study - ten patients and nine asymptomatic persons (21). The standing on blocks method has a better correlation with radiographs than the tape measurement (16). A pediatric study that compared two clinical methods (tape method and standing block) with orthoroentgenograms in 190 children found that 95% of the standing blocks were within -

14 mm and +16 mm of the radiographic results, while the tape measure agreement was lower (4). Even with broad amplitude, this can be tolerated depending on what is the adopted cut off, which can varies from 5 to 22 mm, the latter not being very criticized. (21).

The most used and still recommended methods are the ones involving plain/digital radiographies (scanogram, teleroentgenogram, orthoroentgenogram). The reasons for its propagation are the ready available x-ray machines, the good accuracy and precision. Variations of the techniques are mainly related to the magnification error due to the parallax of the x-ray beam(specially for the teleroentgenogram) and lack of additional information (in the case of the scanogram), radiation exposure (specially for the orthoroentgenogram), and foot rotational effects (all of them) (4,11,22). A study found that both teleroentgenogram and scanogram present excellent interobserver ICC values, 0.968 and 0.979, respectively, indicating the use of the teleroentgenogram for patients with angular deformities that need a comprehensive evaluation (23). Differently from the study of Beattie et al, seventy patients were randomly chosen from 114 eligible ones, and 95 % of these patients evaluated by teleroentgenogram and scanogram presented a variation within 10 mm and 90% within 5 mm. Computed radiography can be applied to these techniques, reducing the radiation, specially for the digital teleroentgenogram (4).

Digital CT scout presents accuracy and interobserver agreements similar or superior to the orthoroentgenogram (10,24). The radiation dose received by a CT scout is 66 to 80% less than produced by the orthoroentgenogram (4,24). This method avoids error due to nonparallel positioning of the limb relative to the axis of the x-ray film and the radiolucent ruler, in the case of the scanogram (25). A pediatric study that evaluated the intraobserver and interobserver reliabilities demonstrated a difference of +- 7 mm for the total limb length (95% limit of agreement) and intraclass correlation coefficient of 0.96. This study presented some limitations regarding the number of patients, 26, and the use of professionals of different areas and levels of expertise for the measurements (five orthopedists, one resident orthopedist and one radiologist) (26). Nevertheless, they suggested that discordances of more than 1 cm should be made more than once to minimize the interpretation error (26). Other limitations of the scout technique are the absence of upright position and three dimensional evaluations. It is known that conventional axial CT can give us three dimensional reconstructions but, the radiation dose is considered high, specially for children.

Recently the low-dose radiation techniques are drawing attention as methods that present a low magnification rate, good accuracy and precision, such as the low-dose biplanar x-ray. However, these machines are still expensive and not immediately available. Still, the possibility of obtaining images in upright position and also three dimensional values, as in the case of the biplanar technique, makes this method very promising, specially in cases of rotational deformities and in patients who are unable to reach the near complete extension in upright position (9).

Lower extremity discrepancies evaluation can also be made with non-ionizing radiological methods, US and MR. The first one, US, is known to be an inexpensive method but, a trained radiologist is required to perform this kind of measurement (14). Terjesen et al, using ultrasound to evaluate 45 patients, children and adults with a mean age of 20 years old, found a 95% confidence interval of +- 7 mm (14). The second one, MRI, presents a hight cost and is time consuming (4,16). Considering both techniques, the main problems are related to the accuracy, which was shown to be lower than conventional radiological methods and CT scout (4,14,16,17,27). However, it should be pointed out that additional studies are required, since, with the exception of the paper published by Terjesen *et al*, all the others used just a small group of patients - five in the paper of Doyle *et al* and 15 in the work of Liodakis *et al* (14, 17, 26).

Given the great variety of the methods, a careful analysis should be made to offer the best diagnostic imaging for each patient, considering them individually (Table 1). Follow-up or diagnostic purposes should be taken in consideration, as well as safety, specially for the pediatric population (19,20).

Comparison between the most significant methods for evaluating LED

Methods	**Accuracy#**	**Precision##**	**Radiation Dose**	**Magnification**	**Weight Bearing**	**Availability**
Tape Measure	+	+	-	-	Yes	+++
Standing on Blocks	+	+	-	-	Yes	+++
Orthoroentgenogram	++	++	++	++	No	+++
Teleroentgenogram	++	+++	+	+++	Yes	++
Scanogram	+++	+++	++	++	Varies	+++
Digital Radiography	++	+++	+	++	Varies	++
Bi-Planar X-Ray Device	+++	+++	Minimal	Minimal	Yes	+
Computed Tomography*	+++	+++	+	Minimal	No	+++
Ultrasound**	+	++	-	-	Varies	+
Magnetic Resonance	++	++	-	-	Varies	++

Table 1. + = low degree, ,++ = moderate degree, +++ = high degree, * = scout CT, ** = ultrasound equipment with accessories for lower limb measurement, #: the degree to which a variable actually represents what is supposed to represent, ##: the degree to which a variable has nearly the same value when measured several times (28).

References

1. Shapiro F. Developmental patterns in lower-extremity length discrepancies. J Bone Joint Surg Am. 1982 jun;64(5):639–51.

2. Brunner R, Baumann JU. Three-dimensional analysis of the skeleton of the lower extremities with 3D-precision radiography. Arch Orthop Trauma Surg. 1998;117(6-7):351–6.

3. Song KM, Halliday SE, Little DG. The effect of limb-length discrepancy on gait. J Bone Joint Surg Am. 1997 nov;79(11):1690–8.

4. Sabharwal S, Kumar A. Methods for assessing leg length discrepancy. Clin. Orthop. Relat. Res. 2008 dez;466(12):2910–22.

5. Gurney B. Leg length discrepancy. Gait Posture. 2002 abr;15(2):195–206.

6. McCaw ST, Bates BT. Biomechanical implications of mild leg length inequality. Br J Sports Med. 1991 mar;25(1):10–3.

7. Shultz SJ, Nguyen A-D. Bilateral asymmetries in clinical measures of lower-extremity anatomic characteristics. Clin J Sport Med. 2007 set;17(5):357–61.

