Biomechanical gait parameters in children with unilateral and bilateral clubfoot

CDD. 20.ed. 612.76
796.023

http://dx.doi.org/10.1590/1807-55092016000200279

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Abstract

A variety of congenital pediatric disorders have demonstrated that foot deformities interfere in locomotion ability. However, there are uncertainties about the mechanical effects of this deformity. Quantitative gait analysis allows the measurement and assessment of walking biomechanics, which facilitates the recommendation of treatment alternatives. The purpose of this investigation was to analyze gait parameters in unilateral and bilateral clubfoot children after operative therapy. Observational Original Scientific Article. The protocol consisted of self-selected speed gait investigation with parameter identification in vertical and antero-posterior ground reaction forces and ankle and knee angles. Non-parametric statistics tests were used in analysis of the results. Children with clubfoot showed larger imbalances in parameters with an emphasis towards the greatest differences occurring between unilateral clubfoot group and controls. For initial stance phase, we found higher first vertical force peak and knee and ankle angular alterations. For midstance, we observed more knee flexion and ankle dorsiflexion, and less vertical force. For propulsion phase, there were smaller values in antero-posterior force, second vertical force peak and plantarflexion. Unilateral clubfoot presents more imbalances in gait biomechanical parameters compared with bilateral clubfoot children. The alterations in gait parameters in this study help to understand the imbalances and provide information to understand the lower extremity movements during gait in clubfoot children.

Key Words: Clubfoot; Biomechanics; Gait; Kinetics; Kinematics.

Introduction

Clubfoot (CF), or talipes equinovarus, is the most common congenital deformity, in which foot remains in adduction, supination and varus position. Calcaneus, navicular and cuboid are medially rotated in relation to talus, and they are held in adduction and inversion. Although foot is supinated, forefoot is pronated in relation to rearfoot, causing cavus. In addition, the first metatarsal is more plantar flexed[1]. Treatment for CF must be started as soon as deformities appear. In addition, periodic checkups are needed because recurrences and residual deformities may require new treatment[2-3]. CF diagnosis includes radiological analysis, physical examination, questionnaires based on functional activities and pain level[3-4], and biomechanical gait analysis[5-8].

Information about kinematics, kinetics and electromyography of CF gait are controversies[2, 4-5, 9-10], because children with CF have different movement patterns. Why do children with CF have different gait patterns? Usually, children with CF have different anatomical features and developed their own adaptation to those constraints. Therefore, individual adaptations leads to different movement patterns and explains why children with have large differences in gait patterns.

To improve the knowledge about how children with CF coordinate and control their body to walk, under such anatomical constraints, is necessary to reduce bias. Bias is produced by anatomical conditions and it can be reduced by clinical treatment. Surgery in CF aims to reduce anatomical constraint. After the same type of surgery, children with CF will have similar anatomical and kinesiological condition for walking. Our rationale is based on this fact. Children with CF who were subject to the same surgical procedure might have similar anatomical constraint and similar gait pattern. One major problem is whether CF occurs in one or both feet. Club foot affects typically developed foot and none of them have similar pattern compared to normal children[11]. Moreover, we suggest that children with one CF and both CF should walk different due to compensatory behavior in the typically developed foot.

To verify those two hypotheses, the aim of this study is to measure and analyze the kinematics and kinetics gait parameters in unilateral and bilateral CF children after surgery.

Method

Participants

Participants were 14 children with idiopathic CF (7 unilateral CF affected side, 6.8 ± 0.9 years old, 30.0 ± 5.1 kg mass, 1.30 ± 0.05 m tall) and seven bilateral (7.4 ± 1.1 years old, 34.4 ± 11.0 kg mass, 1.32 ± 0.07 m tall). These children had not suffered any musculoskeletal lesions in the previous six months, nor foot pain or functional difficulties in daily activities. Surgical procedure was a stepwise release of posterior and medial structures of the foot, as required. Cincinnati incision was used. Control group consisted of 11 children (7.6 ± 0.7 years old, 26.3 ± 4.3 kg mass, 1.30 ± 0.06 m tall) without CF history and without musculoskeletal lesions six months before the evaluation. These 25 subjects all participated in the study. Ethical procedures in the study were approved by Local commission of ethics in research, and all parents gave informed consent before children participation. All information was explained to participants and their parents or guardians before evaluation.

