Biomechanical analysis of the custom made insoles on gait of pes cavus patients

Jungkyu Choi[1], Ji-Yong Jung[1], Hwa-In Kim[2], Yonggwan Won[3], and Jung-Ja Kim[4,*]

***Abstract*—**The purpose of this study was to evaluate the biomechanical characteristics of lower limbs on a subject group of pes cavus based on plantar foot pressure and electromyograph (EMG) activities by the effects of the custom-made insoles. The subjects were 10 females who were diagnosed bilateral pes cavus by a podiatrist among 30 females in their twenties (an age 22.3±0.08 years, a height 159.9±2.2 cm, a weight 50.8±3.69 kg, a foot size 237.9±3.27 mm, mean±SD). The subjects walked on a treadmill under two different experimental conditions: walking on Normal Shoes (NS) condition and walking on normal shoes with the Custom-made Insoles (CI) condition. When walking, plantar foot pressure data such as the contacting area, the maximum force, the peak pressure and the mean pressure were collected using Pedar-X System (Novel Gmbh, Germany) and EMG activities of four lower limb muscles such as Rectus Femoris (RF), Tibialis Anterior (TA), Musculus Biceps Femoris (MBF) and Medial Gastrocnemius (MG) were also gathered using Delsys EMG Work system (Delsys, USA). Accumulated data was then analyzed using paired t-test in order to investigate the effects of each of experimental condition. As a result of the analysis, the maximum force, the peak pressure and the mean pressure of midfoot increased by the contacting area increased of midfoot when the custom-made insoles were equipped, so the contacting area and the maximum force of forefoot and rearfoot decreased. In addition, the peak pressure and the mean pressure of rearfoot decreased significantly. In case of EMG, all the muscle activities decreased significantly when wearing the custom-made insoles. An important contribution of this study is an analysis of all the changes in muscle activities caused by wearing the custom-made insoles. Thus, the result of this study can be applied for designing functional insoles and lower extremity orthoses for individuals with pes cavus.

***Keywords*—**Biomechanical analysis, Custom-made insole, Pes cavus, Foot pressure, EMG.

[1]Jungkyu Choi and Ji-Yong Jung are with the Department of Healthcare Engineering, Chonbuk National University, 664-14, Deokjin-dong 1, Deokjin-gu, Jeonju, Jeolabuk-do, Republic of Korea (e-mail: chaosjoozak@nate.com and cholbun@hanmail.net).

[2]Hwa-In Kim is with the Foot Clinic of Jeonju Pediatrics, 485-42, Junghwasan-dong 2, Wansan-gu, Jeonju, Jeolabuk-do, Republi of Korea (e-mail: mssy1016@yahoo.com).

[3]Yonggwan Won is with the School of Electronics and Computer Engineering, Chonnam National University, 77 Yongbong-ro, Buk-gu, Gwangju, Republic of Korea (e-mail: ykwon@chonnom.ac.kr).

[4,*]Jung-Ja Kim is with the Division of Biomedical Engineering and Research Center of Healthcare & Welfare Instrument for the Aged, Chonbuk National University, 664-14, Deokjin-dong 1, Deokjin-gu, Jeonju, Jeolabuk-do, republic of Korea (corresponding author to provide phone: 82-63-270-4102; fax: 82-63-270-2247; e-mail: jungjakim@jbnu.ac.kr).

I. Introduction

Feet play the most important role in the bipedalism and the standing posture of human. Feet, only 5 % of the entire surface of the body, sustain the body weight of 95 % and have the function of absorbing the impact from the ground [1]. When human walk for 1 km, about 15 t weights increase on feet and pressure occurred by weight or the push-off exercise cause stress or the soft tissue strain.

Locomotion is motion to move position and gait is special exercise to work a combination of the feet, legs and waist during moving the human body from one point to another [2]. The human bipedal including walking, running and jumping involves a high amount of balancing and stability along with complex synchronous oscillation of its different joints of the body [3]-[4]. The gait movement is the most natural action in human and the default behavior that anyone can easily if have a normal body. However, the gait is a possible action if the skeletal muscles and nerves of human are used and coordinated complexly among the various joints. When body move forward, one of the lower limbs maintain stability by supporting weight in stance phase during another lower limb step forth. Using this sequence of the lower limbs is the gait of human [5].

Pes cavus, commonly known as “high-arched foot” or “cavoid foot”, is a medical condition in which the medial longitudinal arch (MLA) that runs the length of the foot raised and structurally accepted to be rigid and a complicated deformity to cause the equinus of forefoot or the varus of rearfoot [6], [7]. It is cause that the excessive internal version of ankle joint and knee joint or muscles constricted by high-heel or disease like polio that transform musculoskeletal. As a consequence, the area that the foot contacts the floor is narrowed while the ankle or heel is tilted out exteriorly. In case of mild, patients are often no symptoms but patients with an advanced disease feel fatigue of walking easily and appeal oppressive pain frequently in metatarsal heads [8]-[12]. Over time, the mechanical overloading resulting from the raised MLA adversely affects the balance of body and causes diseases such as plantar fasciitis, metatarsalgia, sesamoiditis and asymmetry of the pelvis [13]-[15].

