Long-Term Outcome Evaluation in Young Adults Following Clubfoot Surgical Release

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Background: The aim of this study was to evaluate the long-term outcome of a comprehensive surgical release for congenital talipes equinovarus (CTEV).

Methods: Gait, strength, segmental foot motion, and outcomes questionnaire data were collected on 24 adults (21.8 ± 2.3 y) who were surgically treated for CTEV as infants. These data were statistically compared with of 48-age group matched controls (23.2 ± 2.4 y).

Results: The clubfoot group was functional in activities of daily living, although most patients did experience foot pain after a day of typical activities, such as walking, standing, using stairs and doing exercise. Lower extremity gait kinematics was similar to the control group. There were differences in segmental foot motion with the hindfoot in a more plantarflexed position relative to the tibia and the forefoot dorsiflexed, and adducted relative to the hindfoot. Ankle plantarflexion and inversion strength and range of motion was reduced in the clubfoot group in association with an increase in hip power generation during the preswing and initial swing phases of the gait cycle.

Conclusions: Surgical correction of CTEV was successful in providing a functional plantigrade foot as the patients reached adulthood. However, limitations included foot pain, limited foot range of motion, and weakness.

Level of Evidence: Level III.

Key Words: Clubfoot, congenital talipes equinovarus, foot and ankle, motion analysis, outcomes, kinematics, kinetics, Milwaukee Foot Model


Congenital talipes equinovarus (CTEV) or clubfoot is a deformity affecting approximately 1 in 1000 births. Most infants are initially treated with manipulation and serial casting; the goal of intervention is a pain-free functional foot. From 1983 to 1987, at our institution, the most commonly carried out procedure to treat infants with residual foot deformity after casting was a comprehensive clubfoot release, a technique described and modified by several investigators.1–4 A Cincinnati incision was used in all releases to obtain a full correction of the foot deformity in 3 dimensions.5–6 The current standard of care utilizes the Ponseti casting technique.7–10

There are a number of published studies involving adults who underwent manipulation and serial casting to correct clubfoot as infants. These studies have shown that foot function is good or excellent for the majority of patients,7–9 but there are limitations of motion and pain with prolonged activities.10 Earlier studies have reported that during adolescence, individuals who underwent surgery present with residual pain, strength, and functional deficits and gait kinematic and kinetic disparities, when compared with typically developing children.11–14 Differences are also reported within the forefoot using segmental foot and ankle motion analysis during gait in children who underwent surgical correction for CTEV.15

It has been reported that a series of adults who had multiple surgeries during childhood to correct clubfoot showed ankle and subtalar joint stiffness, arthritis, ankle muscle weakness, pain, and residual deformity.16–18 However, Alkjaer et al19 described adults who underwent early surgical intervention were similar to uninvolved individuals when comparing gait kinematics and kinetics using a single-segment foot model.

There are no studies that have evaluated a series of adults treated with “modern” comprehensive release techniques as developed in 1983. There are no published data assessing segmental foot and ankle motion during gait along with isokinetic ankle strength testing in adults with surgically treated clubfeet. The purpose of this study is to analyze the long-term effects of surgical correction for patients with CTEV. The study is designed to improve our understanding of clubfoot during adulthood and to provide comparison with normal foot function by quantifying segmental foot motion during gait, lower extremity strength, and range of motion (ROM). We also describe the outcome variability of clubfoot pathology using measures of patient satisfaction, self perception, and outcome measures.

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METHODS

Participants
This case control study was approved by the institutional review boards of Shriners Hospitals for Children, Chicago and Medical College of Wisconsin. Medical record reviews were used to retrieve patient contact information for the 137 patients who underwent surgical clubfoot correction from 1983 to 1987. Fifty-two patients (38%) met the criteria and received phone calls after a mailing inviting them to participate in the study. Twenty-four patients (“Clubfoot group,” 17 M, 7 F; 21.8 ± 2.3 y; 11 unilateral and 13 bilateral clubfeet) agreed to participate. All patients having failed the serial casting had undergone a comprehensive posteromedial release with a Cincinnati incision for idiopathic clubfoot before the age of 18 months. All surgeries were carried out by the same surgeon. Fourteen of the 24 patients required further soft tissue and/or bony procedures for residual deformity on average of 6.2 years subsequent to their initial surgery with an average of 2 surgeries per patient. In total, 19 soft tissue procedures were carried out, including 7 plantar fascia releases, 6 anterior tibial tendon transfers, 2 tendo Achilles lengthening, 2 hallucis releases, 1 posterior tibialis transfer, and 1 toe surgery. Seventeen bony procedures were carried out, including 11 lateral column shortening, 5 tibia/fibula external rotation osteotomies, and the use of 1 Ilizarov device. The clubfoot group was compared with 48 healthy young adults without foot or gait pathologies matched for age and gender distribution (“Control group,” 29 M, 19 F; 23.2 ± 2.4 y). The control group data were collected in the Motion Analysis Laboratory at the Medical College of Wisconsin. Before comparing the data of the 2 groups, sufficient reliability was established between labs.

