Pathological gait in children with Legg-Calvé-Perthes disease and proposal for gait modification to decrease the hip joint loading

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Abstract

Purpose Legg-Calvé-Perthes disease (LCP) severely limits the range of hip motion and hinders a normal gait. Loading of the hip joint is a major consideration in LCP treatment. The aim of this study was to evaluate gait patterns in LCP and identify gait modifications to decrease the load on the affected hip.

Methods Forty children with unilateral LCP were divided into three groups based on the time base integral of the hip abductor moments during single stance on the affected side acquired during instrumented 3D gait analysis. X-rays of the affected hip were classified according to Herring and Catterall.

Results Children in the “unloading” group spontaneously adopted a Duchenne-like gait with pelvis elevation, hip abduction and external rotation during single support phase. The “normal-loading” group showed pelvis elevation with a neutral hip position in the frontal plane. In the “overloading” group the pelvis dropped to the swinging limb at the beginning of stance accompanied by prolonged hip adduction. The time base integral of the hip abductor

moments during single stance correlated positively with the X-ray classifications of Herring and Catterall, hip abduction angle and age. Older children preferred to walk in hip adduction during single stance, had more impaired hips and tended to overload them.

Conclusion The hip overloading pattern should be avoided in children with LCP. Gait training to unload the hip might become an integral component of conservative treatment in children with LCP.

Introduction

Legg-Calvé-Perthes disease (LCP) is a syndrome in which an avascular event affects the capital physis (head) of the femur. It is more common in boys, and the onset of the disease usually occurs between five and eight years of age. The aetiology of LCP remains unclear. Factors identified as related to the aetiology of LCP include coagulation abnormalities, venous outflow obstruction, abnormal arterial status, trauma in the “predisposed child”, synovitis of the hip and hereditary influences [1].

Patients with LCP often present with a limp, which is exacerbated by physical activity and alleviated with rest. The limping has been previously described as antalgic [2], a Trendelenburg or Duchenne gait. The Trendelenburg gait is characterised by a pelvic drop on the unloaded side during single support stance while Duchenne gait is described as a trunk lean toward the stance limb with pelvis level or elevated on the unloaded side [3].

During the single support phase of the normal gait cycle the pelvis tends to drop towards the swinging limb. This mechanism is normally counteracted by the activity of the

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hip abductor muscles. The abductor muscles' moment has been identified as the predominant factor for hip joint loading or unloading [4, 5] and its direction is important to estimate contact pressures of the involved hip joint. Furthermore, if the hip has a poor lateral coverage, which is often the case in children with LCP, the peak contact pressure increases [6]. Therefore, the preservation of the containment of the femoral head has been recommended as a principle of treatment in LCP disease to allow physiological distribution of the forces [7]. During the examination of patients with LCP in the gait laboratory we observed that some were able to change their walking pattern to unload the affected hip joint and walk with increased abduction in the single stance phase. While these patients decreased their hip abductor moment, others increased the load on their hips.

The aim of this study was to evaluate gait patterns in patients with LCP based on the extent of the hip loading, predominantly in the frontal plane and to identify gait modifications decreasing the load on the affected hip in children with LCP.

Methods

Subjects

Fifty-two children with LCP disease were identified using a database obtained from our gait laboratory. The inclusion criteria were diagnosis of LCP confirmed by X-ray and complete data sets of kinematic and kinetic data. The exclusion criteria were previous surgery of the affected hip, bilateral LCP disease, and other orthopaedic or neurological disorders affecting gait. Based on these criteria, the data sets of 40 patients were evaluated in this study. Data sets of ten normally developing children with a mean age of eight years three months (SD, one year six months) served as a control.

The group of children with LCP was divided into three subgroups. Subgroups were formed according to the extent of the time base integral of the hip abductor moments during the single stance on the affected side in the frontal plane. The cut-off limit classifying subgroups was the mean time base integral of the hip abductor moments in single stance of the control group $\pm$ standard deviation (SD). The means of the hip abductor moments for the three subgroups are shown in Fig. 1. Eight children were identified as overloading their hip joints (OverLoad group), 19 showed abductor moments within the normal range of the control group (NormLoad group), and 13 children unloaded their hips when compared to the control group (UnLoad group). Details on group demographics, X-ray classifications (Herring et

Fig. 1 Means of the hip abductor moments for all three subgroups. Subgroups were identified based on the extent of the time base integral of the hip abductor moments during the single stance in the frontal plane on the affected side. The split-off limit classifying subgroups was the mean time base integral of the hip abductor moments in single stance of the control group $\pm$ standard deviation (SD)

al. [8] and Catterall [9]) and the Perthes stadium according to Waldenström are presented in Table 1.