8. Siffert RS. Lower limb-length discrepancy. J Bone Joint Surg Am. 1987 set;69(7):1100–6.

9. Gheno R, Nectoux E, Herbaux B, Baldisserotto M, Glock L, Cotten A, et al. Three-dimensional measurements of the lower extremity in children and adolescents using a low-dose biplanar X-ray device. Eur Radiol [Internet]. 2011 out 20 [citado 2012 jan 18];Available from: http://www.ncbi.nlm.nih.gov/pubmed/22011904

10. Aitken AG, Flodmark O, Newman DE, Kilcoyne RF, Shuman WP, Mack LA. Leg length determination by CT digital radiography. AJR Am J Roentgenol. 1985 mar;144(3):613–5.

11. Sabharwal S, Zhao C, McKeon JJ, McClemens E, Edgar M, Behrens F. Computed radiographic measurement of limb-length discrepancy. Full-length standing anteroposterior radiograph compared with scanogram. J Bone Joint Surg Am. 2006 out;88(10):2243–51.

12. Kogutt MS. Computed radiographic imaging: use in low-dose leg length radiography. AJR Am J Roentgenol. 1987 jun;148(6):1205–6.

13. Dubousset J, Charpak G, Dorion I, Skalli W, Lavaste F, Deguise J, et al. [A new 2D and 3D imaging approach to musculoskeletal physiology and pathology with low-dose radiation and the standing position: the EOS system]. Bull. Acad. Natl. Med. 2005 fev;189(2):287–97; discussion 297–300.

14. Terjesen T, Benum P, Rossvoll I, Svenningsen S, Fløystad Isern AE, Nordbø T. Leg-

length discrepancy measured by ultrasonography. Acta Orthop Scand. 1991 abr;62(2):121–4.

15. Keppler P, Strecker W, Kinzl L, Simmnacher M, Claes L. [Sonographic imaging of leg geometry]. Orthopade. 1999 dez;28(12):1015–22.

16. Leitzes AH, Potter HG, Amaral T, Marx RG, Lyman S, Widmann RF. Reliability and accuracy of MRI scanogram in the evaluation of limb length discrepancy. J Pediatr Orthop. 2005 dez;25(6):747–9.

17. Doyle AJ, Winsor S. Magnetic resonance imaging (MRI) lower limb length measurement. J Med Imaging Radiat Oncol. 2011 abr;55(2):191–4.

18. Brink JA, Amis ES Jr. Image Wisely: a campaign to increase awareness about adult radiation protection. Radiology. 2010 dez;257(3):601–2.

19. Frush DP. Radiation, CT, and children: the simple answer is ... it's complicated. Radiology. 2009 jul;252(1):4–6.

20. Goske MJ, Applegate KE, Boylan J, Butler PF, Callahan MJ, Coley BD, et al. The Image Gently campaign: working together to change practice. AJR Am J Roentgenol. 2008 fev;190(2):273–4.

21. Beattie P, Isaacson K, Riddle DL, Rothstein JM. Validity of derived measurements of leg-length differences obtained by use of a tape measure. Phys Ther. 1990 mar;70(3):150–7.

22. Hunt MA, Fowler PJ, Birmingham TB, Jenkyn TR, Giffin JR. Foot rotational effects on radiographic measures of lower limb alignment. Can J Surg. 2006 dez;49(6):401–6.

23. Sabharwal S, Zhao C, McKeon J, Melaghari T, Blacksin M, Wenekor C. Reliability analysis for radiographic measurement of limb length discrepancy: full-length standing anteroposterior radiograph versus scanogram. J Pediatr Orthop. 2007 fev;27(1):46–50.

24. Aaron A, Weinstein D, Thickman D, Eilert R. Comparison of orthoroentgenography and computed tomography in the measurement of limb-length discrepancy. J Bone Joint Surg Am. 1992 jul;74(6):897–902.

25. Terry MA, Winell JJ, Green DW, Schneider R, Peterson M, Marx RG, et al. Measurement variance in limb length discrepancy: clinical and radiographic assessment of interobserver and intraobserver variability. J Pediatr Orthop. 2005 abr;25(2):197–201.

26. Poutawera V, Stott NS. The reliability of computed tomography scanograms in the measurement of limb length discrepancy. J Pediatr Orthop B. 2010 jan;19(1):42–6.

27. Liodakis E, Kenawey M, Doxastaki I, Krettek C, Haasper C, Hankemeier S. Upright MRI measurement of mechanical axis and frontal plane alignment as a new technique: a comparative study with weight bearing full length radiographs. Skeletal

Radiol. 2011 jul;40(7):885–9.

28. Zar JH. Biostatistical Analysis. 5º ed. Prentice Hall; 2009. p. 5.

CAPÍTULO III

ARTIGO ORIGINAL

Three-Dimensional Measurements of the Lower Extremity in Children and Adolescents Using a Low-Dose Biplanar X-Ray Device

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Abstract

Objective:

To evaluate three-dimensional (3D) measurements of the lower extremity using a biplanar low-dose X-ray device in children and adolescents.

Methods:

In the first part of this study, 3D measurements of eight dried bones were analyzed by a biplanar low-dose X-ray device(LDX) using stereoscopic software and compared with 3D Computed Tomography (CT). In the second part, 47 lower limbs of children and adolescents were studied using LDX two-dimensional (2D) and 3D measurements. Both parts evaluated: femoral and tibial lengths, femoral and tibial mechanical angles, frontal and lateral knee angulations, and the femoral neck-shaft angle.

Results:

The 3D specimen comparison between LDX and CT measurements showed no significant differences: femoral length (p:0.069), tibial length (p:0.059), femoral mechanical angle (p:0.475), tibial mechanical angle (p:0.067), frontal knee angulation(p:0.198), lateral knee angulation(p:0.646) and femoral neck-shaft angle (p:0.068). The comparison between LDX 2D and 3D measurements in patients showed significant differences in tibial length (p:0.003), femoral mechanical angle ($p<0.001$) and femoral neck-shaft angle (p:0.001); other parameters were unremarkable.