Apparatus

A force plate (Bertec #k80204, type 4060-15) was used to measure ground reaction forces (GRF) and a digital camera (Redlake Motion Scope PCI 8000) was used to record lower limb movements during gait. Sampling frequency for GRF was 1 kHz, and for kinematics data was 50 Hz (shutter 1:100). For kinematics reconstruction, it was used a reference system based on a cube shaped frame with spherical markers at known distances from each other. Acknowledge software (Biopac System Inc, CA, USA) was used to synchronize GRF and film analysis data. APAS (Ariel Dynamics) software was used to digitize and rebuild the coordinates of anatomical landmarks selected previously.

Protocol

Camera was positioned to capture images in sagittal plane. Passive reflective markers were glued onto subjects with double-sided adhesive tape on anatomical landmarks: feet and ankles (tuberosity of the fifth metatarsal bone, lateral surface of calcaneus, and distal apex of lateral malleolus), knees (apex of head of fibula, and the furthest distal point of lateral femoral condyle) and hips (greater trochanter of femur). Before trials, children walked around the testing area to feel comfortable with experimental procedure and to select their comfortable gait speed. Five trials were captured for right stance phase of gait cycle and other five for left stance phase. Data collection from force plate and cameras were synchronized by trigger.

Data analysis

EMG and GRF offset signal were removed and 2nd order Butterworth low-pass 200 Hz filter was used on raw kinetic data. For kinematic raw data, we used 2nd-order Butterworth low-pass 10 Hz filter. Both data sets were normalized for gait cycle time, and GRF were also normalized by body weight. For all calculations, we ran codes written in Matlab 6.5 (The Mathworks Inc.).

Variables

To analyze GRF, some parameters were calculated. For breaking phase: loading rate, LR (first vertical GRF peak, F1, divided by time to reach this magnitude); minimum value between vertical GRF peaks, Fmin; and braking impulse, I_brake (area under antero-posterior GRF curve during braking phase). For propulsion phase: second vertical GRF peak, F2; and propulsion impulse, I_prop (area under antero-posterior GRF in propulsive phase).

Knee and ankle angles at F1, Fmin and F2 were calculated and named as knee1, knee2 and knee3; and ankle1, ankle2 and ankle3, respectively.