Gait analysis

All patients walked at a self-selected speed along a ten-metre walkway. Gait analysis was performed using a ten-camera video-based motion capturing system (VICON MX; Oxford Metrics, Oxford, UK) and four floor mounted force plates (AMTI). Marker arrangement, calculation methods and model assumptions applied have been described in detail by Kadaba et al. [10]. Calculations of kinematic and kinetic parameters were performed using the Vicon Clinical Manager (VICON, Oxford Metrics, Oxford, UK). Moment and power parameters were normalised to the weight of the patients. For each patient a minimum of five trials providing a clear foot force plate contact were captured and averaged. The Gillette Gait Index [11] was calculated to evaluate overall gait pathology. This index has been proposed as a summary measure of gait pathology taking into account 16 independent kinematic and temporal variables (Table 2). Higher GGI values indicate greater deviation from the gait of typically developing individuals. GGI represents a reliable measure of overall gait pathology [12].

Statistical analysis

Time-distance parameters, pelvic and hip kinematics and kinetic data were compared with the values obtained from

Table 1 Details on groups' demographics and X-ray classifications

Demographic	Hip OverLoading group	Hip UnLoading group	Hip NormLoading group
Number of children	8	13	19
% of boys in the group	100	85	85
Mean age	11 years 4 months	7 years 6 months	6 years 5 months
Herring A	0	5	5
Herring B	4	5	8
Herring C	4	3	6
Catterall 1	0	3	1
Catterall 2	2	4	9
Catterall 3	2	5	5
Catterall 4	4	1	4
Waldenström - Initial	2	2	2
Waldenström - Condensation	0	6	7
Waldenström - Fragmentation	3	4	7
Waldenström - Regeneration	3	1	3

the control group using one-way ANOVA with the Fisher post-hoc test. P-values of less than 0.05 were considered as statistically significant. The Spearman rank correlation coefficient was used to express the relationship between outcome parameters.

Results

The Gillette gait index revealed substantial differences between the control and LCP groups. However, no difference was noted among the LCP groups (Table 3). The dynamic range of motion of the hip and pelvis during gait was decreased in LCP groups. The clinical findings did not show any statistical difference among the LCP groups in the passive range of hip motion. Even though the children who overloaded their hips tended to have the lowest range of passive abduction we did not prove any statistical difference among the LCP groups.

For the OverLoad group, walking velocity was slower than the velocity of the controls and the other two LCP groups. Stride length was shorter, but in contrast to the other two LCP groups, stance time was only slightly prolonged. Hip extension at the end of the stance was not different from normal (Fig. 2). Even though the mean hip adduction during single support was not different from the control group, its timing was abnormal and the hip remained longer in adduction during the stance phase of gait (Table 3). There was no rotational pathology of the hip in the OverLoad group. Pelvis motion was within normal limits in the sagittal and transversal planes. In the frontal plane the pelvis dropped to the swinging limb and was not

compensated for by the abductor muscles as observed in a normal gait.

The NormLoad group showed normal time-distance parameters except for the prolonged stance duration. The hip did not reach normal extension at the end of stance but was close to neutral in the frontal and transversal planes during single support (Fig. 2). The pelvis revealed abnormal motion only in the frontal plane where a pelvis elevation on the swinging side was observed.