Conclusions:

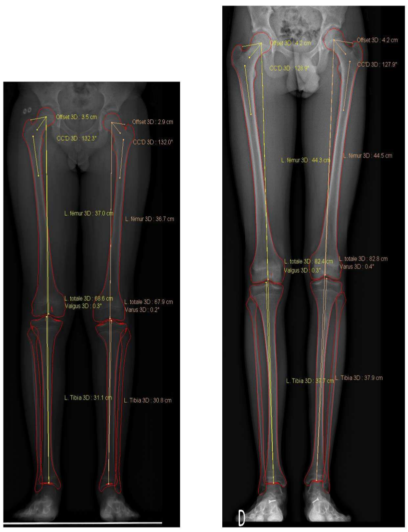
The 3D LDX system presented good accuracy when compared with 3D CT. Differences between LDX 2D and 3D measurements were noted in the femoral mechanical angle, femoral neck-shaft angle and tibial length. Moderate to good interobserver agreement for the 3D LDX measurements were found.

Keywords: three-dimensional, lower extremity, measure, children, adolescent.

Introduction

Leg-length discrepancy (LLD) in children and adolescents is one of the most common complaints encountered in the pediatric orthopedic practice. It may be structural (i.e. leg lengths are unequal and one leg is shorter or longer than the other) or functional (i.e. leg lengths are equal but one leg seems shorter or longer than the other). In structural LLD, the femur, tibia or both are shorter or longer in the affected extremity whereas in functional LLD, a tight or weak muscle as well as a tight joint is responsible for the asymmetry [1,2]. LLD is diagnosed clinically on the basis of medical history and physical examination and may be secondary to a variety of causes (congenital deformity, infection, trauma, skeletal dysplasia, and metabolic disease) [3-7]. Therapeutic management varies from conservative treatment to various surgical techniques, according to the aetiology of the LLD and, more importantly, to the leg-length prediction at skeletal maturity [6,8]. Minor discrepancies are frequently neglected as they have no known cause and tend to evolve favorably. By contrast, major discrepancies may cause gait deviations and long-term degenerative changes of the lower affected extremity and lumbar spine, and usually require both early diagnosis and regular monitoring for proper treatment [9,10]. Consequently, one must accurately quantify the LLD and identify possible associated structural abnormalities. These two needs are currently met with different imaging techniques, but conventional radiography is still the mainstay for primary evaluation of LLD and misalignment [4,9,11-15]. It is usually based on a full-length (from the hip to the ankle) standing (or supine) anteroposterior (AP) radiograph of the lower extremities (teleoroentgenogram), or on a combination of three separate exposures centered over the hip, knee, and ankle while the patient lays supine (orthoroentgenogram) [11,16]. However, these two-dimensional (2D) imaging methods are subject to error from possible torsional deformities and muscle contractures of the ipsilateral or contralateral lower limb, and both rely on careful positioning of the patient. Orthoroentgenography does not take into account effects of the pelvis or the foot on LLD, requires lack of motion of the patient between exposures, and is associated with greater radiation exposure compared to teleoroentgenography. This last method includes the pelvis and the foot but, this technique has more magnification error compared to orthoroentgenography [9]. More recently, other imaging investigations such as microdose digital radiography, computed tomography (CT) scanogram, ultrasound and magnetic resonance imaging have been used to measure LLD and reduce the amount of radiation exposure, but these techniques still await widespread use and adoption, and are unable to assess patients in the functional standing position [7,9,13,14,17, 18] . Moreover, unless additional lateral views are obtained, sagittal plane misalignment may be responsible for distorted measurements of LLD in the frontal plane.

In the past decade, a biplanar low-dose X-ray device (LDX), also called EOS® 2D/3D system (Biospace Imaging, Paris, France) was developed [19]. Using two orthogonal sources of radiation and linear detectors that are coupled together, this new imaging technique produces two orthogonal X-ray images of the lower limbs in standing position. Simultaneous capture of these two images allows the system to generate surface three-dimensional (3D) reconstructions and measurements of the lower limbs, with its sterEOS® 3D reconstruction software, and 2D measurements of the lower limbs automatically generated from 3D reconstructions (Fig. 1 a, b). This technique has proven to be very useful for studying the lower limbs and the spine [19-24]. In our institution it is used among other indications, for the evaluation of scoliosis and LLD. Moreover, the LDX system uses 8 to 10 times less radiation compared to conventional radiography and 800 to



1000 times less radiation, compared to 3D CT reconstructions [25].

Fig. 1a. 2D measurements derived from 3D reconstructions obtained with the LDX workstation in two patients, an 11-year (left) and an 15-year old boys (right).