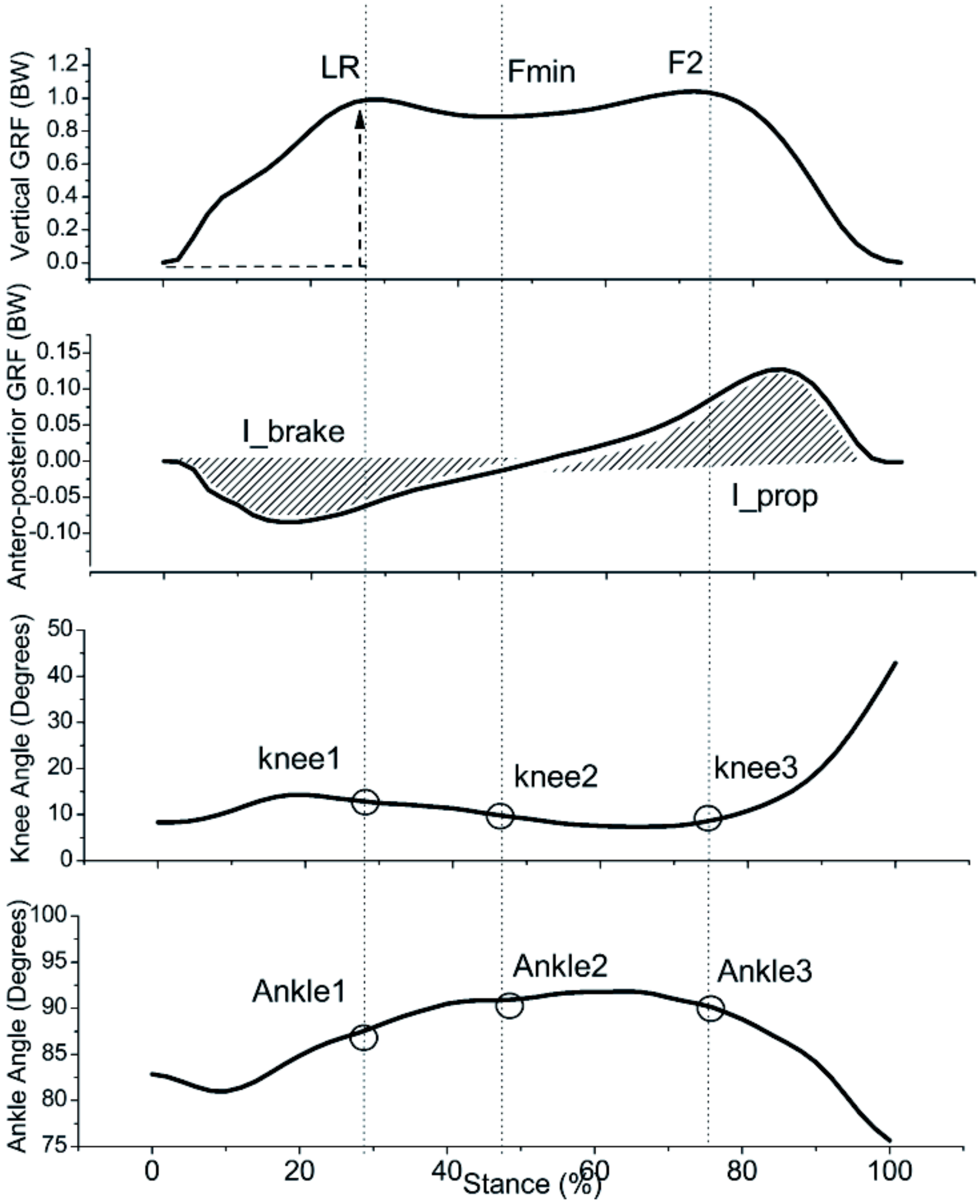

FIGURE 1 - Biomechanical parameters for gait analysis used in the investigation.

Statistical analysis

The investigated variables did not have normal distribution. We ran Kruskal-Wallis test to verify the effect of group (control group; bilateral CF group right side; bilateral CF group left side; unilateral CF group affected side; unilateral CF group unaffected side) on those variables. Mann-Whitney test was applied as post hoc test. Wilcoxon test was applied to compare kinematics and kinetics parameters between body sides. Significance level was set at $p < 0.05$.

Results

Ensemble averages of vertical and anterior posterior GRF are presented in FIGURE 2. Vertical and anterior posterior GRF for CF groups are similar to control group and similar to normal gait[12].

For kinetics, there were differences during breaking and propulsion phases. For breaking phase, LR was larger for CF and the highest LR occurred at unilateral CF affected side (chi = 24174 df = 34 p < 0.001). Control showed the highest braking impulse (chi = 175 df = 34 p < 0.001). At F1, unilateral CF showed the largest knee flexion (chi(2) = 66 df = 34 p < 0.001) and Control group showed the largest plantarflexion angle (chi(2) = 31 df = 34 p < 0.001).

For midstance phase, at Fmin, the largest dorsiflexion angle (chi(2) = 33 df = 34 p < 0.001) and the largest knee flexion angle (chi(2) = 42 df = 34 p < 0.001) occurred for unilateral CF groups and the smallest Fzmin was observed for unaffected side (chi(2) = 27 df = 34; p < 0.001).

For propulsion phase, the largest propulsion impulse (chi(2) = 176 df = 34 p < 0.001) and the second vertical GRF peak (chi(2) = 74 df = 34 p < 0.001) were observed for Control. Besides, F2 was the smallest for affected side of unilateral CF. In this phase, the largest plantarflexion angle at the ankle was observed for Control and unaffected side of unilateral CF presented the smallest plantarflexion angle (chi(2) = 46 df = 34 p < 0.001). For knee, CF group presented the largest flexion angle (chi(2) = 22; df = 34; p < 0.001).

