APPLICATION OF CUSTOM-FIT FOOT ORTHOSES TO ENHANCE ATHLETIC PERFORMANCE –EXAMPLES IN RUNNING AND CYCLING

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Running or cycling related soft tissue and joint injuries of the lower extremities are thought mainly due to the malalignment of skeletal structure which causes muscle overuse activity and high joint obstruct loading. In correcting this abnormal foot and lower extremity dysfunction, functional foot orthoses (or orthotic) are often prescribed to control abnormal foot motions and to alter the abnormal joint loadings, particularly for the over- pronated foot. They are many types of orthosis on the market, most of off-shelf products and expensive custom made ones are usually exaggerated, some even provides misleading concepts, which results in over expectation from users. Many recent literatures have challenged the accepted concept that the foot dysfunction is necessary associated with sports injury, and the orthosis is good prescription for sports injury prevention. The disagreement of efficacy of functional orthosis may be caused by the experimental setup of biomechanical researches and underlined abnormality of recruited individuals. This paper presented three separate studies to reveal the efficacy of foot orthosis in sports injury prevention and pitfall of experimental design.

KEY WORDS: Cycling, Foot orthotic, sports injury, skeletal malalignment

INTRODUCTION: About 50% of runners are injured at once per year; the repetitive loading on the lower extremity and overuse of soft tissues are thought to be associated with a number of injury problems including stress fractures, shin splints, cartilage breakdown, osteoarthritis, and low back pain. Person who has dynamic or static structure malalignment of the leg axis as well as the foot type likely suffers in these Musculoskeletal related injuries; for instance, genu varum or valgum usually results in excessive or insufficient tibial rotation, when combined with excessive foot pronation or supination would increase the abnormal muscle actives and joint moments (Bruggmann 2007). Therefore, sport shoes are designed for maximizing the performance and minimizing the injury; foot orthoses are used further to alter the foot motion pattern and reduce the loading impact on the lower extremities for overuse injury prevention. However, the efficacy and function of either custom made or prefabricated orthoses are questioned and debated from time to time; for instance, in a group of female recreational runners study, the custom foot orthotic intervention showed significantly decreased in rearfoot eversion angle, ankle inversion moment, and loading rate during the load phase, and increased in knee external rotation moment, and significant decrease in pain (MacLean 2008). But systematic literature reviews concluded that the function of foot orthosis is only in rearfoot motion control of reducing the ankle inversion moment (Razeghi 2000, McMillan 2008); and the evidence in the overuse injury prevention and pain relief is insufficient(Richter 2011).

All the efficacy studies are evidence based on the either kinetic (force platform or plantar sensor parameters, joint forces and joint moments) or kinematic data (tempo parameters, joint ROM) during a gait analysis; if the conflict results due to the characters of foot type and leg axis of participants, or the variance of recruited subjects ?

In order to answer the question, we conducted a series of studies in prescribing prefabricated orthoses to each individual according to one's leg axis pattern and foot type.

METHODS:

A. Effect of arch support insert for high arch foot in normal walking study

Participants: Twenty six healthy university students were recruited with the age ranged from 18 to 25 years and average BMI ranged from 19.5 to 19.9. Institutional Review Board (IRB) was approved by the Shin Kong Wu Ho-Su Memorial Hospital, Taipei, Taiwan. All participants were informed the detail of test and signed the consent form before the evaluation.

The foot type was examined first by the Harris mat and classified into normal (N) and high arch(HA) according to the arch index (AI)(Cavanagh 1987), among them 6 males and 11 males classified as the high arch (0<AI<0.19), and 4 males, 3 female were normal arch (0.21<AI<0.25) 14 normal feet including 8 males and 6 females.

Procedures and instrumentation: off-shelf 3/4 orthoses (arch insert) with several foot length sizes were used in this study (made of polypropylene, shore A 90, arch height 2.5~2.9cm, Powerstep, Dr Kong, HK). flat outsole and canvas upper Kong-fu shoes were used as the baseline shoes, and an off-shelf sneaker as the control shoes. Body segment kinetics and kinematics in each condition were measured using an eight-camera motion-capture system (MX13, Vicon, Oxford, UK) with three force platforms (AMTI, USA), and Pedar insole plantar pressure system (Novel, Germany). 16 markers were placed on low extremities according to the modified Helen Hayes model. Each subject warmed up for 5 min at a self-selected cadence walking on a 10 meter-long walk way, then five successful trials in each random order of barefoot, Kong-fu shoes (kf), sneaker(ss), with/o orthosis (kfA,ssA) were selected for data analysis. Prior the gait analysis, each subject had the feet X-ray examined and ankle range of motion, plantar ulcer, voluntary muscle force, foot length and girths measured.