Pes cavus deformities are commonly treated using surgical method or orthoses like custom-made insoles [16], [17]. The orthoses, non-invasive method, are defined as being external devices applied to a body segment in order to prevent or correct the disfunctionality of that segment (mobility limitation, correction or prevention of vicious positions or deformations, reduction of the axial load) [18]. The custom-made insoles are produced to fit patient's feet for decreasing pain from fatigue and disease in feet. It controls the movement of abnormal foot and reduces symptoms of diseases caused by plantar pressure and distributes weight properly [19]. They are also used for controlling the excessive or the undesired movement [20]. According to former studies on the effect of the custom-made insoles, results from several researches show difference at a measurement factor. B. M. Nigg, W. Herzog and L. J. Read analyzed the changes in the peak vertical force and the maximum vertical loading rate in a group wearing shoes with four different types of insoles. The results showed that the different insoles had no appreciable influence on the measured values [21]. G. P. Brown, R. Donatelli, P. A. Catlin and M. J. Wooden found different insoles resulted in no significant difference in the maximum pronation, calcaneal eversion or total pronation of the foot [22]. On the other hand, the custom-made insoles prevent usually a deformity and a necrosis of feet by dispersion of pressure on forefoot where an ulcer is caused in diabetes patients [23]-[25]. S. Albert and C. Rinoie noted that a plantar foot pressure was reduced by 30-40 % in area of first metatarsal head and medial calcaneus and increased by 5-10 % in a total contacting area when insoles were equipped [26]. C. M. Windle, S. M. Gregory and S. J. Dixon reported the custom-made insoles for absorbing a ground reaction reduced by 37 % in heel and by 27 % in forefoot [27]. J. H. Kang, M. D. Chen, S. C. Chen and W. L. His informed that a pain on forefoot and metatarsal was caused by excessive pressure load. The results of the study were that plantar pressure was distributed and pain was relieved after wearing insoles with a metatarsal pad for 2 weeks [28]. Mueller et al. noted that maximum plantar pressure and integral pressure-time were reduced by 16-24 % under area of metatarsal heads when the total-contact insoles which controlled abnormal movement of feet and dispersed excessive plantar pressure were equipped and decreased by 29-47 % when the total-contact insoles with metatarsal pad which dispersed pressure of forefoot additionally were equipped [29]. J. Y. Jung, J. H. Kim, P. H. Trieu, Y. G. Won, D. K. Kwon and J. J. Kim reported the custom-made insoles distributed concentrating pressure of specific area to the whole of foot and relieved impact and pain by high pressure [19].

To date, study about gait characteristic of the custom-made insoles have been conducted but more accurate studies are necessary because there are still a wide variety of variables such as various diseases of foot and forms of insole on the influence of the custom-made insoles. So far, most of previous studies were research the effect of the custom-made insoles from the viewpoint of pressure distribution but muscles activity of lower limbs on grounds of mechanical movement when walking was not investigated. That is why the purpose of this study was to provide the information of biomechanical as analyzing the influence of the custom-made insoles in plantar foot pressure and muscle activity.

II. Methods

A. Subjects

The study was conducted using on 10 persons who were diagnosed bilateral pes cavus by a podiatrist among 30 females in their twenties (Figure 1, Table 1). All subjects had no history of injury in the musculoskeletal system of the lower extremities except pes cavus. An ethical approval was obtained from the Human Ethics Committee of Chonbuk National University Medical School, and the subjects were provided information about this study like purpose and procedure and sign the test consent form.

Fig. 1. Diagnosis and prescription

Table 1. Subject Characteristic

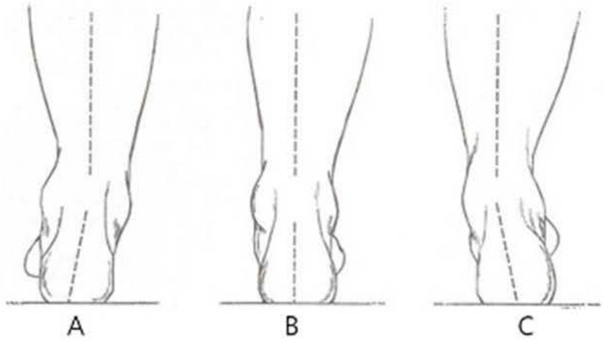
Characteristics	Subjects
Age (years)	22.3±0.08
Height (cm)	159.9±2.2
Body Mass (kg)	50.8±3.69
Shoe Size (mm)	237.9±3.27

B. Clinical Assessment

To classify shape of the foot, Resting Calcaneal Stance Position (RCSP) is measured, radiograph of the lower limbs is taken or soleprint is checked by a podiatrist [30]-[34]. Method using RCSP measurement is the most commonly used in clinical diagnosis. It is showed to important way that position of the calcaneus is not only appeared in stance phase of gait but also inversion or eversion is decided in forefoot [35]. Through this measurement, the foot is categorized into normal foot, pes planus, pes cavus or etc (Figure 2-(a)). The most usually method to analyze rearfoot composed of the talus and calcaneus among bones in the foot is what inversion and eversion of calcaneus is measured [36].

For measurement of RCSP, bisector is marked on bilateral facet of the heel after a subject is laid easily to prone position, and a slope of the calcaneus bisector is measured by using anglefinder (700 contractor magnetic angle locator, Johnson level & Tools, USA) after a subject is stood naturally on spreading to 10~15 cm between the foot (Figure 2-(b), (c), (d)).