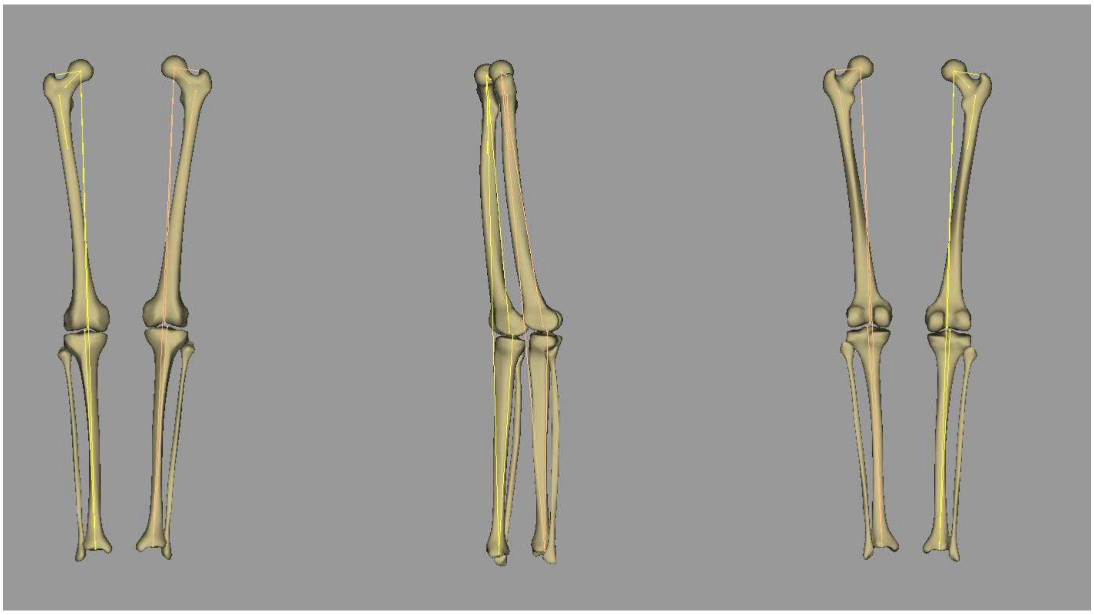


Fig. 1b. LDX 3D reconstructions in a 15-year-old boy on anterior (left), lateral (center) and posterior (right) perspectives.

To the best of our knowledge, there are no studies in the literature comparing 2D and 3D measurements of the lower limbs in children and adolescents. The purpose of this study was to evaluate LDX 3D measurements in terms of accuracy, precision, and differences when compared to 2D measurements.

Materials and Methods

This study was divided in two parts, a specimen study and a clinical study. The first part of the study evaluated the accuracy of 3D LDX measurements in dried bones, comparing the values obtained with the low-dose biplanar device with those obtained with 3D CT. The second part of the study consisted of a comparison between 3D LDX and 2D LDX measurements in a group of patients.

Specimen Study

Eight dried lower limbs that were obtained from an archaeological museum were used for the first part of the study. They were harvested from four adolescents and four adults and exhibited no gross abnormalities. For each specimen, the femur and tibia were attached to a plastic stand and to each other with a polymer foam, in order to maintain a fixed alignment between the bones (Fig. 2). The LDX system was used to evaluate the eight specimens as if they were in a standing position. Each of them was examined three times, in both frontal and lateral planes, with three different degrees of rotation (neutral, 10 degrees of internal rotation and 10 degrees of external rotation) so that a total of six AP and lateral X-rays were obtained for each specimen. The latter was then transferred to a dedicated workstation to perform 3D reconstructions and measurements of the femur and tibia, with sterEOS®, using statistical modeling and shape recognition techniques. Strictly following the guidelines of the manufacturer, the operator was asked to adjust precisely the position and shape of the different bone structures using specific points on the femoral head, the greater and lesser trochanters, the femoral diaphysis, the femoral condyles, the tibial plateaux and diaphysis, and the medial and lateral malleolus. The mean reconstruction time for each specimen took about 15 minutes.

Fig. 2. LDX images of an osseous specimen with unfused epiphyses used for comparison between LDX and CT measurements, in frontal (left) and lateral (right) views.

The measured parameters were chosen on the basis of their clinical significance and routine use, including the ones used in our institution [26-28]. They were the following: the femoral and tibial lengths, the femoral and tibial mechanical angles, the frontal (i.e.

valgus/varus) and lateral (i.e. *flessum/recurvatum*) leg angulations, and the femoral neck-shaft angle. All the points used for measurements were taken at the center of the anatomical structures. The femoral length was measured from the femoral head to the intercondylar fossa and the tibial length, from the intercondylar eminence to the inferior articular surface of the tibia. The femoral mechanical angle was defined as the angle between the femoral length line and another line parallel to the distal medial and lateral condyles. The tibial mechanical angle was defined as the angle between the tibial length line and another line parallel to the proximal medial and lateral condyles. The frontal knee angulation, used to evaluate *varus* or *valgus* angulation and also known as the hip-knee-ankle angle, was measured between a first line connecting the femoral head and the distal femoral epiphysis and a second line connecting the distal femoral epiphysis and the talar dome [28]. The lateral knee angulation, used to evaluate flexion or hyperextension (*recurvatum*) of the knee, was measured between a line connecting the femoral head to the intercondylar fossa and another line connecting the intercondylar eminence to the inferior articular surface of the tibia. The femoral neck-shaft angle was formed between the long axis of the femoral head and the proximal axis of the femoral diaphysis.

Multidetector CT (Siemens Sensation 64, Erlangen, Germany) was used thereafter to evaluate the eight lower limbs. Each specimen was examined with the following protocol: 140 kV, 46 mAs, and 0.75-mm collimation. Multiplanar 3-mm-thick reconstructions were obtained in order to perform 3D measurements, as previously described.

Clinical Study

After ethics committee approval, data from the Pediatric Radiology department were obtained 120 radiological examinations with the LDX, from March to October 2010. Following sample size calculation, 56 lower limbs, in 28 patients, were randomly chosen. Lower limbs that presented severe congenital malformations or surgical implants were excluded from the study, leaving 47 lower limbs (20 bilateral and 7 unilateral) to assess in 27 patients. From this sample, three main analyses were performed using the LDX system. The first one compared the differences between 2D and 3D measurements in coronal and sagittal planes. The second one assessed the influence of knee flexion or extension on measurements, dividing the patients in two groups: one with flexion or extension inferior to 5 degrees and another one with flexion or extension superior or equal to 5 degrees. A 5-degree limit enabled us to have a similar number of lower limbs in each group. The third one evaluated the interobserver agreement, since all measurements were done separately by two musculoskeletal radiologists, with 4 and 12 years of experience, respectively.

All patients were evaluated with the LDX system in both frontal and sagittal planes. They were examined in a standing position, with the right foot about 5 cm ahead, to avoid superposition of both limbs on the lateral X-ray image. AP and lateral X-ray images were transferred to the dedicated workstation to obtain surface 3D reconstructions of the lower extremities, and derived parameters. For each patient, the two musculoskeletal radiologists performed 3D reconstructions separately. After downloading AP and lateral X-ray images from the PACS system to their personal computers, both operators also measured separately the same 2D parameters using an imaging software (Osirix; The Osirix Foundation, Geneva, Switzerland).

