DOI: http://dx.doi.org/10.1590/1413-785220223006e256112

RADIOGRAPHIC STUDY OF THE MEDIAL JOINT SPACE OF THE HIP IN LEGG-CALVÉ-PERTHES DISEASE

ESTUDO RADIOGRÁFICO DO ESPAÇO ARTICULAR MEDIAL DO QUADRIL NA DOENÇA DE LEGG-CALVÉ-PERTHES

Rene Dujardin[1], *Diego Praxedes de Miras*[1], *Caio Falk Giannotti*[1], *Roberto Bezerra Nicolau*[1], *Eiffel Tsuyoshi Dobashi*[1]

1. Universidade Federal de São Paulo, Paulista School of Medicine, Department of Orthopedics and Traumatology, São Paulo, SP, Brazil.

ABSTRACT

Objective: To evaluate medial joint space in affected and normal contralateral hips in patients with Legg-Calvé-Perthes disease (LCPD). Methods: To compare joint space, femoral head extrusion (FHE), medial space coefficient (MSC) of the hip, and femoral head width (FHW) in affected and normal hips, using 127 radiographs of patients with unilateral LCPD and considering age groups under and over six years old as well as their disease stage. Results: No statistically significant differences were observed regarding MSC between normal and affected hips regardless of disease staging. However, medial joint distance was significantly greater in affected hips than in normal hips. In the necrosis and fragmentation phase, distance from medial space in affected hips was significantly greater than in contralateral normal hips. Comparing only affected hips, MSC and FHW showed statistically significant differences and the group > 6 yo presented higher values. Among normal hips, the group < 6 yo presented a statistically significant difference considering the MSC and FHW. Conclusions: No statistically significant difference was found between the medial joint space of affected and normal hips, except for early stages of the disease (necrosis and fragmentation). The isolated use of radiographic study is insufficient in LCPD and the lack of complementation with other exams, such as magnetic resonance, can delay diagnosis of and onset of treatment for the disease. ***Level of Evidence III, Study of Non Consecutive Patients; without Consistently Applied Reference "Gold" Standard.***

Keywords: Legg-Calvé-Perthes Disease. Radiography. Classification. Child.

RESUMO

Objetivo: Avaliar o espaço articular medial entre o quadril afetado e o contralateral normal em pacientes com doença de Legg-Calvé-Perthes (DLCP). Métodos: Comparação do espaço articular, da extrusão da cabeça femoral (ECF), do coeficiente do espaço medial do quadril (CEM) e da largura da cabeça femoral (LCF) entre quadris afetados e normais a partir de 127 radiografias de pacientes com DLCP unilateral. Foram consideradas faixas etárias maiores e menores de 6 anos e o estágio evolutivo da doença. Resultados: Na comparação dos lados normal e afetado, independentemente da fase da doença, não se observou diferença estatisticamente significativa quanto ao CEM. Contudo, a distância articular medial no quadril afetado foi significantemente maior que a do quadril normal. Na fase de necrose e fragmentação, a distância do espaço medial dos quadris afetados foi significativamente maior em comparação aos contralaterais. Entre os quadris afetados, o CEM e a LCF apresentaram diferenças estatisticamente significantes, sendo que o grupo com idade > 6 anos apresentou valores maiores. Nos quadris normais, observou-se diferença estatisticamente significante do CEM e da LCF no grupo com idade < 6 anos. Conclusões: Não foi observada diferença estatisticamente significante quanto ao espaço articular medial entre quadril afetado e quadril normal, exceto nas fases iniciais da doença (necrose e fragmentação). O uso isolado do estudo radiográfico mostra-se insuficiente na DLCP, de forma que a falta de complementação com outros instrumentos, como a ressonância magnética, pode retardar o diagnóstico e, consequentemente, o início do tratamento. ***Nível de Evidência III, Estudo de Pacientes Não Consecutivos; sem Padrão de Referência "Ouro" Aplicado Uniformemente.***

Descritores: *Doença de Legg-Calvé-Perthes. Radiografia. Classificação. Criança.*

Citation: Dujardin R, Miras DP, Giannotti CF, Nicolau RB, Dobashi ET. Radiographic study of the medial joint space of the hip in Legg-Calvé-Perthes disease. Acta Ortop Bras. [online]. 2022;30(6): Page 1 of 5. Available from URL: http://www.scielo.br/aob.