As results on research of cavus foot by the talonavicular joint in neutral state, three kinds of pes cavus cause were unearthed.



(a) Foot(left) type classification according to RCSP
A : Pes planus, B : Normal, C : Pes Cavus

(b) Calcaneal bisector

(c) Anglefinder

(d) RCSP Measurement

Fig. 2. Clinical assessment

(1) Adduction of forefoot to transverse plane in weightbearing line, (2) Eversion of forefoot to frontal plane, (3) Inversion of the heel to frontal plane [37]-[39]. The 1st metatarsal is to be plantar flexion, and range of that is widened. In general, the cavus foot has characteristics that adduction and eversion of forefoot and varus of the heel intensify in transverse plane. These deformities are not curved nearly to the opposite side, and degree of deformities would degenerate if condition is heavy. The pes cavus is caused if one of these deformational structures appear, but all of abnormalities is verified if the pes cavus is severe.

C. Study Design

In this study, all subjects walked on a Gait Trainer treadmill (BIODEX., New York, USA) under two conditions: walking with Normal Shoes (NS) and walking with the Custom-made Insoles in normal shoes (CI). Each subject walked on a treadmill at a step speed of 3.0 km/h in reference to 1.08 m/s that was the average woman step speed in Korea [40]. Before the experiment, subjects walked for 5 minutes took rest for 5 minutes to prevent fatigue in between experiments. For comparative analysis of data from NS and CI, subjects were asked to walk five times for 1 minute during each condition (Figure 3).

Fig. 3. Experiment process

D. Tool

The custom-made insoles were made by prescriptions of podiatrist to reduce the supination of the foot for each subject and molded with insertion of metatarsal pads to distribute pressure concentrated in forefoot area and had structure to reduce heel tilted out to exterior. It were composed of 2/3 length insole because foot pressure could be changed by material of patched part in forefoot and results by structures for reducing pes cavus symptoms would be analyzed objectively. The shell, metatarsal pad and surface of the custom-made insoles were composed of polypropylene, polyurethane and artificial leather, respectively (Figure 4). Shoes were selected common running shoes and the custom-made insoles were inserted in shoes suitably (Figure 5).

Fig. 4. Casting the custom-made insoles

Fig. 5. Shoes

E. Data Collection

In this study, plantar foot pressure and electromyography (EMG) were measured to evaluate the effect of the custom-made insoles on gait. Muscle activities were recorded using the Delsys EMG Work System (Delsys Inc., Boston, USA) which was able to collect data from 8 channels (Figure 6). DE-3.1 surface electrodes (Delsys Inc., Boston, USA) were attached to the rectus femoris (RF), the tibialis anterior (TA), the musculus biceps femoris (MBF) and medial gastrocnemius (MG) of both legs (Figure 7) [41]. Foot pressure distributions were measured using the Pedar-X system (Novel GmbH, Munich, Germany). Each insole was composed of 99 capacitive sensors (sample rate 100 Hz) and measured plantar foot pressure data were transmitted by using a Bluetooth connection to a computer and recorded (Figure 6). The reliability of this system has been documented in previous studies [1], [42].

Fig. 6. Pedar X-system and Delsys EMG system

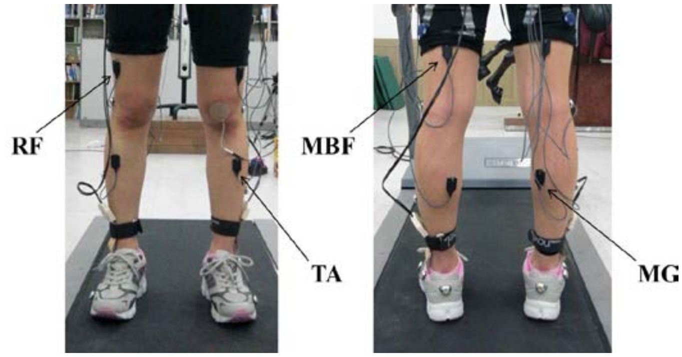


Fig. 7. Measurement of EMG

F. Data Analysis

After the bilateral foot was divided into three areas of masks (forefoot, midfoot and rearfoot) to compare plantar foot pressure data collected from each condition, data of contacting area, maximum force, peak pressure and mean pressure were analyzed (Figure 8). The masks were defined and data were analyzed using Pedar-X Analyze Software (Novel GmbH., Munich, Germany). Measured EMG signals from surface electrodes attached on each muscle were filtered by bandpass filter (passband 20-450 Hz) and sampled at 1,000 Hz to reduce EMG noise and collect accurate data. The muscle activity was analyzed integrated EMG (IEMG) value.