Statistical Analysis

Statistical analysis was performed by a spreadsheet software (OpenOffice; Oracle, Redwood Shores, USA) and a statistical package software (PASW Statistics 18; SPSS, Chicago, USA). The Shapiro-Wilk test was applied to evaluate the normality of the distribution. For parametric data, the Student’s t test and the Pearson product-moment correlation coefficient (r) were used. For non-parametric data, the Wilcoxon signed-rank test, the Friedman’s test and the Spearman’s rank correlation coefficient (rs) were used. For all the measurements, significant results were set at $p < 0.05$, except for the interobserver agreement for which the Pearson and Spearman correlations were set at p: 0.01.

Results

Specimen Study

The mean value, range and standard deviation of each parameter are described in table 1. The comparison between LDX measurements (in neutral, internal and external rotations) and CT measurements (both non-parametric data) showed no statistical significant differences for the seven following parameters: the femoral length (p: 0.069), the tibial length (p: 0.059), the femoral mechanical angle (p: 0.475), the tibial mechanical angle (p: 0.067), the frontal knee angulation (p: 0.198), the lateral knee angulation (p: 0.646), and the femoral neck-shaft angle (p:0.068). Direct comparison between each LDX and CT measurement are shown in figure 3. When the seven LDX parameters were compared to each other (in neutral, internal and external rotation) in the eight specimens, no significant difference was found. The p values for each specimen were: 0.549 (specimen 1); 0.212 (specimen 2), 0.143 (specimen 3); 0.104 (specimen 4); 0.953 (specimen 5); 0.676 (specimen 6); 0.280 (specimen 7) and 0.607 (specimen 8).

Mean, standard deviation (SD) and range of specimen 3D measurements with LDX and computed tomography (CT)

		FL (cm)	TL (cm)	FMA (°)	TMA (°)	FKA (°)	LKA (°)	FNSA (°)
	Mean	37,0	33,2	92,4	88,9	178,9	170,8	123,4
EOS	SD	1,8	3,0	1,7	2,2	8,0	4,0	4,5
	Range	34 – 39.6	29 – 38.1	90 – 95	85 – 94	165 – 191	166 – 182	115 – 129
	Mean	36,7	33,1	91,4	90,9	181,6	170,4	120,5
CT	SD	2,3	2,9	4,2	3,2	7,2	3,8	5,2
	Range	33.2 – 40.1	28.8 – 38	84 – 97	86 – 97	169 – 190	164 – 175	115 – 130

Table 1. FL: femoral length, TL: tibial length, FMA: femoral mechanical angle, TMA: tibial mechanical angle, FKA: frontal knee angulation, LKA: lateral knee angulation, FNSA: femoral neck-shaft angle. cm: centimeters; °: degre es

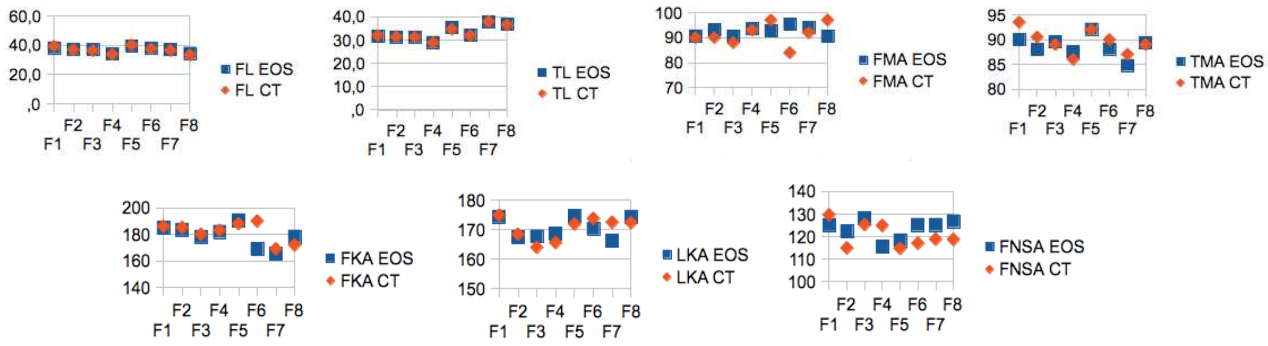


Fig. 3. Direct comparison between each LDX and CT measurements in the specimens. FL: femoral length, TL: tibial length, FMA: femoral mechanical angle, TMA: tibial mechanical angle, FKA: frontal knee angulation, LKA: lateral knee angulation, FNSA: femoral neck-shaft angle. F1 to F8: each one represents one anatomic specimen.

Clinical Study

The clinical study included 13 male and 14 female patients. The mean age of the patients were 13.56 +- 1.95 years (range: 11 – 17 years). The most common clinical indications were lower limb asymmetry (21%), epiphysiodesis (10%), Legg-Calvé-Perthes disease (6%) and *pes planus* (6%). The others (57%) presented with *genu valgum/varum*, metabolic diseases, *talipes equinovarus*, previous fracture, congenital hip dislocation, and infection. The average absorbed radiation dose for each examination was 1756.47 +- 486.4 mGy.cm^2 (range: 734.16 – 2665.43 mGy.cm^2).

The mean value, range and standard deviation of clinical measurements are described in table 2. A non-Gaussian distribution was found for all parameters, except for the tibial mechanical angle and the lateral knee angulation. Comparison between 2D LDX and 3D LDX measurements showed statistically significant differences in tibial length (p: 0.003), femoral mechanical angle ($p < 0.001$), and femoral neck-shaft angle ($p < 0.001$). The femoral length (p: 0.267), frontal knee angulation (p: 0.725), tibial mechanical angle (p: 0.342), and lateral knee angulation (p: 0.101) presented unremarkable “p” values (Figure 4).