Physical Examination
Each patient underwent a physical exam by a licensed physical therapist. Goniometric ROM measurements were taken at the ankles and feet in concordance with the International Clubfoot Study Group (ICFSG) rating score. Standing radiographs of the foot and ankle were obtained at the time of evaluation for part of the ICFSG evaluation. A single-leg Heel Rise Test as described by Daniels and Worthingham was conducted to assess plantarflexor strength. Isokinetic ankle strength testing was completed on the Biodex System 3 Dynamometer (Biodex Medical Systems, Inc., Shirley, NY). Peak torque, normalized to body weight, was averaged over 3 trials for plantarflexion/dorsiflexion and inversion/eversion at a rotational speed of 30 deg/s.

Gait Analysis
Patients underwent quantitative gait analysis using a 14-MX camera 3-dimensional motion analysis system (VICON, Motion Analysis Corporation, Oxford, UK) and 2 force-plates (AMTI, Newton, MA) embedded in the walkway. Dynamic data were processed using Vicon Workstation (version 5.2.4) software and the PlugInGait model. This provided kinematic and kinetic data for the pelvis, hip, knee, ankle, and foot. Simultaneously, the Milwaukee Foot Model (MFM) was used to measure the motion of multiple segments of the foot and ankle. The MFM uses weight bearing radiographs to reference the motion of 4-marker-based segments to the motion of the underlying bony anatomy.

Outcomes Assessment
Outcomes assessments for all patients were done using the American Orthopaedic Foot and Ankle Society (AOFAS) Ankle/Hindfoot and Midfoot scales, the Foot Function Index (FFI), and the SF-36. In addition, members of the clubfoot group were assessed using the Disease Specific Index, Turco and International Clubfoot Study Group scores to classify the outcome of surgery. This array of outcomes tools provided measures of pain, satisfaction, function, activity restriction and disability level.

Statistical Analysis
Statistical analysis was done using SAS version 9.1 (The SAS Institute, Cary, NC). Once no statistical difference was determined, right and left sides were averaged together in patients with bilateral CTEV. The data from the uninvolved side were removed from analysis. Categorical variables were summarized in frequency tables. Continuous measures (all outcomes and physical exam measures) were summarized by measures of central tendency and minimum and maximum values. A Kruskal-Wallis (Wilcoxon) test was used to compare scores from the SF-36, AOFAS, FFI, and Heel Rise Test for nonparametric results. Mann-Whitney 95% confidence intervals are given for the median difference between groups, and 95% confidence intervals for the median response of each group are determined by applying a binomial distribution (P = 0.5) to the order statistics. Regression analysis was used to control for age, BMI, and gender in the clinical strength and ROM results.

Temporal spatial parameters were averaged over multiple measurements for each patient. A regression model was then fit to estimate the difference in groups while controlling for age, BMI, and gender. Kinetic and kinematic data were summarized into 7 phases of the gait cycle. Summary statistics used for each phase were minimum and maximum (peaks), mean, and range (ROM). Kinetic and kinematic parameters were analyzed using a generalized linear model utilizing control for repeated measurements. Factors of age, BMI, and gender were also entered in the model to control for these sources of variation. A separate model was used for each phase (n = 7) and summary statistic (n = 4). Owing to the large number of comparisons, a conservative significance level of 0.001 was selected. The Benjamin-Hochberg method was applied for a 5% false discovery rate on all group comparisons; this procedure rejects all hypotheses with P < 0.025.
RESULTS

Demographics
Analysis of the patient demographics found no differences in age, height, or weight between the 2 groups.