INTRODUCTION

Since its description in 1910, Legg-Calvé-Perthes disease (LCPD) has always stimulated interest among researchers, being one of the subjects with the most controversies in the orthopedic literature. Considering the aspects of imaging diagnosis, for a long time authors focused on analyzing radiographic aspects. The evolutionary phases of the disease were first described by Waldenström, whose

All authors declare no potential conflict of interest related to this article.

The study was conducted at Pediatric Orthopedics Outpatient Clinic of Hospital São Paulo, Paulista School of Medicine, Universidade Federal de São Paulo.
Correspondence: Diego Praxedes de Miras. Rua Borges Lagoa, 980, apt 45, São Paulo, SP, Brazil, 04038002. diegopraxedes07@gmail.com

Article received on 09/06/2021, approved on 11/01/2021.

classification was later simplified and correlated with Jonsäter's pathological findings.[1] Catterall then systematized the assessment of the involvement of the femoral head (FH) ossification center based on the maximum fragmentation phase. To determine the proportions of the lesion in its initial or necrosis phase, Salter and Thompson showed that the size of the subchondral fracture in the incidence of the head profile could accurately reflect how much the disease affected the proximal femoral epiphysis (PFE).[2] More recently, Herring[3] proposed a classification based on the height of the lateral column of the femoral epiphysis.

Since the growing hip presents a cartilaginous mold that is not visible by plain radiography, only pneumoarthrography (PAG) or Magnetic Resonance Imaging (MRI) would allow early recognizing changes in the shape of the head and femoral extrusion.[4]

The thickness of the hyaline cartilage of the FH, recognized virtually by conventional radiography as joint space, varies according to the growth of children. A reduction of this gap is a direct indication of joint disease and occurs in several arthritic hip disorders.[5] In LCPD, an increase in the joint space, especially in the early stages of the disease, indicates tapering of the articular cartilage of the FH. Less commonly, the occurrence of a chondrolysis, especially in the more severe forms of LCPD, indicates a great reduction of the medial space.

These concepts are considered essential for understanding the disease and indicating treatment. The preservation of the spherical form of the FH is known to minimize the risk of secondary degenerative hip osteoarthritis in adulthood.[6]

In the orthopedic literature, few studies discuss the importance of the joint space, especially of its medial aspect of the coxofemoral joint in LCPD observed by radiographic analysis. This study thus aimed to measure medial joint distance in hips affected by unilateral LCPD and compare the values obtained with contralateral hips unaffected by the disease. We also sought to verify if this radiographic parameter is correlated with the extrusion of the PFE or patients' age at the occurrence of the disease.

METHODS

This research project was submitted to the Research Ethics Committee of Plataforma Brasil and approved for execution under no. CAAE 53730316.6.0000.5625.

Patients and/or their guardians signed an informed consent form to participate in the study.

Radiographic images of 127 patients affected by LCPD from the Outpatient Clinic of the Pediatric Orthopedics Discipline of the Department of Orthopedics and Traumatology of EPM-UNIFESP were unilaterally assessed. The material was collected from 1996 to 2008. Of all patients studied, 96 (75.6%) were male and 31 (24.4%) were female. The mean age of patients was 7.3 years (ranging from three to 16 years). Regarding the affected side, 68 (53.5%) had a compromised right hip and 59 (46.5%) had the left hip compromised.

This study's patient inclusion criteria were:

- Patients with unilateral LCPD.
- Adequate and well-defined radiographic documentation.
- Patients not submitted to surgical treatment.
- Skeletal immaturity.

The study's exclusion criteria were as follows:

- Patients with bilateral LCPD.
- Incomplete or poor quality radiographic documentation.
- Patients submitted to surgical treatment.
- Skeletal maturity.