Mean, standard deviation (SD) and range of clinical measurements in three (3D) and two (2D) dimensions

		FL (cm)	TL (cm)	FMA (°)	TMA (°)	FKA (°)	LKA (°)	FNSA (°)
	Mean	29,2	30,4	75,9	72,5	149,1	145,1	104,0
3D	SD	15,2	22,9	49,6	50,2	65,8	64,0	45,8
	Range	36.1 – 45.2	30.8 – 39.9	90 – 98	82 – 96	174 – 187	168 – 192	105 – 138
	Mean	28,4	35,8	84,8	78,2	160,4	152,7	105,7
2D	SD	14,9	27,6	54,0	37,4	57,7	54,9	37,7
	Range	36 – 45	30.8 – 39.4	91 – 100	83 – 96	174 – 186	167 – 192	119 – 145

Table 2. FL: femoral length, TL: tibial length, FMA: femoral mechanical angle, TMA: tibial mechanical angle, FKA: frontal knee angulation, LKA: lateral knee angulation, FNSA: femoral neck-shaft angle.

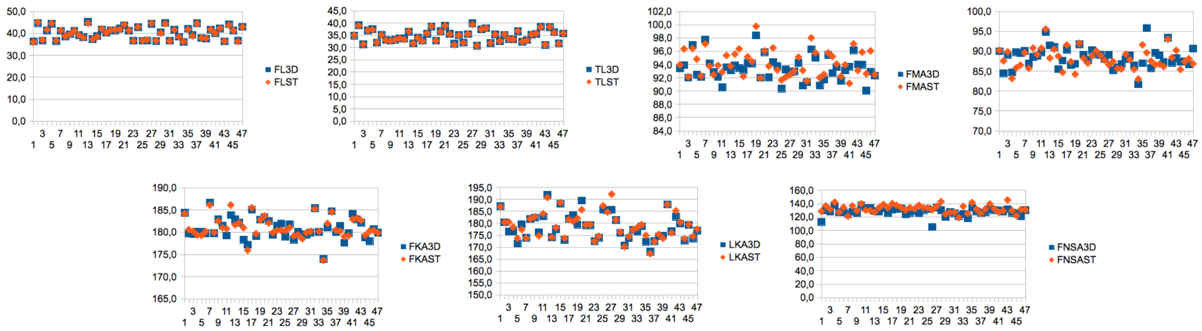


Fig. 4. Comparison between 2D and 3D measurements in the patients. FL: femoral length, TL: tibial length, FMA: femoral mechanical angle, TMA: tibial mechanical angle, FKA: frontal knee angulation, LKA: lateral knee angulation, FNSA: femoral neck-shaft angle. Numbers 1 to 47 represents each patient.

Regarding the influence of knee flexion/extension on measurements, the Wilcoxon test revealed statistically significant differences both in femoral mechanical and femoral neck-shaft angles. However, the femoral and tibial lengths showed no statistically significant differences when the degree of flexion/extension was less than five (p: 0.213 and 0.053 respectively), but significant differences when the degree of flexion/extension was five or more (p: 0.020 and 0.011). The other parameters (i.e. the tibial mechanical angle and the frontal and lateral knee angulations) remained unchanged whatever the degree of flexion/extension.

Interobserver agreement for 3D measurements showed strong statistically significant correlations for the femoral length (rs: 0.991), the tibial length (r: 0.996), the frontal knee angulation (r: 0.823), and the lateral knee angulation (rs:0,964). Moderate agreement was found for the tibial mechanical angle (r: 0,609), the femoral mechanical angle (r: 0.660), and femoral neck-shaft angle assessment (rs: 0.666). (Fig. 4)

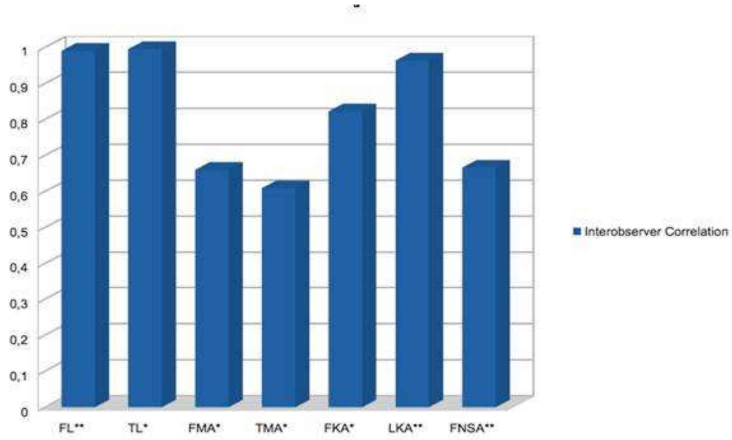


Fig. 4. Interobserver correlation of the three-dimensional measurements using Pearson(*) and Spearman(**) tests. FL: femoral length, TL: tibial length, FMA: femoral mechanical angle, TMA: tibial mechanical angle, FKA: frontal knee angulation, LKA: lateral knee angulation, FNSA: femoral neck-shaft angle.

Discussion

Lower limb alignment is commonly assessed two-dimensionally by imaging. However, it is determined by the geometry of the femur and the tibia as well as by the spatial relationship between these two bones [29]. Therefore, 3D evaluation of lower extremity alignment, especially in the weight-bearing standing position, may provide more precise information related to both normal and abnormal alignment. Besides, when alignment is abnormal, a better understanding of the 3D geometry of the lower extremity can be especially important, not just for planning surgery but also for better understanding long-term secondary degenerative diseases [13,29].