Physical Examination
In the clubfoot group, 18/24 patients had leg length differences ranging between 0.5 to 3.5 cm (unilateral patients: 0.91 ± 0.77 cm; bilateral patients: 1.0 ± 1.1 cm). All patients with unilateral clubfeet had a reduced calf circumference compared with the unaffected side (3.6 ± 1.6 cm smaller). The clubfoot group ankle ROM measured 25° of plantarflexion, 4.5° dorsiflexion (10° normal with knee extended), 2° adduction (40° normal), and 5° abduction (30° normal). The average thigh foot angle was 10° external (18° normal) and hip and knee ROM was within normal limits. The clubfoot group had significantly reduced strength in ankle plantarflexors, inverters, and evertors as measured by the Heel Rise Test and Biodex System 3 (Table 1).

Gait Analysis

Temporal Spatial Parameters
Several temporal spatial parameters were significantly different in the clubfoot group compared with the control group. Walking speed and stride length were reduced, and foot off occurred later in the gait cycle (GC) increasing double support time (Table 1).

Lower Extremity Kinematic Parameters
Little difference between the groups was observed in sagittal and coronal plane motion of the pelvis, hips, and knees. There was significantly greater mean internal hip rotation (Fig. 1) in the clubfoot group throughout the GC (clubfoot group 10.1° ± 2.0°, control group 2.2° ± 2.2°). The greatest deviations between groups were found at the foot and ankle during Preswing; the clubfoot group displayed an external foot progression angle and reduced ankle plantarflexion motion (Table 2).

Segmental Foot and Ankle Kinematic Parameters
The clubfoot group walked with reduced hindfoot dorsiflexion relative to the tibia throughout the GC and reduced hindfoot inversion ROM during Initial Swing phase (Fig. 2). The forefoot was dorsiflexed relative to the hindfoot throughout the GC. The forefoot also showed reduced adduction and inversion during Terminal Stance and Preswing phases.

Kinetic Parameters
The clubfoot group displayed no reduction in peak ankle plantarflexion moment but showed a slight decrease in ankle power generation during Preswing (Fig. 3). A significant increase in hip power generation was observed during Terminal Stance, Preswing, and Initial Swing (Fig. 3). This coincided with reductions in ankle power generation.

Outcomes Assessment
In the ICFSG evaluation 5 out of the 37 clubfeet scored “excellent,” 17 “good,” and 15 “fair to poor.” Turco scores rated 6 of 37 feet “excellent,” 24 “good,” and 7 “fair.”

AOFAS Ankle/Hindfoot scores were significantly lower for the clubfoot group because of pain and sagittal plane/hindfoot motion deviations (Table 1). The clubfoot group also scored low on the AOFAS Midfoot scale with regards to pain and footwear. The Disease Specific Index scores detected pain in 96% of the surgically corrected clubfeet. All 3 categories of the FFI were significantly lower in the clubfoot group. SF-36 scores for the clubfoot group were significantly lower than the control group in 3 out of the 4 of the physical health scales, but no differences were found in the mental or social health scales.

DISCUSSION
This study was the first to describe lower extremity dynamics and segmental foot and ankle motion during gait in adults who were treated with comprehensive surgical release as infants for clubfoot. All of the patients...
walked with a plantigrade foot without custom shoes or braces. The findings support the statement that surgical correction of CTEV results in a functional foot for low level gross motor and daily living activities. Range of motion and strength deficits coupled with pain were the primary factors affecting these patients as adults.

Evaluation of gait parameters revealed both temporal spatial and kinematic differences. The clubfoot group ambulated with a conservative gait pattern consisting of reduced walking speed, stride length with increased double limb support, and delayed foot off.

In the kinematic analysis, the clubfoot group showed few deviations from the normal pattern. In the sagittal plane, ankle plantarflexion was limited during the Initial Swing phase of gait probably because of limited motion available and diminished push off power. Most gait studies of clubfoot have also found limited kinetic abnormalities. In the transverse plane, we found increased internal rotation at the hip. The clubfoot group did not have a significantly different foot progression angle than the control group during most of stance, but during Preswing and Initial Swing phases, it was significantly external. Other studies have shown an internal progression in individuals with clubfoot, but 21% of our clubfoot group had an external rotation osteotomy of the tibia to correct any residual internal foot progression deformity.

There were differences detected in the clubfoot group with segmental foot and ankle motion analysis. Limitations of ROM of the foot and ankle have also been seen by Theologis et al and Carson et al using the Oxford Foot Model during gait for children who have undergone clubfoot surgery. Both studies found a plantarflexed hindfoot position, forefoot adduction, and dorsiflexion. Clubfoot comprehensive surgery achieves a plantigrade foot, but results in residual decreased calcaneal pitch, parallelism of the talus, and calcaneus with a corresponding dorsiflexed forefoot in relation with the hindfoot. In our study, abnormalities of foot segmental position are explained, because our kinematic data is linked to radiographic measurements.