Data analysis and statistics

The independent variables were gender, foot type, footwear, and with/o orthosis. Chi square test was performed first to test gender effect on two foot types, sports activity, and regular footwear worn preference. Age, height, BMI, foot measurement, angle ROM were examined using t-test. The instrumentation measured variables were peak ground reaction forces, force-time integration, peak plantar pressure, CoP trajectory, CoP speed, joint ROM, joint moment. A two-way MANOVA was examined for main effects on the foot type and footwear with/o orthosis factors. Post hoc test was used to conduct pairwise comparisons of the main effects with the α level 0.05.

RESULTS and DISCUSSION: The anthropometric measured showed no difference between two groups in age, height, body weight, BMI, foot dimension measurements, ankle ROM tests, and tempo parameters. The bare foot examination revealed the high arch foot presented high occurrence of callus formation at the medial site of hallux (Williams et al 2001).

In the condition of barefoot gait, the HA group showed significant smaller vertical reaction forces *(p=0.015)*at the push off phase (Fig 1-a), significant lower medical reaction force through the stance phase (Fig 1-b), and significant smaller fore-aft reaction force *(p=0.021, 0.029)*at the loading response and push off phase, respectively (Fig 1-c).

The kinetic data were corresponded to the kinematic observations, the HA group presented significant smaller knee internal rotation, smaller ankle dorsiflexion, internal rotation, and eversion, inversion angles, and associate ankle moments except the higher dorsiflexion moment at the loading response. This result is different from previous study (Benedetti, 1997).

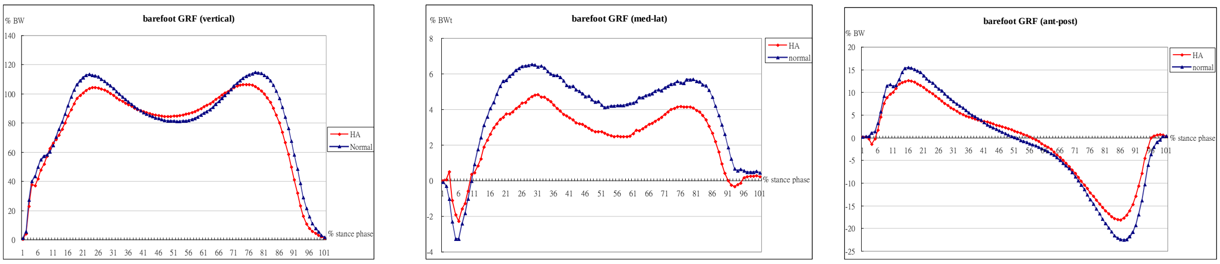

Fig. 1-a vertical ground reaction force, Fig. 1-b medical-lateral Fig. 1-c fore-aft

In the gait analysis, the HA group showed significant higher peak plantar pressure(PPP), pressure-time integral(PTI) at the hindfoot and forefoot regions. With the orthosis, PPP and PTI decreased at hindfoot and MTH regions, but PTI increased at the hallux.
After wearing the orthosis, the HA group had similar kinetic and kinematic data with the normal group, except the plantar pressure parameters. There was a trend that the peak pressures at LH, MH, M1-5, and T1 region when shod Kong-fu shoe was higher than the N group, but it did not reach a statistical difference. The arch support insert decreased the peak pressure at heel and MTH regions, but increased at T1 region (Fig 2a).And this effect was less significant when shod sneakers (Fig 2b). Apparently, the rigid foot orthosis did provide a hindfoot stability when worn the soft unsupported footwear.

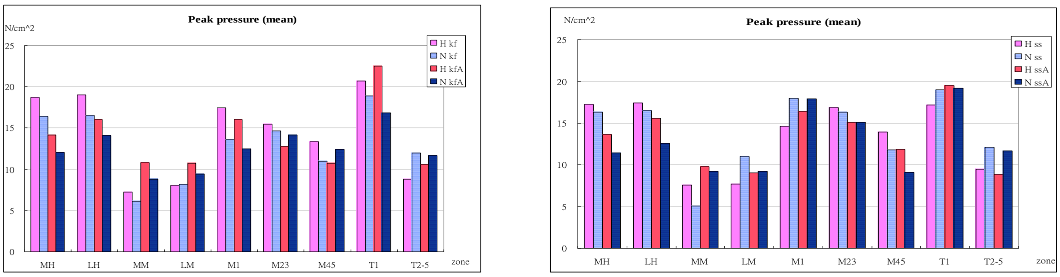

Fig 2: Effect of arch insert in different foot type when wearing heel unsupported (a) and firm heel footwear (b)

CONCLUSION: High arch subjects presented less internal rotation, smaller dorsiflexion motion and ankle moment, which resulted in lower ground reaction forces but higher peak pressure and PRI at hindfoot and forefoot. With a proper arch insert or sports footwear, the high arch subject could restore a similar kinetic and kinematic pattern of normal foot subject and possible of injury prevention.