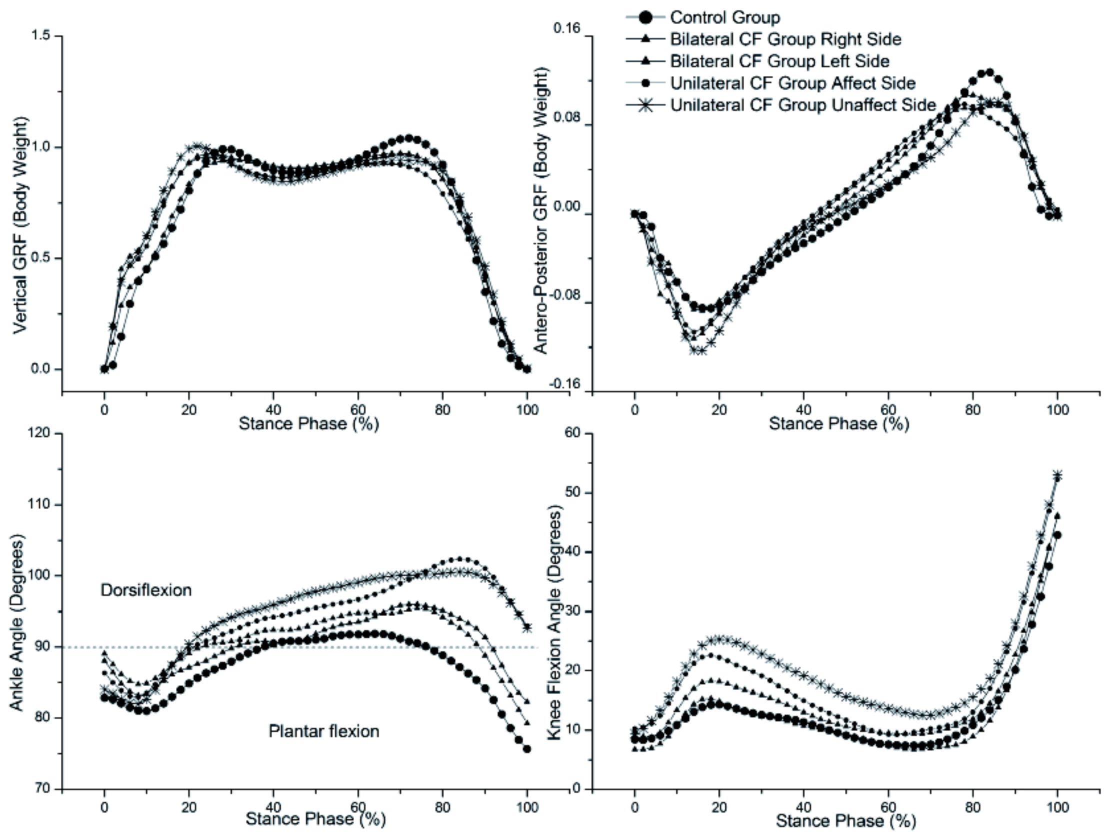

FIGURE 2 - Mean curves of biomechanical variables measured for all groups investigated during self-selected gait.

Discussion

We compared gait patterns of children with CF and typically developed children without anatomical abnormality in lower limbs. Vertical and anterior posterior GRF for CF groups are similar to control group and to normal gait pattern, described by Winter[12]. Children with CF presented lower breaking and propulsion impulses. These results suggest that children with CF walk slower than typically developed children when they are asked to walk at preferable walking speed.

Our first hypothesis was that children with CF who were subject to the same surgical procedure might have similar gait pattern. This hypothesis was not accepted. Children with unilateral CF presented higher loading rate, dorsiflexion and knee flexion during midstance than others in our study. Although every child with CF was submitted to same surgical procedure, unilateral CF children hit the ground with less smoothly. How gentle should people hit the foot to ground during foot strike suggest how controlled is the body during walking.

The second hypothesis we posed in this study was that children with unilateral and bilateral CF walk differently because the compensatory behavior in the typically developed foot. There is some information that this hypothesis is not wrong. First, the not acceptance of previous hypothesis suggest that children with unilateral or bilateral CF walk differently. Some other results support the second hypothesis: typically developed foot in children with unilateral CF presented the smallest vertical GRF during midstance and the smallest plantaflexion angle during propulsion, even less than control group. Those results suggest that during midstance the body releases less body weight onto the nonaffected foot, which leads to less plantarflexion for propulsion. This is only a different movement pattern that not changes the amount of propulsion impulse. Therefore, to counterbalance the CF behavior during walking, the no affected foot changes the way it applies forces to ground during propulsion.

Human locomotion presents complex movements and the measurement techniques that contribute to understanding the mechanisms that guarantee efficient movement and provide information for better functional rehabilitation. Surgical release procedure for CF decreases deformity and leads to a life without significant functional difficulties. However, many biomechanical gait parameters are abnormal when compared with a control group. For initial stance phase, at 10% of gait cycle, the events presented can be explained by the decrease in load control in CF group, especially in unilateral CF group. Loading rate has been used to quantify force absorption at greatest impact in gait, which has been shown to be a useful parameter for diagnosing overload. In this phase, Karol et al.[5] reported a decrease in knee flexion angle in CF group, which can explain this deficiency in controlling foot placement on the ground.

When heel touches the ground, knee is close to full extension and moves to flexion of close to 20º to control the mechanical impact[9]. We found about 14º of knee flexion in this phase for Control group and for bilateral CF group. However, we found angular differences in both knees in unilateral CF groups, which can contribute to kinetic differences. At midstance, which presents contralateral swinging and decrease in vertical GRF, the unaffected side of unilateral CF group presented the greatest dorsiflexion ankle angle. Karol et al.[5] also noted a decreased dorsiflexion angle in the unaffected side of unilateral CF group. However, these researchers only evaluated the unilateral CF children and therefore they compared data with unaffected side. In our study, we noted that both sides of unilateral CF group obtained more dorsiflexion angle than control group. Additionally, as a possible compensation, in this midstance phase, we found more knee flexion angle for unilateral CF group. The weakness of muscle stabilizers or decreased amplitude in ankle angle (normally found in CF children) could contribute to these angular alterations and could justify the decrease in vertical GRF in midstance phase found in the unilateral CF group.