Radiographs were classified according to Waldenström criteria modified by Jonsäter and divided into necrosis, fragmentation, reossification, and definitive phases. Therefore, 55 (43.31%) hips were categorized in the necrosis phase, 42 (33.07%) in fragmentation, 21 (16.53%) in reossification, and nine (7.09%) in the definitive phase (Chart 1).

Parameters used for the study were the relationships of the measurements obtained on pelvis radiographs in the anteroposterior incidence of patients (Figure 1).

The relationships of the medial space, the subluxation of the FH, and the size of the femoral head of both hips were assessed by estimating the following coefficients:

- Coefficient of medial space of the affected hip (CMSA): BD/CD.
- Extrusion of the FH of the affected hip (EFHA): AC/AB
- Width of the FH of the affected hip (WFHA): AD-AC
- Coefficient of medial space of the normal hip (CMSN): EG/EF
- Normal FH extrusion (NFHE): FH/GH
- Normal FH width (NFHW): EH-EF

Methodology for data analysis

A professional specialized in medical statistics evaluated the results using Spearman's correlation coefficient and the nonparametric Wilcoxon and Mann-Whitney test to compare the measurements of normal and affected hips. All tests were applied considering the significance level of 5% and significant values were marked with the symbol (*).

Chart 1. Distribution of the 127 patients affected by Legg-Calvé-Perthes disease according to Waldenström's classification of the evolutionary phases modified by Jonsäter.

Evolutionary phase	Patients	Variable	Minimum	Maximum	Mean	p
Necrosis	55	normal hip	0.10	0.50	0.25	0.047
		affected hip	0.06	0.33	0.22	
Fragmentation	42	normal hip	0.09	0.44	0.21	0.790
		affected hip	0.08	0.33	0.22	
Reossification	21	normal hip	0.10	0.85	0.26	0.079
		affected hip	0.11	0.31	0.21	
Definitive	9	normal hip	0.11	0.33	0.20	0.767
		affected hip	0.13	0.34	0.21	

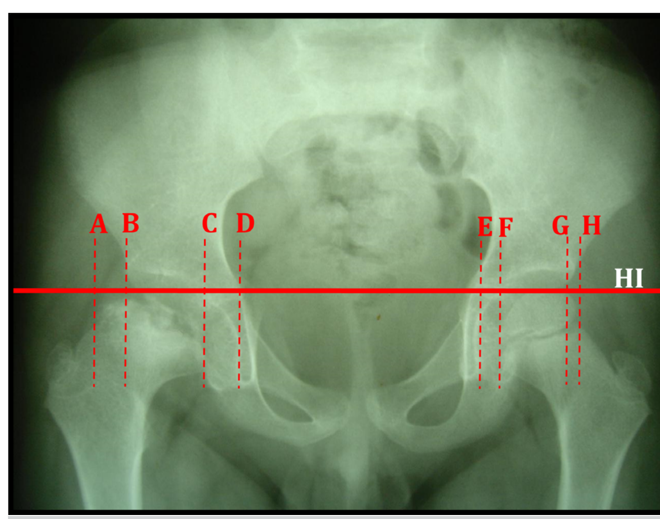

Figure 1. Pelvis radiography showing the references used to estimate the measurements studied in the LCPD.

HILG: Hilgenreiner's line; A: line perpendicular to Hilgenreiner's line crossing the lateral edge of the PFE of the affected hip; B: line perpendicular to Hilgenreiner's line crossing the lateral edge of the affected hip acetabulum; C: line perpendicular to Hilgenreiner's line crossing the medial edge of the PFE of the affected hip; D: line perpendicular to Hilgenreiner's line crossing the medial edge of Köhler teardrop of the affected hip; E: line perpendicular to Hilgenreiner's line crossing the medial edge of Köhler teardrop of the normal hip; F: line perpendicular to Hilgenreiner's line crossing the medial edge of the PFE of the normal hip; G: line perpendicular to Hilgenreiner's line crossing the lateral edge of the normal hip acetabulum; H: line perpendicular to Hilgenreiner's line crossing the lateral edge of the PFE of the normal hip. Measurements obtained from the affected hip: AB: extrusion of the PFE of the affected hip; AC: width of the PFE of the affected hip; CD: medial joint space of the affected hip. Measurements obtained from the normal hip: EF: medial joint space of the normal hip; FH: PFE width of the normal hip; GH: PFE extrusion of the normal hip.