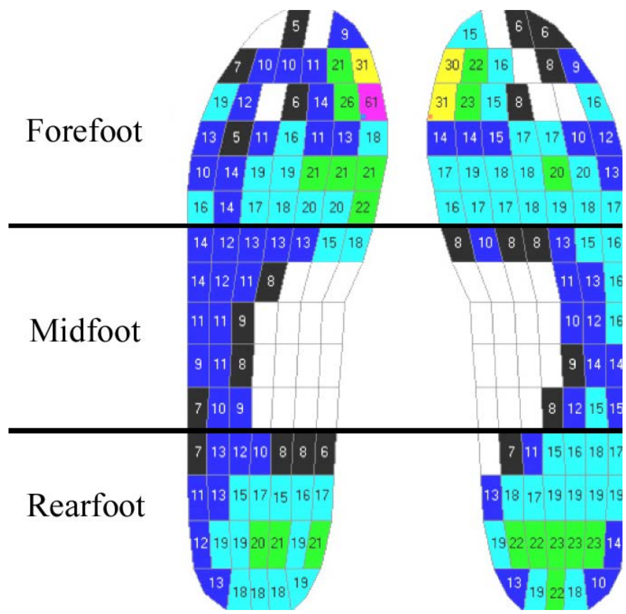


Fig. 8. Definition of masks

G. Sataistical Analysis

Data of plantar foot pressure and muscles activities from NS and CI conditions were analyzed and compared using SPSS 18.0 statistical software (SPSS Inc., Chicago, USA). A paired t-test was performed to compare between data and a statistical significance was determined at $p < 0.05$ level.

III. RESULT

Through a distribution of plantar foot pressure measured in three masks, a contacting area decreased by 2.63 % (NS : 40.24 cm^2, CI : 38.17 cm^2) and 1.5 % (NS : 32.44 cm^2, CI : 31.48 cm^2) respectively in forefoot and rearfoot significantly and increased by 12 % (NS : 30.21 cm^2, CI : 38.45 cm^2) significantly in midfoot when CI condition (Fig. 9, Table 2). A maximum force decreased also by 2.58 % (NS : 312.58 N, CI : 296.83 N) and 3.14 % (NS : 301.66 N, CI : 283.29 N) respectively in forefoot and rearfoot significantly and increased by 29.68 % (NS : 133.87 N, CI : 236.39 N) significantly in midfoot (Fig. 9, Table 2). In case of a peak pressure, it decreased by 0.58 % (NS : 153.5 kPa, CI : 151.73 kPa) significantly in rearfoot and increased by 2.28 % (NS : 171.09 kPa, CI : 179.06 kPa) and 5.58 % (NS : 116.98 kPa, CI : 130.8 kPa) respectively in forefoot and midfoot significantly when CI condition (Fig. 10, Table 2). A mean pressure on CI condition decreased by 0.07 % (NS : 82.51 kPa, CI : 82.39 kPa) and 0.81 % (NS : 94.36 kPa, CI : 92.84 kPa) respectively in forefoot and rearfoot and increased by 10.69% (NS : 52.99 kPa, CI : 65.67 kPa) significantly in midfoot. A mean pressure of forefoot was no statistical significance (Fig. 10, Table 2).

Through EMG measured, muscle activities of RF and TA were decreased significantly by 1.74 % and 5.61 % respectively when CI condition (Fig. 11, Table 3). In case of MBF and MG on CI condition, muscle activities also decreased respectively by 3.01 % and 6.38 % significantly (Fig. 12, Table 3).