Table 2 Parameters used to calculate Gillette gait index

Parameters
Time of toe off
Walking speed
Cadence
Mean pelvic tilt
Range of pelvic tilt
Mean pelvic rotation
Minimum hip flexion
Range of hip flexion
Peak abduction in swing
Mean hip rotation in stance
Knee flexion at initial contact
Time of peak knee flexion in swing
Range of knee flexion
Peak dorsiflexion in stance
Peak dorsiflexion in swing
Mean foot progression angle in stance

Table 3 One-way analysis of variance results of important outcome parameters

Parameters	NORM x HNL	NORM x HUL	NORM x HOL	HNL x HUL	HNL x HOL	HUL x HOL	Hip NormLoading		Hip UnLoading		Hip OverLoading		Control group	
							Mean	SD	Mean	SD	Mean	SD	Mean	SD
Cadence (steps/min)	0.687	0.294	0.503	0.487	0.317	0.133	138.76	12.67	144.04	20.69	130.09	34.03	136.62	15.01
Velocity (m/s)	0.689	0.448	0.015	0.257	0.031	0.004	1.94	0.30	2.07	0.26	1.65	0.40	2.06	0.30
Stride length (m)	0.411	0.951	0.046	0.485	0.170	0.065	1.01	0.16	1.05	0.16	0.93	0.12	1.09	0.11
Stride time (s)	0.655	0.513	0.185	0.801	0.092	0.074	0.87	0.07	0.85	0.12	1.02	0.45	0.90	0.12
Stance time (% of gait cycle)	0.039	0.012	0.145	0.505	0.823	0.448	60.36	1.99	60.88	2.43	60.16	2.36	58.57	1.68
Age (years)	0.271	0.014	0.001	0.135	0.000	0.000	7.54	2.39	6.39	1.20	11.36	3.43	8.29	1.55
Hip abduction in single stance (°)	0.033	0.000	0.147	0.003	0.003	0.000	1.76	3.60	-1.77	4.13	5.96	2.03	3.99	2.35
Maximal hip extension (°)	0.009	0.023	0.250	0.939	0.375	0.440	-3.29	8.25	-3.50	6.49	-6.19	8.27	-9.94	7.65
Mean hip rotation in stance (°)	0.937	0.019	0.646	0.017	0.692	0.022	-5.89	8.05	-13.17	10.01	-4.52	8.24	-6.10	6.90
Mean hip rotation in single stance (°)	0.765	0.008	0.687	0.018	0.531	0.014	-5.69	8.21	-12.80	9.95	-3.54	7.93	-4.91	6.57
Sum of hip abductor moments in single stance (Nm/kg)	0.513	0.000	0.000	0.000	0.000	0.000	11.87	2.23	3.72	4.57	22.50	3.94	12.63	3.87
Pelvic obliquity at the end of single stance (°)	0.040	0.001	0.036	0.128	0.000	0.000	-2.88	3.59	-4.45	2.82	1.56	2.64	-0.98	1.91
Mean pelvic obliquity in single stance (°)	0.004	0.001	0.463	0.381	0.004	0.001	-1.30	3.63	-2.22	2.82	2.39	3.13	1.50	1.87
Mean pelvic tilt over the gait cycle (°)	0.589	0.492	0.536	0.841	0.307	0.264	12.95	7.28	13.43	6.91	10.07	6.18	11.80	5.91
GGI	0.000	0.000	0.002	0.964	0.698	0.743	207.60	177.09	205.52	79.59	186.69	194.49	16.06	5.03
Ankle ROM (°)	0.000	0.001	0.035	0.601	0.252	0.509	21.90	4.56	22.73	5.13	24.05	2.19	28.02	4.38
Knee ROM (°)	0.000	0.014	0.000	0.010	0.701	0.015	49.32	5.36	54.27	5.13	48.48	5.74	58.91	4.71
Hip ROM (°)	0.000	0.000	0.003	0.523	0.373	0.744	34.47	7.25	36.26	5.78	37.40	9.09	47.56	8.64
Pelvic tilt ROM (°)	0.004	0.001	0.005	0.476	0.538	0.995	5.22	2.09	5.77	1.40	5.77	4.13	3.21	1.18
Hip abduction ROM (°)	0.000	0.000	0.003	0.683	0.346	0.575	7.71	2.59	8.21	3.78	9.08	4.51	13.52	3.41
Pelvic obliquity ROM (°)	0.000	0.009	0.001	0.358	0.700	0.273	5.94	2.33	6.78	2.31	5.54	2.49	9.19	2.78
Hip abduction at the end of single stance (°)	0.655	0.018	0.003	0.007	0.009	0.000	0.74	3.93	-2.92	4.65	4.88	2.21	0.22	2.95
Mean pelvic rotation in single stance (°)	0.587	0.067	0.770	0.178	0.902	0.232	1.00	4.85	3.22	6.32	0.77	3.69	0.21	2.78

HOL Hip OverLoading group, *HNL* Hip Normloading group, *HUL* Hip UnLoading group, *NORM* control group, *ROM* range of motion, *SD* standard deviation

Fig. 2 Pelvis and hip kinematics reveal differences between the subgroups

The UnLoad group walked with a slight hip abduction during single support. Similar to the NormLoad group, the UnLoad group did not reach the normal hip extension during walking. In contrast to all other groups, the hip was externally rotated during single limb support and an internal rotation of the pelvis was documented (Fig. 2). The elevation of the pelvis on the swinging-limb side was even more pronounced than in the NormLoad group.