RESULTS

The Wilcoxon test showed no significant differences between normal and affected sides regardless of the evolutionary phase of the disease. However, medial joint distance was significantly higher in the affected hip than in the normal hip (p = 0.025*).

Table 1 shows that in the NECROSIS phase, the distances of the medial space of the hips affected by LCPD present no statistically significant difference. The distances of the medial space of the hips of the normal contralateral side also showed no statistically significant difference. Moreover, the distances of the medial space in hips affected by LCPD were statistically significant and higher than in hips of the contralateral side unaffected by the disease (p = 0.047*). In the FRAGMENTATION phase, distances of the medial space of the hips affected by LCPD showed a statistically significant difference (p = 0.001*). However, no statistically significant differences were found among the hips unaffected by the disease and between the affected and normal sides. In the REOSSIFICATION and DEFINITIVE phases, no statistically significant differences were found among the affected and unaffected hips and between the affected and normal sides.

Table 2 shows the results of the evaluation between the medial space coefficient, FH extrusion, and FH width of the hips affected by LCPD considering the age groups < 6 years and > 6 years after applying the Mann-Whitney nonparametric test. Analysis of the CMSA shows a statistically significant difference among age groups, with the group aged > 6 years presenting significantly higher values (p = 0.025*). No statistically significant difference was observed between the two groups regarding EFHA (p = 0.170). The groups presented statistically significant differences regarding WFHA, with the group aged > 6 years presenting significantly higher values (p = 0.012*). Among unaffected hips, groups presented a statistically significant difference regarding CMSN, with the group aged < 6 years presenting higher values (p < 0.001*). The groups also showed a statistically significant difference regarding NFHW, with the group aged < 6 years presenting higher values (p = 0.006*). No statistically significant difference was observed between the two groups regarding NFHE, with p = 0.810 (Table 3).

Table 1. Comparison of the coefficient of medial space according to disease phase (Wilcoxon parametric test).

Phase	Variable	n	Mean	SD	Minimum	Maximum	P25	Median	P75	p
Necrosis	CD	55	2.04	1.24	0.40	4.00	0.70	2.4	3.00	0.543
	EF	55	2.06	1.05	0.50	4.00	1.00	2.20	3.00	
	Normal side relationship	55	0.25	0.10	0.01	0.50	0.15	0.25	0.30	0.047 (*)
	Affected side relationship	55	0.22	0.06	0.09	0.33	0.17	0.22	0.26	
Fragmentation	CD	42	1.55	1.24	0.40	4.50	0.60	0.80	2.80	0.001 (*)
	EF	42	1.80	1.24	0.40	4.50	1.00	1.05	3.00	
	Normal side relationship	42	0.21	0.09	0.09	0.44	0.15	0.18	0.27	0.790
	Affected side relationship	42	0.22	0.07	0.08	0.33	0.16	0.22	0.27	
Reossification	CD	21	2.25	1.32	0.50	4.00	0.70	2.80	3.40	0.226
	EF	21	2.13	0.98	0.50	3.5	1.10	2.50	3.00	
	Normal side relationship	21	0.26	0.15	0.10	0.85	0.18	0.22	0.30	0.079
	Affected side relationship	21	0.21	0.05	0.11	0.31	0.17	0.20	0.24	
Definitive	CD	9	1.52	1.37	0.40	3.5	0.55	0.70	3.25	0.361
	EF	9	1.68	1.17	0.50	3.7	0.75	1.30	2.90	
	Normal side relationship	9	0.20	0.07	0.11	0.33	0.13	0.18	0.26	0.767
	Affected side relationship	9	0.21	0.08	0.13	0.34	0.15	0.16	0.30	

CD: medial joint space of the affected hip; EF: medial joint space of the normal hip; n: number of cases; SD: standard deviation; p: result of the statistical calculation.