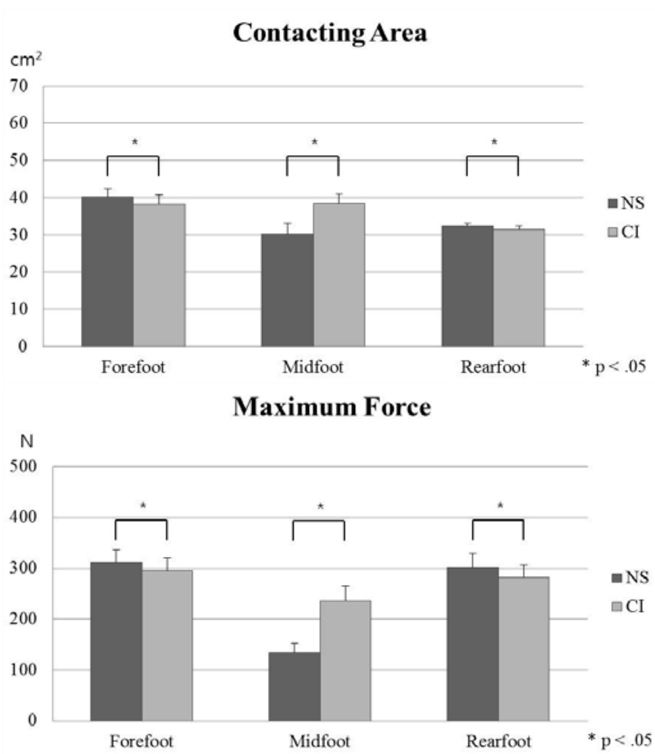


Fig. 9. The results of the contacting area and maximum force

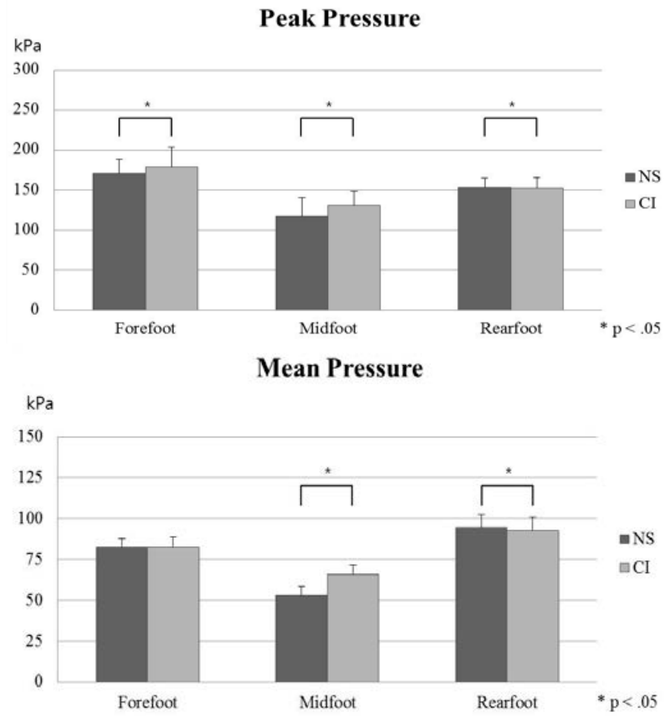


Fig. 10. The results of the peak pressure and mean pressure

Table 2. The result of plantar pressure, * $p < 0.05$

		Normal Shoes (NS)	Custom-made Insoles (CI)
Contacting Area (cm^2)	Forefoot	40.24 ±4.23	38.17 ±4.79*
	Midfoot	30.21 ±5.77	38.45 ±5.16*
	Rearfoot	32.44 ±1.23	31.48 ±1.95*
Force (N)	Forefoot	312.58 ±49.20	296.83 ±53.79*
	Midfoot	133.87 ±37.8	236.39 ±58.49*
	Rearfoot	301.66 ±54.21	283.29 ±48.36*
Peak Pressure (kPa)	Forefoot	171.09 ±34.9	179.06 ±49.4*
	Midfoot	116.98 ±48.33	130.8 ±35.01*
	Rearfoot	153.5 ±22.53	151.73 ±27.48*
Mean Pressure (kPa)	Forefoot	82.51 ±10.81	82.39 ±13.21
	Midfoot	52.99 ±10.83	65.67 ±11.13*
	Rearfoot	94.36 ±15.97	92.84 ±16.14*

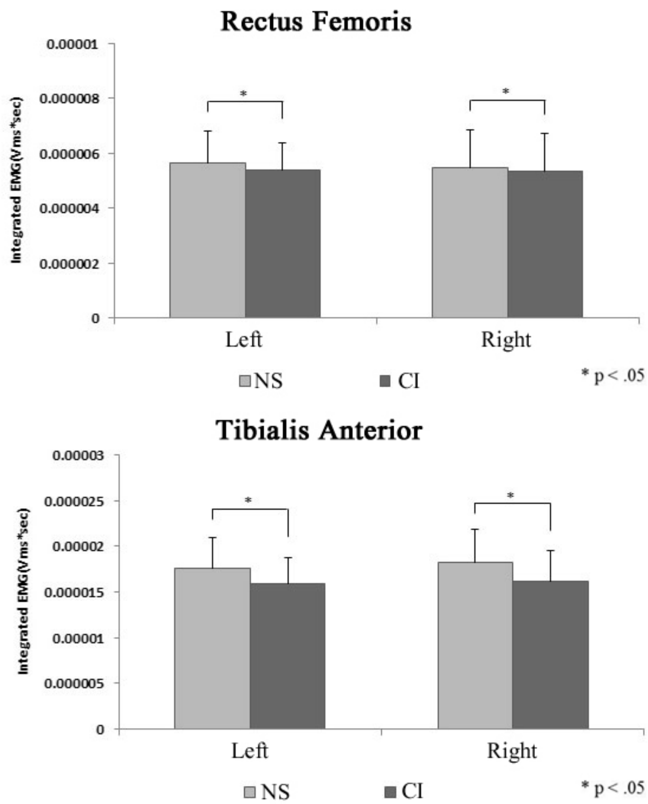


Fig. 11. The result of EMG in Rectus Femoris (RF) and Tibialis Anterior (TA)

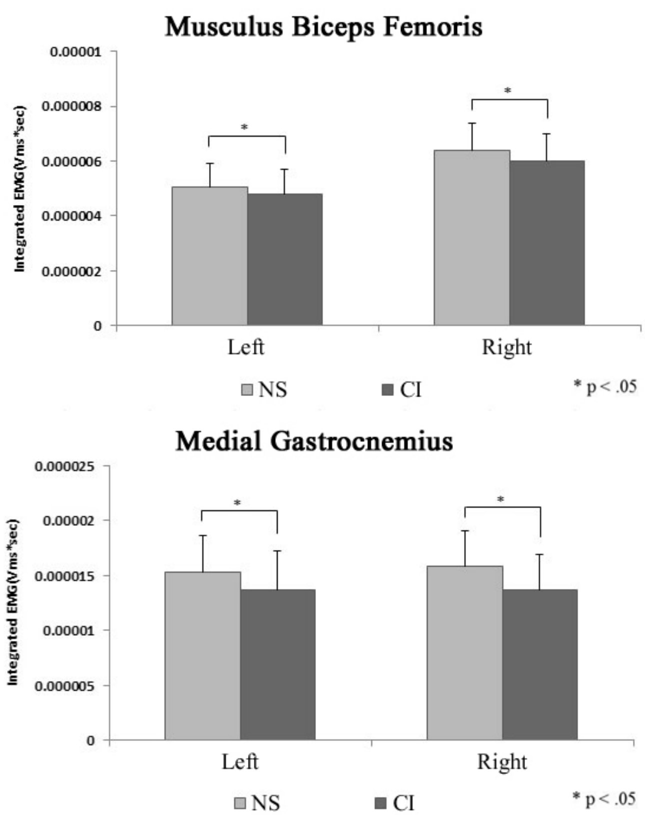


Fig. 12. The result of EMG in Musculus Biceps Femoris (MBF) and Medial Gastrocnemius (MG)