The clubfoot group showed decreased ROM of the foot and ankle on physical exam. Some patients showed marked limitations of inversion/eversion range, and ankle plantarflexion/dorsiflexion even to the point of restrictive range of hindfoot motion during normal gait. The extent to which comprehensive release surgery is responsible for segmental foot and ankle abnormalities is not known, as adults who had correction through casting also showed limitations of foot and ankle motion when evaluated with physical examination and electrogoniometric analysis.

Our findings are similar to Cooper and Deitz’s on adults who had Ponseti correction in that the differences of ROM between the groups measured by physical examination were greater than the differences measured dynamically during gait.

Strength assessment on the Biodex System 3 revealed some of the greatest separation between the groups in this study. The clubfoot group measured only 47% of the plantarflexion strength of the Control group. The clubfoot group’s inversion strength was 61%, and eversion strength 62% of the control group. Earlier studies involving children have also found normal dorsiflexor strength, but weak plantarflexors. These deficits may be attributed to reduced foot ROM, lengthening of the Achilles tendon and posterior tibialis, pain and/or diminished muscle mass because of calf atrophy. Significant plantarflexor weakness was identified after comparing the maximum torque generated between the groups (Table 1), but the moment necessary to produce normal “push off”
### TABLE 2. Lower Extremity Gait and Segmental Foot Kinematics and Kinetics

<table>
<thead>
<tr>
<th>Mean parameter (± St. Err)</th>
<th>Loading Response</th>
<th>Midstance</th>
<th>Terminal Stance</th>
<th>Preswing</th>
<th>Initial Swing</th>
<th>Midswing</th>
<th>Terminal Swing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Clubfoot</td>
<td>Control</td>
<td>Clubfoot</td>
<td>Control</td>
<td>Clubfoot</td>
<td>Control</td>
<td>Clubfoot</td>
</tr>
<tr>
<td>Maximum ankle plantarflexion (degrees)</td>
<td>3.9 ± 0.6</td>
<td>1.7 ± 0.5</td>
<td>8.7 ± 0.8</td>
<td>9.8 ± 0.5</td>
<td>8.6 ± 0.9</td>
<td>12.0 ± 0.8</td>
<td></td>
</tr>
<tr>
<td>External foot progression angle (degrees)</td>
<td>9.19 ± (1.1)</td>
<td>5.85 ± 0.7</td>
<td>8.60 ± 0.77</td>
<td>5.77 ± 1.10</td>
<td>10.30 ± 0.72</td>
<td>8.25 ± 0.12</td>
<td>9.57 ± (1.2)</td>
</tr>
<tr>
<td>Internal (+) hip rotation (degrees)</td>
<td>5.9 ± 0.9</td>
<td>2.1 ± 0.7</td>
<td>7.9 ± 0.9</td>
<td>1.5 ± 0.9</td>
<td>7.2 ± 0.1</td>
<td>1.52 ± 0.9</td>
<td>8.2 ± 0.1</td>
</tr>
<tr>
<td>Maximum ankle flexion moment (Nm/kg)</td>
<td>0.04 ± 0.02</td>
<td>0.14 ± 0.05</td>
<td>0.35 ± 0.06</td>
<td>0.54 ± 0.09</td>
<td>1.04 ± 0.12</td>
<td>1.05 ± 0.12</td>
<td>0.98 ± 0.07</td>
</tr>
<tr>
<td>Maximum ankle power (W/kg)</td>
<td>2.50 ± 0.18</td>
<td>2.85 ± 0.11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum hip power (W/kg)</td>
<td>0.25 ± 0.04</td>
<td>0.47 ± 0.03</td>
<td>0.28 ± 0.03</td>
<td>0.45 ± 0.03</td>
<td>0.31 ± 0.05</td>
<td>0.07 ± 0.02</td>
<td>1.27 ± 0.06</td>
</tr>
<tr>
<td>Hindfoot plantarflexion (Degrees)</td>
<td>5.0 ± 1.94</td>
<td>10.9 ± 25.9</td>
<td>19.4 ± 1.11</td>
<td>7.9 ± 1.52</td>
<td>7.2 ± 0.1</td>
<td>1.52 ± 0.9</td>
<td>8.2 ± 0.1</td>
</tr>
<tr>
<td>Hindfoot inversion ROM (degrees)</td>
<td>2.0 ± 0.2</td>
<td>3.0 ± 0.1</td>
<td>2.4 ± 0.1</td>
<td>3.0 ± 0.1</td>
<td>3.1 ± 0.3</td>
<td>1.1 ± 0.2</td>
<td>4.7 ± 0.3</td>
</tr>
<tr>
<td>Forefoot dorsiflexion (degrees)</td>
<td>27.5 ± 45.7</td>
<td>27.6 ± 45.2</td>
<td>24.5 ± 42.1</td>
<td>27.3 ± 43.6</td>
<td>28.2 ± 45.4</td>
<td>27.7 ± 45.2</td>
<td>28.4 ± 45.5</td>
</tr>
<tr>
<td>Maximum forefoot inversion (degrees)</td>
<td>5.8 ± 0.2</td>
<td>3.0 ± 1.8</td>
<td>1.8 ± 1.8</td>
<td>3.1 ± 8.5</td>
<td>17.6 ± 25.1</td>
<td>17.6 ± 23.4</td>
<td>12.9 ± 13.2</td>
</tr>
<tr>
<td>Maximum forefoot adduction (degrees)</td>
<td>11.5 ± 16.8</td>
<td>6.5 ± 12.2</td>
<td>3.6 ± 14.4</td>
<td>6.1 ± 17.1</td>
<td>6.2 ± 13.3</td>
<td>13.1 ± 18.3</td>
<td>14.6 ± 19.5</td>
</tr>
</tbody>
</table>