Table 2. Evaluation of the coefficient of the medial space, extrusion of the femoral head, and width of the femoral head of the hips affected by Legg-Calvé-Perthes disease considering the age groups < 6 years and > 6 years after applying the Mann-Whitney nonparametric test.

Variable	Group	n	Mean	SD	Minimum	Maximum	P25	Median	P75	p
CMSA	Up to six years old	41	3.79	1.48	1.39	9.33	2.91	3.56	4.57	0.026 (*)
	Over six years old	65	4.38	1.59	1.88	9.80	3.36	4.05	5.13	
EFHA	Up to six years old	41	38.01	83.33	– 28.00	280.00	4.75	9.45	20.00	0.170
	Over six years old	65	17.37	47.19	– 5.00	290.00	3.78	6.33	13.10	
WFHA	Up to six years old	41	3.68	1.62	2.55	10.66	2.80	3.15	3.7	0.012 (*)
	Over six years old	65	4.19	1.67	2.30	10.33	3.05	3.8	4.93	

Table 3. Evaluation of the coefficient of medial space, extrusion of the femoral head, and width of the femoral head of the normal hips considering the age groups < 6 years and > 6 years after applying the Mann-Whitney nonparametric test.

Variable	Group	n	Mean	SD	Minimum	Maximum	P25	Median	P75	p
CMSN	Up to six years old	41	3.63	1.29	1.18	8.00	2.82	3.30	4.57	< 0.001 (*)
	Over six years old	65	4.53	1.20	1.18	8.00	3.67	4.56	5.00	
NFHE	Up to six years old	41	22.45	59.49	– 6.50	290.00	4.16	6.00	9.68	0.810
	Over six years old	65	15.09	47.34	– 25.00	280.00	3.69	7.00	10.34	
NFHW	Up to six years old	41	3.31	1.42	1.24	8.47	2.35	2.70	4.14	0.006 (*)
	Over six years old	65	4.10	1.62	1.24	10.20	2.70	4.13	5.43	

DISCUSSION

In LCPD, the bone part of the PFE undergoes several alterations in its medullary part, that can be recognized radiographically a few weeks after the disease onset, and in its trabecular arrangement after the onset of ischemia.[7]

Throughout this condition, the PFE could contain viable bone tissue interwoven with the necrotic bone. Therefore, radiographic staging cannot be properly performed during the first weeks after the initial FH infarction[8], postponing treatment.[9]

Our findings showed that in the early stages of the disease, even plain radiography indicated a lateral subluxation of the FH evidenced by the increased medial joint space considering the epiphysis and acetabulum. Flattening the PFE could also increase this virtual radiographic space.

These alterations were recognized statistically in the necrosis and fragmentation phases of LCPD, indicating FH deformity since the initial phases of the disease. Although many authors consider FH extrusion as extremely important to predict the risk of and indicate treatment for degenerative osteoarthritis, our findings showed no direct relationship between this variable and medial joint space. The increase of the medial space was statistically significant in the affected hips.

The extent of the FH deformity in LCPD is considered a determining factor to establish a long-term prognosis. A serial analysis of the radiographs indicates a progressive deformation of the PFE from the early stages of the disease. However, the hyaline cartilage of the FH is damaged a few days after the occurrence of arterial insufficiency, leading to its hypertrophy. Importantly, such structural modification can only be analyzed by an examination that can directly visualize the cartilaginous tissue, as in MRI.[10,11]

Since radiographic analysis is insufficient, assessment of cartilaginous structures should indicate the disease phase and treatment more accurately.[12] Accordingly, the incipient knowledge of changes in the cartilaginous molds of the PFE and acetabulum results in limited conclusions and sometimes equivocal interpretations to radiographic examinations when trying to establish the actual position of the FH in relation to the acetabulum.

The most studied radiographic alterations in LCPD include FH deformation and enlargement, adductor brevis with trochanteric overgrowth, acetabular dysplasia, joint incongruity, and FH extrusion.[13]

Among these, some authors consider that the two most important prognostic radiographic parameters are femoral head deformation and joint incongruity.