Table 3. The result of EMG, * $p < 0.05$

(unit : Vrms ∗ sec)	Normal Shoe (NS)	Custom-made Insoles (CI)
Rectus Femoris (RF)	0.0056 ±0.0013	0.0054 ±0.0012*
Tibialis Anterior (TA)	0.0179 ±0.0035	0.0159 ±0.0031*
Musculus Biceps Femoris (MBF)	0.0057 ±0.0009	0.0054 ±0.0009*
Medial Gastrocnemius (MG)	0.0156 ±0.0033	0.0137 ±0.0034*

IV. Discussion

In this study, the results of comparative analysis on distribution of plantar foot pressure showed that a plantar pressure increased by the weight concentrated on area of forefoot and rearfoot in pes cavus foot. When the subjects walked with wearing custom-made insoles in shoes, a contacting area, a maximum force, peak pressure and mean pressure in midfoot increased significantly by the effects that were structural characteristics which reduced heel tilted out exteriorly and metatarsal pads which distribute a plantar foot pressure in forefoot. As a result, all of the contacting area, the maximum force, the peak pressure and the mean pressure decreased significantly in rearfoot. The contacting area and maximum force also decreased significantly in a forefoot. However, the peak pressure increased and the mean pressure had no significant difference. This results were judged by the influence of 2/3 length custom-made insoles which contacted only area of midfoot and rearfoot. A comparative research was, therefore, necessary with full length custom-made insoles for future experiment.

All of the four measured muscle activities decreased significantly when subjects walked with wearing custom-made insoles in shoes. More muscles in the lower limbs are needed to prevent a body unbalance caused by higher MLA of pes cavus deformities. When walking in shoes with wearing custom-made insoles, therefore, a reduction of EMG activity means that custom-made insoles support a relief from burden and a pain on the lower limbs muscles by delaying fatigue.

V. Conclusion

In this study, we evaluated the biomechanical characteristics of lower extremities while 10 females walked in wearing shoes and shoes with custom-made insoles manufactured to relieve pes cavus deformities. The results analyzed data of a contacting area, a maximum force, peak pressure and mean pressure calculated using plantar foot pressure measure system showed that plantar pressure was distributed on forefoot and rearfoot by the increasing contacting area in midfoot. Peak pressure and mean pressure in forefoot had different trends. These results were considered due to the use 2/3 length custom-made insoles, not full length ones. In EMG, all of muscle activities were decreased from the results of activities analyzed on RF and TA concerned in dorsiflexion and MBF and MG concerned in plantarflexion. The conclusion of this study was that custom-made insoles for pes cavus foot affected significantly the biomechanical movement of lower extremities on gait. The result of useful analyses will able to utilize manufacture of functional insoles and lower extremity orthoses for individuals with pes cavus. This study shows that custom-made insoles can improve plantar muscle activities in pes cavus patient.

ACKNOWLEDGMENT

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (2012-3003952) and the Technology Innovation Program (project no. S2044863) funded by the Small & Medium Business Administration (SMBA, Korea).

.

REFERENCES

[1] A. K. Ramanathan, P. Kiran, G. P. Arnold, W. Wang, and R. J. Abboud, “Repeatability of the Pedar-X in-shoe pressure measuring system,” *Foot and Ankle Surgery*, vol. 16, pp. 70-73, Jun 2010.

[2] T. Marasovic, M. Cecic, and V. Zanchi, “Ground Reaction Forces in Gait: Statistical Analysis and Interpretation,” *9th WSEAS Int. Conf. SIMULATION, MODELLING and OPTIMIZATION (SMO ’09)*, Budapest, 2009.

[3] R. A. Donatelli, “The Biomechanics of the foot and ankle,” The F. A. Davis Company, Philadelphia, PA, 1995.

[4] S. Shahid, A. Nandy, S. Mondal, M. Ahamad, P. Chakraborty, and G. C. Nandi, “A study on human gait analysis,” *Second Int. Conf. COMPUTATIONAL SCIENCE, ENGINEERING and INFORMATION TECHNOLOGY (CCSEIT ’12)*, Coimbatore, 2012.

[5] J. Perry, “Gait Analysis,” SLACK, INC., 1992.

[6] S. L. Turek, “Turek’s Orthopaedics: Principles and their application 5th ed.,” Williams & Wilkins, Baltimore, 1984.

[7] J. R. Kim, S. K. Lee, and H. S. Lee, “First metatarsal dorsal close wedge osteotomy combined with medial cuneiform plantar openwedge osteotomy for the treatment of a cavus Foot,” *The Korean Orthopaedic Association*, vol. 45, no. 1, pp. 32-38, Feb 2010.