The final gait stance phase, propulsion deficiencies found in CF groups are similar to Widhe and Berggren[6], Theologis et al.[3] and Favre et al.[11]. Angular parameters were also different in CF children with less plantarflexion range of motion for unilateral CF group, on both sides, compared with control group. These findings are similar Widhe and Berggren[6] and Hee et al.[7]. These imbalances are related to constrains in m. triceps surae associated with surgical procedures and residual deformities after treatment. Otis and Bohne[2] presented changes in gastrocnemius muscular activation in gait analysis for bilateral CF. Karol et al.[5] have reported alterations in anterior tibialis and fibularis muscle activations with isokinetic weakness in knee flexion, extension and plantarflexion in children with unilateral CF.

Motor control of locomotion is affected by medular and supramedular mechanisms. Cortical, cerebelar, brain stem and medular activities are necessary for child development[13]. Medular control of locomotion is based on activation of central pattern generators, which can be modulated by reflexes. In order to deal with external and internal mechanical constraints, central nervous system selects the proper muscle synergy to perform the motor task. To overcome functional constraints developed by muscle weakness and muscle-tendon stiffness, different coordination pattern needed to emerge to accomplish gait. If there is synergy among joint and muscles, there is compensation action that develops to prevail over CF deformity.

During development, child gradually becomes stronger to support body weight during walking and learns how to spend less energy to perform the same task. Besides, child learns how to control lower limb to reduce the mechanical impact of heel to ground and how to control lower limb swing to avoid the risk to fall[12]. To better understand such development process, Sutherland[14] point out the importance of maturation on gait control.

One limitation to our findings is not to explain how muscular factors affect gait in CF groups. It is mandatory to analyze EMG activity combined to kinetics and kinematics during walking in children with CF.

This study has identified that unilateral CF presents more imbalances in gait biomechanical parameters compared with bilateral CF[6]. These larger imbalances between affected and unaffected sides in this population explain larger compensations between sides. Future investigations should quantify internal forces in the affected area to identify real situation of intra articular characteristics. Alterations in gait parameters in this study should encourage physical activities for this group of children to normalize their gait patterns.

Resumo

Parâmetros biomecânicos da marcha em crianças com pé torto congênito unilateral e bilateral

Uma variedade de disfunções congênitas pediátricas demonstra que deformidades do pé interferem na capacidade de locomoção. No entanto, há em muitas vezes incertezas sobre os seus reais efeitos mecânicos. O pé torto congênito é um exemplo de uma disfunção pouco conhecida no que diz respeito as suas influências na locomoção de crianças. Desta forma, uma melhor compreensão da marcha destas crianças pode auxiliar no melhor no direcionamento de futuras ações na tentativa de minimizar ou corrigir tais possíveis desequilíbrios. O objetivo da pesquisa foi analisar parâmetros cinéticos e cinemáticos da marcha de crianças com pé torto congênito unilateral e bilateral submetidas a tratamento cirúrgico. Artigo Científico Original Observacional. O protocolo consistiu da investigação da marcha em velocidade auto-selecionada, com identificação de parâmetros em forças de reação do solo vertical e antero-posterior, além de parâmetros angulares do tornozelo e do joelho. Testes estatísticos não-paramétricos foram utilizados na análise dos resultados. As crianças com pé torto mostraram maiores desequilíbrios nos parâmetros investigados, com ênfase para as diferenças entre o grupo de pé torto unilateral e controle. Nesta comparação, no início da fase de apoio, foram encontradas maior primeiro pico da força vertical e alterações angulares do joelho e tornozelo; no médio apoio, foram observados aumento da flexão do joelho e dorsiflexão do tornozelo, além de menor magnitude da força vertical; na fase de propulsão foram encontrados menores valores na força antero-posterior e no segundo pico da força vertical, além de menor flexão plantar. Crianças com pé torto unilateral apresentam maiores desequilíbrios em parâmetros biomecânicos da marcha em comparação com crianças acometidas bilateralmente. As alterações encontradas nos parâmetros da marcha no presente estudo podem contribuir nas compreensões dos desequilíbrios e fornecer informações para entender os movimentos dos membros inferiores durante a marcha em crianças pé torto.

Palavras-chave: Pé torto; Biomecânica; Marcha; Cinética; Cinemática.

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Acknowledgments

Financial support for this research came from CAPES Brazilian Funding Agency.

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Submitted: 12/20/2014
Accepted: 05/04/2015