In the past years, different techniques were developed for 3D evaluation of the spine, the pelvis or for all or part of the lower extremity, using radiation devices such as X-rays and CT, in combination with specialized imaging softwares [13,29-33]. Some of them were specially designed to obtain precise 3D measurements before surgery [13,31,34]. However, factors related to complexity of these techniques, reproducibility and accessibility could impede their use in daily practice. Moreover, a technique like CT cannot be performed in standing position, is limited to short bone segments and requires a high dose of radiation. With its ability to capture X-ray images in a weight-bearing position with a lower dose of radiation than with conventional X-ray radiography and to visualize the lower limbs in 3D, the LDX system may be useful in better assessing lower limb alignment. Therefore, the first part of our study, the specimen part, was aimed to validate LDX 3D measurements, using CT as the gold standard. Our results confirmed the good accuracy of these measurements since no statistically significant differences were found between the two techniques. Previous studies achieved similar conclusions regarding the reproducibility of the LDX system [19,24]. In addition, in our study, the 3D parameters evaluated by the LDX system in different degrees of rotation (i.e. internal, neutral and external) showed no statistically significant differences among them. This is especially relevant when we know that both internal and external rotations can affect 2D measurements on conventional radiographs [35]. The second part of our study, the clinical one, was conducted on patients to compare 2D with 3D measurements of the lower limbs. Statistically significant differences were found regarding the tibial length, the femoral mechanical angle, and the femoral neck-shaft angle. Differences in terms of tibial length can be explained by the degree of knee flexion/extension. Using lateral scout CT scanograms in cadavers, Aaron et al. reported similar findings in 2D measurements of the tibial length and the total limb length when the knee was flexed [7]. Differences in terms of femoral mechanical and femoral neck-shaft angles are presumably related to the degree of femoral rotation, another parameter that is considered to be a source of error in lower limb measurements. Regarding interobserver concordance, we found a strong agreement for linear LDX measurements, such as the femoral and tibial lengths. However, agreement was ranged from moderate to strong for the angles (frontal and lateral knee angulation, femoral mechanical angle, tibial mechanical angle, and femoral neck-shaft angle), as reported in the literature [36].

Besides the accuracy and precision, it should be stressed that one of the main advantages of the LDX 2D/3D system is the low dose of radiation delivered to patients in comparison with conventional radiographic techniques and CT. Upright MRI is capable of provide 2D and even 3D weight-bearing measurements without ionizing radiation, but the time-consuming and underestimation of the limb length are considerable disadvantages

[18]. This radiation exposure has been under debate for some time, but recently it has gained particular attention in the pediatric population in which concepts like “Image Gently” are being applied. “Image Gently” consists in special children's protocols that are aimed to reduce the amount of radiation [37-39]. This is of paramount importance when a regular follow-up is necessary, like in some cases of lower limb misalignment.

Both our specimen and clinical studies presented limitations. First, the small sample size of the specimen study and its heterogeneity should be mentioned. Second, some of the p values were close to the pre-defined cutoff (0.05); a bigger sample might however contribute in the future to a better understanding of the results. Third, the LDX semi-automated method of surface 3D reconstruction relies on anatomical landmarks being manually identified, which may lead to more errors than 3D CT reconstructions. Moreover, a small number of machines are currently available due to its cost and recent clinical utilization.

In summary, the objective of the present study was to evaluate the characteristics of a biplanar low-dose X-ray 2D/3D system for quantifying LLD. The specimen study showed similar 3D measurements, both with LDX and CT, attesting the good accuracy of the method. The clinical study showed that 3D parameters like the tibial length, the femoral mechanical angle and the femoral neck-shaft angle may be significantly different from corresponding 2D parameters, when 3D measurements are used. As 3D measurements provide us more precise information than 2D measurements, we believe that this technique may be a useful and reliable tool in the assessment of lower extremity alignment in children and adolescents, especially when patients present with significant knee flexion/extension or with rotational deformities. However, further clinical studies are clearly required; first, to determine normal 3D values in children and adolescents and second, to better evaluate young children with partially ossified epiphyses that are still difficult to assess with current softwares.

Bibliography

1. Gurney B (2002) Leg length discrepancy. Gait Posture 15(2):195-206

2. Knutson GA (2005) Anatomic and functional leg-length inequality: a review and recommendation for clinical decision-making. Part I, anatomic leg-length inequality: prevalence, magnitude, effects and clinical significance. Chiropr Osteopat 20;13:11

3. Shapiro F (1982) Developmental patterns in lower-extremity length discrepancies. J Bone Joint Surg Am 64(5):639-651

4. Sabharwal S, Zhao C, McKeon JJ, McClemens E, Edgar M, Behrens F (2006) Computed radiographic measurement of limb-length discrepancy. Full-length standing anteroposterior radiograph compared with scanogram. J Bone Joint Surg Am 88(10):2243-2251

5. Reynolds DA (1981) Growth changes in fractured long-bones: a study of 126 children. J Bone Joint Surg Br 63-B(1):83-88

6. Siffert RS (1987) Lower limb-length discrepancy. J Bone Joint Surg Am 69(7):1100-1106

7. Aaron A, Weinstein D, Thickman D, Eilert R (1992) Comparison of orthoroentgenography and computed tomography in the measurement of limb-length discrepancy. J Bone Joint Surg Am 74(6):897-902

8. Paley D, Gelman A, Shualy MB, Herzenberg JE (2008) Multiplier method for limb-length prediction in the upper extremity. J Hand Surg Am 33(3):385-391

9. Sabharwal S, Kumar A (2008) Methods for assessing leg length discrepancy. Clin Orthop Relat Res 466(12):2910-2922

10. Song KM, Halliday SE, Little DG (1997) The effect of limb-length discrepancy on gait. J Bone Joint Surg Am 79(11):1690-1698

11. Werlang HZ, Oliveira GA, Tamelini AM, Madalosso BH, Júnior F da SM (2007) Escanometria dos Membros Inferiores: Revisitando Dr. Juan Farill. Radiol Bras 40(2):137-141

12. Delialioglu MO, Tasbas BA, Bayrakci K, Daglar B, Kurt M, Agar M, et al (2006) Alternative reliable techniques in femoral torsion measurement. J Pediatr Orthop B 15(1):28-33

13. Henckel J, Richards R, Lozhkin K, Harris S, Baena FMR y, Barrett ARW, et al (2006) Very low-dose computed tomography for planning and outcome measurement in knee replacement. The imperial knee protocol. J Bone Joint Surg Br 88(11):1513-1518

14. Aitken AG, Flodmark O, Newman DE, Kilcoyne RF, Shuman WP, Mack LA (1985) Leg length determination by CT digital radiography. AJR Am J Roentgenol 144(3):613-615

15. Kogutt MS (1987) Computed radiographic imaging: use in low-dose leg length

radiography. AJR Am J Roentgenol 148(6):1205-1206

16. Terjesen T, Benum P, Rossvoll I, Svenningsen S, Fløystad Isern AE, Nordbø T (1991) Leg-length discrepancy measured by ultrasonography. Acta Orthop Scand 62(2):121-124

17. Liodakis E, Kenawey M, Doxastaki I, Krettek C, Haasper C, Hankemeier S (2011) Upright MRI measurement of mechanical axis and frontal plane alignment as a new technique: a comparative study with weight bearing full length radiographs. Skeletal Radiol. 40(7):885-88919.