[8] L. Paulos, S. S. Coleman, and K. M. Samuelson, “Pes cavovarus. Review of a surgical approach using selective soft-tissue procedures,” *J Bone Joint Surg. Am*, vol. 62, pp. 942-953, 1980.

[9] M. Sabir, and D. Lyttle, “Pathogenesis of pes cavus in Charcot-Marie-Tooth disease,” *Clin Orthop Relat Res*, vol. 175, pp. 173-178, 1983.

[10] I. J. Alexander, and K. A. Johnson, “Assessment and management of pes cavus in Charcot-Marie-tooth disease,” *Clin Orthop Relat Res*, vol. 246, pp. 273-281, 1989.

[11] R. Sanders, P. Fortin, T. DiPasquale, and A. Walling, “Operative treatment in 120 displaced intra articular calcaneal fractures. results using a prognostic computed tomography scan classification,” *Clin Orthop Relat Res*, vol. 290, pp. 87-95, 1993.

[12] Z. Azmaipairashvili, E. C. Riddle, M. Scavina, and S. J. Kumar, “Correction of cavovarus foot deformity in Charcot-Marie-Tooth disease,” *J pediatr Orthop*, vol. 25, pp. 360-365, May-Jun 2005.

[13] M. G. Benedetti, F. Catani, F. Ceccarelli, L. Simoncini, S. Giannini, and A. Leardini, “Gait analysis in pes cavus,” Gait Posture, vol. 5, no. 2, pp. 169, 1997.

[14] A. H. Franco, “Pes cavus and pes planus: analysis and treatment,” Physical Therapy, vol. 67, no. 5, pp. 688-694, 1987.

[15] J. Burn, J. Crosbie, A. Hunt, and R. Ouvrier, “The effect of pes cavus on foot pain and plantar pressur,” *Clinical Biomechanics*, vol. 20, no. 9, pp. 877-82, Nov 2005.

[16] D. M. Brody, “Techniques in the evaluation and treatment of the injured runner,” *Orthopedic Clinics of North America*, vol. 13, no. 3, p. 541–58, 1982.

[17] R. D. D’Ambrosia, “Orthotic devices in running injuries,” *Clinics in Sports Medicine*, vol. 4, no. 4, pp. 611-618, Oct 1985.

[18] V. Oleksik, A. Pascu, C. Deac, R. Fleaca, and M. Roman, “Experimental strain field distribution in ankle-foot orthosis (AFO),” 2nd *WSEAS Int. Conf. BIOMECHANICAL ELECTRONICS and BIOMEDICAL INFORMATICS (BEBI ’09)*, Moscow, 2009.

[19] J. Y. Jung, J. H. Kim, K. Kim, P. H. Trieu, Y. G. Won, D. K. Kwon, and J. J. Kim, “Evaluation of Insole-equipped Ankle Foot Orthosis for Effect on Gait based on Biomechanical Analysis,” *Korean Journal of Sport Biomechanics*, vol. 20, no. 4, pp. 469-77, Dec 2010.

[20] M. Badescu, I. Bondrea, and A. Muntean, “About Ankle-Foot Orthosis Optimization,” 5th *WSEAS Int. Conf. ENGINEERING MECHANICS, STRUCTURES, ENGINEERING GEOLOGY (EMESEG ’08)*, Heraklion, 2008.

[21] B. M. Nigg, W. Herzog, and L. J. Read, “Effect of viscoelastic shoe insoles on vertical impact forces in heel-toe running,” *The American Journal of Sports Medicine*, Vol. 16, pp. 70-76, Jan-Feb 1988.

[22] G. P. Brown, R. Donatelli, P. A. Catlin, and M. J. Wooden, “The effect of two types of foot orthoses on rearfoot mechanics,” *The Journal of Orthopaedic and Sports Physical Therapy*, vol. 21, no. 5, pp. 258-67, May 1994.

[23] E. Chantelau, and P. Haage, “An audit of cushioned diabetic footwear: relation to patient compliance,” *Diabet Med*, vol. 11, no. 1, pp. 114-116, 1994.

[24] J. J. Wertsch, L. W. Frank, H. Zhu, M. B. Price, G. F. Harris, and H. M. Alba, “Plantar pressures with total contact casting,” *J Rehabil Res Dev*, vol. 32, no. 3, pp. 205-9, 1995.

[25] M. E. Edmonds, “Progress in care of the diabetic foot,” *Lancet*, vol. 354, no. 9184, pp. 270-272, Jul 1999.

[26] S. Albert, and C. Rinoie, “Effect of custom orthotics on plantar pressure distribution in the pronated diabetic foot,” *The Journal of foot and ankle surgery*, vol. 33, no. 6, pp. 598-604, Nov-Dec 1994.

[27] C. M. Windle, S. M. Gregory, and S. J. Dixon, “The shock attenuation characteristics of four different insoles when worn in a military boot during running and marching,” *Gait & Posture*, vol. 9, no. 1, pp. 31-37, Mar 1999.

[28] J. H. Kang, M. D. Chen, S. C. Chen, and W. L. His, “Correlations between subjective treatment responses and plantar parameters of metatarsal pad treatment in metatarsalgia patients: a prospective study,” *BMC Musculoskeletal Disorders*, vol. 7, pp. 95, Dec 2006.