The time base integral of the hip abductor moments during single stance, as a measure of hip loading, correlated positively with the hip abduction angle ($R=0.66$, $p<0.001$) and with the age of the children ($R=0.624$, $p<0.001$). Another positive correlation was found between the time base integral of the hip abductor moments in single stance and the X-ray classifications of Herring ($R=0.353$, $p=0.027$) and Catterall ($R=0.393$, $p=0.013$). The Gillette gait index did not correlate with any of the X-ray findings.

Discussion

Presenting in the first decade of life, Legg-Calvé-Perthes disease is an important issue for paediatric orthopaedic surgeons; a plethora of literature on the classification and prognosis of the disease exist [13]. However, gait patterns observable in children with LCP have rarely been investigated. Loading of the hip joint is a major consideration in

the treatment of LCP disease. Hip joint loading depends on the extent of hip abductor moments occurring during the single support stance phase of the gait cycle. This study reports on the kinematic patterns of three groups of children with LCP disease. Groups were formed based on the degree of hip joint loading during the single support phase of the gait.

The Gillette gait index was used to assess the overall gait pathology of children with LCP in our study. Even though it was able to show significant differences between the control and LCP groups the index was not sensitive enough to detect gait deviations due to a single-level joint disorder. An important limitation of our study is its retrospective design. As the clinical benefit of the proposed gait modifications for children with LCP has to be proven in a future prospective project, the study should be considered as a pilot study showing interesting features of LCP gait with a potential clinical significance.

In this study, children who were able to unload the hip joint spontaneously adopted a gait pattern with pelvis elevation on the swinging side, hip abduction and external rotation during the single support phase. The elevation of the pelvis on the swinging limb side has been previously described in the literature to be associated with a lean of the trunk towards the stance limb [3]. This mechanism has been identified as an important compensatory mechanism in patients with hip abductor weakness. In our study, the lean

of the trunk was confirmed by video analysis of gait in the frontal plane. Due to the elevation of the pelvis the acetabulum is shifted over the femoral head and thereby the weight-bearing area of the hip increases [14]. Hip abduction in the single support phase is another unloading mechanism, which has not been described in children with LCP thus far. This hip abduction shifts the ground reaction vector closer to the hip joint centre and therefore decreases the internal abductor moment of the hip. The importance of this unloading mechanism is demonstrated by a negative correlation of the hip abduction during single stance with the internal hip abductor moment. Moreover, a biomechanical study of contact stress in hips with osteonecrosis of the femoral head proved that if the necrotic segment is moved medially, which is the case during the abduction, the peak contact stress in the hip joint decreases and the contact stress distribution is more favourable [6].

An external rotation gait, as it was shown in the hip unloading group, has been described to be a compensatory mechanism in children with LCP to avoid femoroacetabular impingement [15].

The patients in this study who loaded their hips normally also showed a pelvis elevation on the swinging side as a sign of abductor weakness. Even if they did not abduct the stance limb, as did the children who unloaded their hips, we may interpret the neutral position of the hip in the frontal plane as a compensation for the weak abductors when compared to the controls.

Walking patterns of children over-loading their hips during gait are different. Similar to the normal gait their pelvis drops to the swinging limb at the beginning of stance, but weak abductor muscles do not allow the child to elevate the pelvis to normal levels during swing. This Trendelenburg sign is accompanied by prolonged hip adduction during stance. Not only does this walking pattern lead to an overloading of the affected hip, but the weight-bearing area of the hip joint is also decreased. Therefore we believe that such a walking pattern should be strongly discouraged in children with LCP.

