Quantitative Assessment of the Effects of Subtalar Arthrodesis on the Planovalgus Foot Using Three-Dimensional Motion Analysis and Plantar Pressure Measurements

† Shriners Hospitals for Children, Chicago-Unit, Chicago, IL 60707, USA.
‡ Department of Biomedical Engineering, Marquette University, Milwaukee, WI 53233, USA.
☼ Department of Biomedical Engineering, American University of Science & Technology, Beirut, Lebanon.

Introduction: Planovalgus foot deformity is frequent in cerebral-palsied patients with diplegic and quadriplegic distribution. This type of foot deformity is progressive and can be debilitating. Difficulties occurring include poor stance phase stability, shoe wear problems, and impaired push-off power during ambulation [1]. Surgical treatment of the planovalgus foot focuses on subtalar joint stabilization to prevent excessive hind foot valgus. Moreover, rehabilitation after surgery is designed to provide better stance phase stability, swing phase foot clearance, and a more efficient walking pattern [2]. This study was designed to determine the quantitative effects of subtalar arthrodesis on the planovalgus foot using three-dimensional (3-D) gait analysis and plantar pressure measurements.

Statement of Clinical Significance: In order to better understand the biomechanics of the planovalgus foot and the effectiveness of intervention in the correction and rehabilitative treatment of this disorder, it is essential to objectively describe plantar foot dynamics and the effects of such intervention on lower-extremity gait.

Methodology: Twelve children and adolescents (8 males and 4 females) with severe planovalgus foot deformity secondary to spastic cerebral palsy participated in this study. Preoperatively, subjects ranged in age from 9 to 17.2 years (MEAN ± S.D. = 13.1 ± 2.6 years), and had a mean height of 146.0 ± 18.4 cm, and mean body mass of 47.8 ± 19.6 kg. The subjects were evaluated just prior to surgery, and at 6- and 12-months following subtalar fusion for correction of the foot deformity. Subtalar fusion was performed on 17 feet following the methods of Dennyson and Fulford [2]. Five subjects received bilateral subtalar fusion, while seven subjects underwent unilateral subtalar fusion, four on the right foot and three on the left foot.

A Holter-type, microprocessor-based, portable, in-shoe, plantar pressure data acquisition system was used to measure the dynamic multi-step pressure history in the pediatric population examined in this study. Sensors were located under the calcaneus (CAL), medial (MMF) and lateral (LMF) midfoot, medial (MMH) and lateral (LMH) metatarsal heads, and hallux (HAL). These six discrete anatomic areas were identified as useful in analyzing the pediatric foot during ambulation [2-3]. Individual pathology and surgical intervention were also considered in this study. A Vicon VX motion analysis system (Oxford Metrics Ltd., Oxford, UK) with 5 CCD cameras was used to capture the 3-D lower extremity joint kinematics of the pediatric population evaluated in this study. Measurements were taken at the pelvis, hip, knee, and foot and ankle structures. Data acquisition was controlled with the use of an ADTECH Motion Analysis Software System (ADTECH, Adelphi, MD) operating on a Micro-VAX 4000 station (Digital Equipment Corporation, Maynard, MA).

To evaluate changes among pre- and post-operative study results, a Wilcoxon Signed Rank Test was conducted using Sigma Stat® (Jandel Scientific Software, San Rafael, CA) with 95% confidence interval. The Signed Rank Test method was conducted in this study with the null hypothesis that subtalar fusion treatment had no effect on the subject.

Results: Eleven of the twelve patients had good or excellent results based on the clinical scoring system evaluating foot position, shoe wear and pain. Pressure metrics acquired from the six plantar regions witnessed significant alterations laterally (Table I). There were no statistically significant changes in temporal and stride characteristics or kinematic data following surgery. The foot progression angle remained unchanged after surgery.

Table I. Postoperative alterations in plantar pressure metrics by sensor location for the study population

Sensor Location	Peak Pressure		Contact Duration		Pressure-Time Integral	
	p-value	% change	*p*-value	% change	*p*-value	% change
CAL	0.358	-35.47	0.119	+20.10	0.855	+137.97
MMF	0.561	-14.57	0.489	+27.54	0.847	+2.44
LMF	**0.002**	**+155.20**	**<0.001**	**+155.65**	**<0.001**	**+291.02**
MMH	0.074	-37.94	0.274	+13.76	0.464	-19.04
LMH	**0.007**	**+114.36**	**0.025**	**+41.64**	**0.002**	**+154.77**
HAL	0.151	-25.70	0.847	+3.60	0.421	-8.89

Discussion: The results obtained from the plantar pressure measurement showed significant increases in mean peak vertical plantar pressures postoperatively at the lateral midfoot and lateral metatarsal heads. Mean contact durations and mean pressure-time integrals were also significantly increased at these plantar locations following foot surgery. This redistribution in pressure metrics suggests the formation of new lateral plantar weight bearing areas. The 3-D gait analysis system, using standardized lower extremity measurements, was unable to reveal any significant changes in joint kinematics, particularly at the foot and ankle where the surgery was performed. This suggests the need for a more refined system to track the complex motion of the pediatric foot and ankle during gait.

This study intended to show that quantitative techniques are possible and are capable of showing quantifiable differences before and after surgery, which might be expected from the type of surgical procedure performed in this study. Consequently, our objective was to demonstrate that these techniques could be used to augment the standard clinical measures.

References:

1. Gage JR. Gait Analysis in Cerebral Palsy. Clinics in Developmental Medicine, No. 121, London: MacKeith Press with Cambridge University Press, New York, 1991.
2. Abu-Faraj ZO, Harris GF, Smith PA. Surgical Rehabilitation of the Planovalgus Foot in Cerebral Palsy. IEEE Transactions on Neural Systems and Rehabilitation Engineering, Vol. 9, No. 2, pp. 202-214, 2001.
3. Abu-Faraj ZO, Harris GF, Abler JH, Smith PA, Wertsch JJ. A Holter-Type Microprocessor-Based Rehabilitation Instrument for Acquisition and Storage of Plantar Pressure Data in Children with Cerebral Palsy. IEEE Transactions on Rehabilitation Engineering, Vol. 4, No. 1, pp. 33-38, March 1996.