However, other authors argue that radiographic examination alone is insufficient to assess the compromised coxofemoral joint, whereas MRI, PAG, or tomography could be useful to show subtle changes in form and phenomena, such as femoroacetabular impingement.[14,15]

Our study found no statistically significant increase in the medial joint space of the affected hip in relation to the normal hip among the evolutionary phases of the disease.

However, our analysis showed that the medial joint space of the affected hips is larger than that of the normal contralateral side. This could be related to the progressive deformation of the femoral head associated or not with PFE extrusion.

Some studies using MRI examinations found an increase in medial joint space.[16] According to these studies, enlargement at an early stage results from a proliferation of PFE chondrocytes without its due endochondral ossification of the secondary nucleus which suffered circulatory damage.[17] This proliferation would also occur in the hyaline cartilage of the acetabulum. Furthermore, this cartilaginous thickening in the active phases of LCPD would be transitory since it does not occur in the more advanced phases of the disease.

Vijayan et al.[5] showed that several patients affected by LCPD undoubtedly had an increased joint space which persisted until skeletal maturity, especially when the hips were classified as belonging to classes III, IV, and V according to Stulberg, Cooperman and Wallensten.[18] The authors also found a relationship regarding the increase in the joint space between the acetabulum and the FH in all its joint extension determined by the magnification of the PFE determined by coxa magna. They also suggested that hypertrophy of the entire proximal femoral complex could cause articular cartilaginous enlargement, being directly related to the poor prognosis of individuals affected by this disease.

Our sample included patients exclusively with skeletal immaturity. Regarding age groups, some authors consider that the age limit for indication of conservative treatment is six years old. We observed that the medial space of the hips affected by the disease was higher in children over six years old, suggesting more severe hip deformity in this age group. Among the hips unaffected by LCPD, the age group under six years old had greater medial space and FH width, which we considered as a physiological condition.

Regardless of our results, we believe that many variables must be researched, even when reporting to radiographic examination. Moreover, further biomechanical, biochemical, and anatomical studies are needed to better understand medial space in LCPD and determine the best treatments and results for the disease after its healing phase.

CONCLUSIONS

Although conventional radiography remains the main instrument for diagnostic aid and follow-up of LCPD evolution, applying this method without other radiological examinations is insufficient, delaying the diagnosis and onset of treatment of the disease.

Accordingly, this study found no statistically significant differences regarding medial space coefficient ($p = 0.087$) among the normal and affected sides regardless of the evolutionary phase of LCPD. In the necrosis phase, however, this relationship was statistically significant (Table 1). In the fragmentation phase, distances of the medial space of the hips affected by LCPD presented a statistically significant difference ($p = 0.001^*$).

The hips affected by LCPD also presented a statistically significant difference for CMSA, with the group aged > 6 years presenting significantly higher values ($p = 0.025^*$). The groups also presented statistically significant differences regarding WFHA, with the group aged > 6 years presenting significantly higher values ($p = 0.012^*$). No statistically significant difference was observed between the two groups regarding EFHA, with $p = 0.170$ (Table 2).

Evaluation of the normal hips showed a statistically significant difference for CMSN among groups, with the group aged < 6 years presenting significantly higher values ($p < 0.001^*$). The groups also showed statistically significant differences regarding NFHW, with the group aged < 6 years presenting significantly higher values ($p = 0.006^*$). No statistically significant difference was observed between the two groups regarding NFHE, with $p = 0.810$ (Table 3).

AUTHORS' CONTRIBUTIONS: Each author contributed individually and significantly to the development of this article. RD, DPM, CFG, RBN: data acquisition, writing of the study, and critical review; ETD: substantial contribution in the study conception or design and approval of the final version of the manuscript.