[29] M. J. Mueller, D. J. Lott, M. K. Hastings, P. K. Commean, K. E. Smith, and T. K. Pilgram, “Efficacy and Mechanism of Orthotic Devices to Unload Metatarsal heads in People with Diabetes and a History of Plantar Ulcers,” *Physical Therapy*, vol. 86, no. 6, pp. 833-42, Jun 2006.

[30] L. K. Dahle, M. Mueller, and A. Delotto, “Visual assessment of foot type and relationship of foot type to lower extremity injury,” *J. Ortho. Sport Phy., The.*, vol. 14, pp. 70-74, 1991.

[31] M. L. Root, W. P. Orien, and J. H. Weed, “Normal and abnormal function of the foot,” *Clinical biomechanics*, vol 3-60, 1977.

[32] S. B. Kim, K. S. Yoon, H. S. Park, H. Kwak, N. J. Ha, and J. S. Park, “Radiologic Measurement of Flatfoot,” *Korean Academy of rehabilitation Medicine*, vol. 24, no. 5, pp. 995-1001, 2000.

[33] T. K. Kim, S. B. Park, and K. M. Lee, “A Study on Assessment of Medial Longitudinal Arch by Foot Printion,” *Korean Academy of rehabilitation Medicine*, vol. 19, no.1, pp. 49-54, 1995.

[34] J. M. Park, K. W. Kim, Y. H. Lee, and H. K. Jung, “A Diagnostic Significance of Simple X-ray Examination for Children's Flatfoot in Footprint,” *Korean Academy of rehabilitation Medicine*, vol. 23, no. 4, pp. 835-41, 1999.

[35] S. J. Cha, Y. H. Kim, N. J. Lee, and W. H. Seo, “Diagnostic Measurements of Flatfoot,” *The Korean society of Radiology*, vol. 24, no. 3, pp. 439-41, 1988.

[36] M. W. Comwall, and T. G. Mcpoil, “Footwear and foot orthotic effectiveness research : a new approach,” *J. Ortho. Sport Phy., The.*, vol. 21, no. 6, pp. 337-44, 1995.

[37] R. L. Bordelon, "Surgical and Conservative Foot Care," Charles B. Slack, Thorofare, NJ, 1988.
[38] J. Gould, "The Foot Book," Williams & Wilkins, Baltimore, 1988.
[39] R. L. Bordelon, "Management of disorders of the forefoot and toenails associated with running," *Clinics in Sports Medicine*, vol. 4, no. 4, pp. 717-24, 1985.
[40] T. Ryu, H. S. Choi, H. Choi, and M. K. Chung, "A comparison of gait characterstics between Korean and Western people for establishing Korean gait reference data," *Industrial Ergonomics*, vol. 36, pp. 1023-1030, Dec 2006.
[41] E. H. Kim, H. K. Cho, T. W. Jung, S. S. Kim, and J. W. Jung, "The biomechanical evaluation of functional insoles," *Korean Journal of Sport Biomechanics*, vol. 20, no. 3, pp. 345-53, Sep 2010.
[42] A. B. Putti, G. P. Arnold, L. Cochrane, and R. J. Abboud, "The Pedar in-shoe system: Repeatability and normal pressure values," Gait & Posture, vol. 25, no. 3, pp. 401-405, 2007.

Jung-Kyu Choi He received the B. S., M. S. degree from the Chonbuk National University, Republic of Korea, in 2011 and 2013, respectively. He is currently pursuing a doctorate in foot biomechanics at the university. His major research interest is the podiatry, and biomechanics.

Ji-Yong Jung He received the B. S., M. S. degree from the Chonbuk National University, Republic of Korea, in 2010 and 2012, respectively. He is currently pursuing a doctorate in biomedical informatics at the university. His major research interest is the medical informatics, podiatry, and biomechanics.

Hwa-In Kim She received the B. S., M. S. degree and a medical doctor's license in medical school from the Wonkwang University, Republic of Korea, in 1996, 1999 and 2001, respectively. She is currently doing medical practice in the Foot Clinic of Jeonju Pediatrics

Yonggwon Won He received the B. S. in Electronics Engineering from Hanyang Univesity in 1987, and M. S. and Ph. D. degrees in Electrical and Computer Engineering from University of Missouri-Columbia in 1991 and 1995, respectively. He worked with Electronics, and Telecommunication Research Institute (ETRI) from 1995 to 1996, and Korea Telecomm (KT) from 1996 to 1999. He is currently a professor in Chonnam National University in Korea, and the director of Korea Bio-IT Foundary Center at Gwangju. His major research interest is the computational intelligence for image analysis, pattern recognition, network and communication security, bio and medical data analysis.

Jung-Ja Kim She received the B.S., M.S. degree in 1985, 1988 and Ph.D. degree from 1997 to 2002, in Computer Science from Chonnam National University respectively. She worked with electronic telecommunication Laboratory at Chonnam National University from 2002 to 2004, and Korea Bio-IT Foundry Center at Gwangju from 2004 to 2006. She is currently an assistant professor at Chonbuk National University. Her major research interet is the bio and medical data analysis, database security, and pattern recognition.