B. The efficacy of foot orthosis in controlling the motion dysfunction of over pronated foot in running

The previous study showed a good intervention of foot orthosis for the high arch young adults to correct their gait pattern similar to that of the normal ones. The second research was to investigate the efficacy of different arch insole in controlling over pronated foot motion during running using a multi-segments motion analytical model. The flatfoot (or over pronated) subject usually acquires excessive rearfoot pronation, which results in lower extremities injury especially in running. Researches and clinical studies have evidenced that the foot orthosis is an effective intervention to control the rearfoot motion and to reduce the foot injury.
Procedures and instrumentation: Sixteen subjects with Arch Index (AI) larger than 0.3 and fifteen age-matched healthy controls with AI ranged 0.21 to 0.25 were recruited. Studies were carried randomly in bare foot, wearing the no arch support insoles (Footdisc®, Taiwan), soft- lower arch-support insoles (Footdisc®, Taiwan), and rigid-high arch-support insoles (Power Step®, Dr. Kong, HongKong). Insoles were properly taped over plantar area and subjects were running on the treadmill at 12Km/hr. Forty reflected markers were placed on the bilateral lower extremities as suggested by Leardini (Leardini et al., 2007) and Modified Helen Hayes Model. The instrumentation and data reduction as well as the statistical analysis were same setup as the previous one. The observation was particularly focused on the calcaneus-to-shank, midfoot-to-calcaneus, and forefoot-to-midfoot three-dimensional foot segmental motions.

Results and Discussion

The results showed the flat foot group had significant average angle measurements in rear foot eversion/inversion ROM, tibia torsion, forefoot varus angle, leg-floor adduction, and heel-leg eversion angle. In bare foot running condition, the flatfoot subjects and normal foot

subjects had similar ROM pattern in knee flexion/extension, ankle dorsi/plantar flexion, and rearfoot (calcaneus-shank) dorsi/plantar flexion; but presented profound foot-segments kinematics in eversion/inversion and external/internal motions (Fig 3). With orthoses, three types of insoles demonstrated no significant affecting on rear/mid foot segmental motions; but did reduce the range of plantar/dorsi motion at forefoot segment (Fig 4), Surprising that the control of range of motion were about the same regardless of height and rigidity of arch support.
This result is different from the common concept of wearing the arch-support insoles could decrease the motion of rearfoot pronation for people with flat foot (MacLean 2006, Mündermann 2003, Zammit 2007). Our results suggest that the function of an orthosis affects more in forefoot motion rather in rear foot particularly during running.