The gait cycle has been broken into 7 phases with summary statistics done on each phase. *Denotes significant difference from control group (P < 0.001). †Denotes forefoot eversion.
during gait (1.05 N·m/kg) was well within the clubfoot group’s limits, as measured by the Biodex. The strength deficits in the clubfoot group had less effect on gait and other low level gross motor activities; however, they become more relevant when high level physical function or endurance is required, which is most apparent from the outcomes evaluations used in this study.

Outcome tool results revealed that when patients in the clubfoot group were on their feet for long periods of time, or attempted higher level functional activities, such as running, jumping, stair climbing, or sports, large deficits were reported on the FFI and SF-36. Their participation and in many of these activities were greatly reduced. Each patient in the clubfoot group reported at least mild pain that may cause restrictions in higher level functional activities. The group scored an average of 4 on a scale of 0 (no pain) to 9 (worst) for foot pain at the end of the day on the FFI. They also experienced foot pain after strenuous activities or exercise, which may limit their participation. These limitations do not seem to affect mental or social health of these individuals as the SF-36 scores were normal for those categories. The finding of pain in patients who had clubfoot surgery, while less common in reported series of children and adolescents, is prevalent in young adults. When interviewed, most patients reported the onset of consistent foot pain after they reached the age of twenty.

In summary, this study shows that adults, surgically treated for CTEV as infants, present measurable differences to age-matched controls. These seem to cause minimal restrictions on gait or other basic activities of

**FIGURE 2.** Diagrams showing segmental foot motion during gait from Milwaukee Foot Model (MFM). The sagittal, coronal, and transverse planes of motion are displayed, respectively, with the hindfoot in the top row and the forefoot on the bottom. The control group is represented by the shaded area. The clubfoot group is represented by the dashed line and the dotted lines are the standard deviation. The hindfoot is in a plantarflexed position, and the forefoot is dorsiflexed throughout the GC for the clubfoot group. The forefoot lacks normal adduction and ROM with reduced varus motion during Terminal Stance and Preswing.

**FIGURE 3.** Diagrams (A and B) showing gait kinetics graphs of the ankle and hip power. The control group is represented by the shaded area. The clubfoot group is represented by the dashed line and the dotted lines are the standard deviation. There is an increase in hip power generation corresponding with a decrease in ankle power.
daily living, but limitations are apparent, when endurance is required and participation suffers, when higher level gross motor activities are attempted. Adults who have undergone clubfoot surgeries as infants were, mildly to moderately, functionally restricted owing to pain, ankle weakness, and reduced ROM at the ankle and within the foot. It might be beneficial in future studies to search for radiographic changes that may be present owing to early onset arthritis and also to examine the plantar pressures of this patient population. It would be valuable to continue to follow these patients over time to determine whether their results deteriorate in a similar manner to those found by Dobbs et al., in which 56% of the population had moderate-to-severe osteoarthritic changes at age of 35+ years.

REFERENCES