REFERENCES

1. Hyman JE, Trupia EP, Wright ML, Matsumoto H, Jo CH, Mulpuri K, et al. Interobserver and intraobserver reliability of the modified Waldenström classification system for staging of Legg-Calvé-Perthes disease. J Bone Joint Surg Am. 2015;97(8):643-50.
2. Kitoh H, Kitakoji T, Katoh M, Takamine Y. Delayed ossification of the proximal capital femoral epiphysis in Legg-Calvé-Perthes' disease. J Bone Joint Surg Br. 2003;85(1):121-4.
3. Herring JA. The treatment of Legg-Calve-Perthes disease. A critical review of the literature. J Bone Joint Surg Am. 1994;76(3):448-58.
4. Zenios M, Hutchinson C, Galasko CS. Radiological evaluation of surgical treatment in Perthes' disease. Int Orthop. 2001;25(5):305-7.
5. Vijayan S, Mehta O, Jacob G, Siddesh ND, Shah H, Joseph B. The fate of the joint space in Legg-Calvé-Perthes' disease. Skeletal Radiol. 2013;42(3):341-5.
6. Podeszwa DA, DeLaRocha A. Clinical and radiographic analysis of Perthes deformity in the adolescent and young adult. J Pediatr Orthop. 2013;33 Suppl 1:S56-61.
7. Larson AN, Sucato DJ, Herring JA, Adolfsen SE, Kelly DM, Martus JE, et al. A prospective multicenter study of Legg-Calvé-Perthes disease: functional and radiographic outcomes of nonoperative treatment at a mean follow-up of twenty years. J Bone Joint Surg Am. 2012;94(7):584-92.
8. Shah H, Siddesh ND, Pai H, Tercier S, Joseph B. Quantitative measures for evaluating the radiographic outcome of Legg-Calvé-Perthes disease. J Bone Joint Surg Am. 2013;95(4):354-61.
9. Kim HKW. Pathophysiology and new strategies for the treatment of Legg-Calvé--Perthes disease. J Bone Joint Surg Am. 2012;94(7):659-69.
10. Siddesh ND, Shah H, Tercier S, Pai H, Nair S, Joseph B. The sphericity deviation score: a quantitative radiologic outcome measure of Legg-Calvé Perthes disease applicable at the stage of healing and at skeletal maturity. J Pediatr Orthop. 2014;34(5):522-8.
11. Kumasaka Y, Harada K, Watanabe H, Higashihara T, Kishimoto H, Sakurai K, Kozuka T. Modified epiphyseal index for MRI in Legg-Calve-Perthes disease (LCPD). Pediatr Radiol. 1991;21(3):208-10.
12. Lobert PF, Dillman JR, Strouse PJ, Hernandez RJ. Unexpected MRI findings in clinically suspected Legg-Calvé-Perthes disease. Pediatr Radiol. 2011;41(3):369-73.
13. Sugimoto Y, Akazawa H, Mitani S, Tanaka M, Nakagomi T, Asaumi K, Ozaki T. Lateral and posterior pillar grade changes during the treatment of Perthes disease in older patients using skin traction and range of motion exercises. Arch Orthop Trauma Surg. 2006;126(2):101-4.
14. Shohat N, Copeliovitch L, Smorgick Y, Atzmon R, Mirovsky Y, Shabshin N, et al. The long-term outcome after varus derotational osteotomy for Legg--Calvé-Perthes disease: a mean follow-up of 42 years. J Bone Joint Surg Am. 2016;98(15):1277-85.
15. Stepanovich M, Upasani VV, Bomar JD, Wenger DR. Advanced containment with triple innominate osteotomy in Legg-Calve-Perthes disease: a viable option even in severe cases. J Pediatr Orthop. 2017;37(8):563-9.
16. Lecuire F. The long-term outcome of primary osteochondritis of the hip (Legg-Calvé-Perthes' disease). J Bone Joint Surg Br. 2002;84(5):636-40.
17. Kamegaya M, Morita M, Saisu T, Kakizaki J, Oikawa Y, Segawa Y. Single versus combined procedures for severely involved Legg-Calvé-Perthes disease. J Pediatr Orthop. 2018;38(6):312-9.
18. Stulberg SD, Cooperman DR, Wallensten R. The natural history of Legg-Calvé--Perthes disease. J Bone Joint Surg Am. 1981;63(7):1095-108.