18. Dubousset J, Charpak G, Dorion I, Skalli W, Lavaste F, Deguise J, et al (2005) [A new 2D and 3D imaging approach to musculoskeletal physiology and pathology with low-dose radiation and the standing position: the EOS system]. Bull Acad Natl Med 189(2):287-297

19. Rousseau M-A, Laporte S, Chavary-Bernier E, Lazennec J-Y, Skalli W (2007) Reproducibility of measuring the shape and three-dimensional position of cervical vertebrae in upright position using the EOS stereoradiography system. Spine 32(23):2569-2572

20. Deschênes S, Charron G, Beaudoin G, Labelle H, Dubois J, Miron M-C, et al (2010) Diagnostic imaging of spinal deformities: reducing patients radiation dose with a new slot-scanning X-ray imager. Spine 35(9):989-994

21. Rillardon L, Campana S, Mitton D, Skalli W, Feydy A (2005) [Evaluation of the intervertebral disc spaces with a low dose radiographic system]. J Radiol 86(3):311-319

22. Azmy C, Guérard S, Bonnet X, Gabrielli F, Skalli W (2010) EOS orthopaedic imaging system to study patellofemoral kinematics: assessment of uncertainty. Orthop Traumatol Surg Res 96(1):28-36

23. Chaibi Y, Cresson T, Aubert B, Hausselle J, Neyret P, Hauger O, et al (2011) Fast 3D reconstruction of the lower limb using a parametric model and statistical inferences and clinical measurements calculation from biplanar X-rays. Comput Methods Biomech Biomed Engin. doi: 10.1080/10255842.2010.540758

24. Ohl X, Stanchina C, Billuart F, Skalli W (2010) Shoulder bony landmarks location using the EOS low-dose stereoradiography system: a reproducibility study. Surg Radiol Anat 32(2):153-158

25. Cooke TDV, Sled EA, Scudamore RA (2007) Frontal plane knee alignment: a call for standardized measurement. J Rheumatol 34(9):1796-1801

26. Paley D, Pfeil J (2000) [Principles of deformity correction around the knee]. Orthopade 29(1):18-38

27. Sabharwal S, Zhao C (2009) The hip-knee-ankle angle in children: reference values based on a full-length standing radiograph. J Bone Joint Surg Am 91(10):2461-2468

28. Ariumi A, Sato T, Kobayashi K, Koga Y, Omori G, Minato I, et al (2010) Three-dimensional lower extremity alignment in the weight-bearing standing position in healthy elderly subjects. J Orthop Sci 15(1):64-70

29. Berthonnaud E, Hilmi R, Dimnet J (2009) Personalized models of bones based on radiographic photogrammetry. Surg Radiol Anat 31(6):461-470

30. Chauhan SK, Clark GW, Lloyd S, Scott RG, Breidahl W, Sikorski JM (2004) Computer-assisted total knee replacement. A controlled cadaver study using a multi-parameter quantitative CT assessment of alignment (the Perth CT Protocol). J Bone Joint Surg Br 86(6):818-823

31. Kadoury S, Cheriet F, Laporte C, Labelle H (2007) A versatile 3D reconstruction system of the spine and pelvis for clinical assessment of spinal deformities. Med Biol Eng Comput 45(6):591-602

32. Pomero V, Mitton D, Laporte S, de Guise JA, Skalli W (2004) Fast accurate stereoradiographic 3D-reconstruction of the spine using a combined geometric and statistic model. Clin Biomech (Bristol, Avon) 19(3):240-247

33. Schlatterer B, Suedhoff I, Bonnet X, Catonne Y, Maestro M, Skalli W (2009) Skeletal landmarks for TKR implantations: evaluation of their accuracy using EOS imaging acquisition system. Orthop Traumatol Surg Res 95(1):2-11

34. Hunt MA, Fowler PJ, Birmingham TB, Jenkyn TR, Giffin JR (2006) Foot rotational effects on radiographic measures of lower limb alignment. Can J Surg 49(6):401-406

35. Cooke TDV, Sled EA (2009) Optimizing limb position for measuring knee anatomical axis alignment from standing knee radiographs. J Rheumatol 36(3):472-477

36. Goske MJ, Applegate KE, Boylan J, Butler PF, Callahan MJ, Coley BD, et al (2008) The Image Gently campaign: working together to change practice. AJR Am J Roentgenol 190(2):273-274

37. Frush DP (2009) Radiation, CT, and children: the simple answer is ... it's complicated. Radiology 252(1):4-6

38. Brink JA, Amis ES (2010) Image Wisely: a campaign to increase awareness about adult radiation protection. Radiology 257(3):601-602

CAPÍTULO IV

CONCLUSÕES

4.1 CONCLUSÕES

As medidas tridimensionais avaliadas pelo sistema de baixa dose de radiação apresentaram dados confiáveis quando comparadas com as da tomografia computadorizada.

O comprimento femoral, ângulo mecânico tibial e as angulações frontal e lateral do joelho não apresentaram diferenças estatisticamente significativas entre as medidas bi e tridimensionais, diferentemente do ângulo femoral mecânico, ângulo cérvico-diafisário e o comprimento tibial, sendo esse último observado somente quando o grau de flexão do joelho foi superior a cinco graus.

A concordância interobservador variou de moderada(ângulos mecânicos femoral e tibial e ângulo cérvico-diafisário) à alta (comprimento femoral, tibial, angulações frontal e lateral do joelho).