The study revealed a positive correlation between X-ray classifications of Herring and Catterall and the loading of the hip joint during single stance. As previously reported, other authors have failed to demonstrate an association between radiological classifications and joint function [16]. This finding makes the functional classification based on the loading of the hip joint even stronger. Other correlations were found between the hip abduction angle in single stance, the age of the patients and the loading of the affected hip joint. These correlations indicate that older children tend to overload their hips, prefer to walk in hip adduction during single stance, and have hips that are more impaired. An explanation for this walking pattern could be

an adductor muscle contracture, which is often present in children with LCP. However, even if the children who overloaded their hips had the lowest range of passive abduction we did not prove any statistical difference among the LCP groups. Therefore, it can also be speculated that these children might have run out of compensation alternatives.

The study presents different patterns of walking observable in children with Legg-Calvé-Perthes disease. Walking patterns were grouped according to the extent of hip loading. Hip abduction and a lean of the trunk to the stance limb are emphasised as important compensatory mechanisms to reduce hip joint loading during walking. As this pattern of walking has successfully been used to unload the hip and to relieve pain in adults suffering from hip problems [14], gait training might become an integral part of conservative treatment in children with Legg-Calvé-Perthes disease.

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References

1. Tachdjian MO (2002) Tachdjian's pediatric orthopaedics. Saunders, Philadelphia
2. Naumann T, Kollmannsberger A, Fischer M, Puhl W (1992) Ultrasonographic evaluation of Legg-Calvé-Perthes disease based on sonoanatomic criteria and the application of new measuring techniques. *Eur J Radiol* 15(2):101–106
3. Westhoff B, Petermann A, Hirsch MA, Willers R, Krauspe R (2006) Computerized gait analysis in Legg Calvé Perthes disease—analysis of the frontal plane. *Gait Posture* 24(2):196–202
4. Stolk J, Verdonschot N, Huijskes R (2001) Hip-joint and abductor-muscle forces adequately represent in vivo loading of a cemented total hip reconstruction. *J Biomech* 34:917–926
5. Plasschaert VF, Horemans HL, de Boer LM, Harlaar J, Diepstraten AF, Roebroek ME (2006) Hip abductor function in adults treated for Perthes disease. *J Pediatr Orthop B* 15(3):183–189
6. Daniel M, Herman S, Dolinar D, Iglič A, Sochor M, Kralj-Iglič V (2006) Contact stress in hips with osteonecrosis of the femoral head. *Clin Orthop Relat Res* 447:92–99
7. Roposch A, Mayr J, Linhart WE (2003) Age at onset, extent of necrosis, and containment in Perthes disease. Results at maturity. *Arch Orthop Trauma Surg* 123(2–3):68–73
8. Herring JA, Kim HT, Browne R (2004) Legg-Calvé-Perthes disease. Part I: classification of radiographs with use of the modified lateral pillar and Stulberg classifications. *J Bone Jt Surg* 86-A(10):2103–2120
9. Catterall A (1989) Legg-Calvé-Perthes disease. *Instr Course Lect* 38:297–303
10. Ramakrishnan HK, Kadaba MP (1991) On the estimation of joint kinematics during gait. *J Biomech* 24(10):969–977
11. Schutte LM, Narayanan U, Stout JL, Selber P, Gage JR, Schwartz MH (2000) An index for quantifying deviations from normal gait. *Gait Posture* 11(1):25–31
12. Schwartz M (2003) The reliability of the normalcy index for quantifying gait pathology. *Gait Posture* 18:S119

13. Kamegaya M, Saisu T, Ochiai N, Hisamitsu J, Moriya H (2004) A paired study of Perthes' disease comparing conservative and surgical treatment. *J Bone Joint Surg Br* 86(8):1176–1181
14. Schröter J, Güth V, Overbeck M, Rosenbaum D, Winkelmann W (1999) The 'entlastungsgang'. A hip unloading gait as a new conservative therapy for hip pain in adults. *Gait Posture* 9:151–157
15. Yoo WJ, Choi IH, Cho TJ, Chung CY, Park MS, Lee DY (2008) Out-toeing and in-toeing in patients with Perthes disease: role of the femoral hump. *J Pediatr Orthop* 28(7):717–722
16. Barker K, Lamb SE, Toye F, Jackson S, Barrington S (2004) Association between radiographic joint space narrowing, function, pain and muscle power in severe osteoarthritis of the knee. *Clin Rehabil* 18(7):793–800