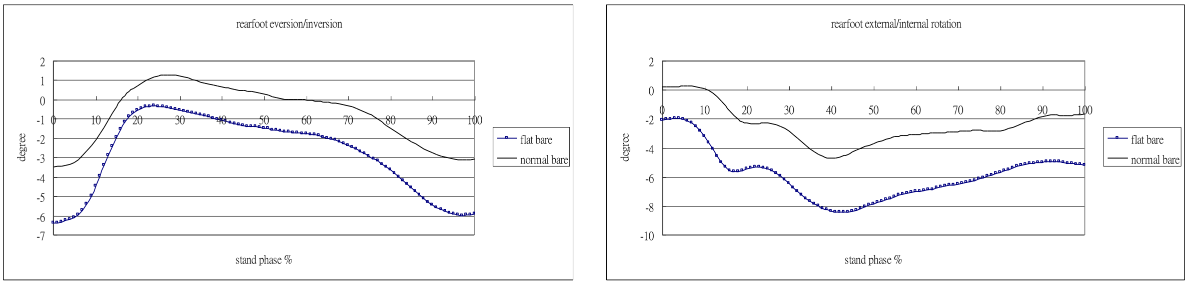

Fig 3: profound rearfoot motion pattern between normal foot and flat foot

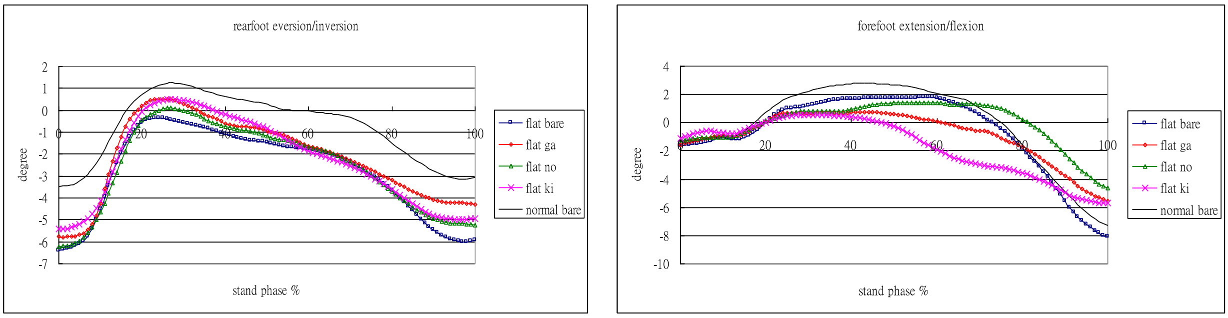

Fig 4: Effect of an orthosis in rearfoot and forefoot motion

CONCLUSION: The runners with over pronated foot demonstrated larger eversion/inversion ROM in the rear/mid foot segment. Without wearing the footwear the arch support orthotics alone significantly controlled the forefoot motion rather than other foot segments, and there is no difference in these three types of insoles.

C. The efficacy of arch support orthosis in increasing the cycling performance

Without boundary support of the footwear, the foot orthosis (or an arch support insole) performs almost no function in foot segment motion control as demonstrated in the previous study. The third section presented if the orthosis was good in increasing the cycling performance and muscle overuse injury prevention.
Bicycle riding is an increasingly popular recreational and competitive activity, however, the more popular the more biking-related injuries. Most of cycling injuries are musculoskeletal related and caused by a combination of inadequate preparation, inappropriate bike fitting, poor technique, and overuse of prolong uphill biking (Willber etal1995, Callaghan etal 2005). Excessive or insufficient movement of lower extremity joints due to the leg alignment and foot types might be an important factor that mainly causes the muscular injury after an appropriate bike fitting (Sanner et al 2000, Callaghan etal 2005).
Procedures and instrumentation: Twenty-three male professional cyclists were recruited for this study. The average age was 28± 12 years old, height (175±3.8cm), weight (65± 5.5Kgs), and BMI(21.4±1.9) with excluding criteria of LE musculoskeletal disorder, neurological disorder, joint replacement, trauma, or any other surgery affected the evaluation.

Subjects were classified into normal, high or low arch foot type according to the arch index with straight, genu varum, or genu valgum leg alignment. Three types of insoles: off-the-shelf EVA flat insoles, cycling sports insole with/o arch support (Footdisc®-Passi)
Surface electromyographic (EMG) data were collected from seven muscles: Gluteus maximum (GM),Biceps femoris (BF),vastus medialis (VM),vastus lateralis (VL),tibialis anterior (TA),medial head of gastrocnemius (GA),and peroneus longus (PL) with a sampling rate of 960Hz (MA-300 Motion Lab Systems ,USA)(Baum et al 2003).
Motion analysis was performed with three insoles in a random order, kinematic data were recorded using a passive marker motion capture system (8 cameras MX13, Vicon, UK) (Sauer et al 2007, Bini et al 2010). Participants rode his own road bicycle on a computerized ergometer set at 150W (Elite RealPower). Each subject warmed up for 10 min at a self-selected cadence before data collecting. Data were checked the normality first, A repeated measure 2-way ANOVA was examined for main effects on the foot type and orthoses factors. Post hoc test was used to conduct pairwise comparisons of the main effects with with the significance of the α level 5%.
Results and Discussion: The ROM of the knee joint had no significant difference between different insoles worn. The ROM at the ankle in frontal and transverse planes did show the significant difference.
To prevent the repeated-overuse muscle injury, the motion trajectories of knee and ankle joints should move in a very narrow oval or figure-eight-shaped excursion with the long axis oriented vertically in order to minimum VMO activity as well as patellofemoral joint compression (Sanner 2000).Subjects with straight leg and high arch foot demonstrated the best muscle power saving, and runner up by subjects with straight leg axis and normal arch foot, genu valgum with flat arch foot was the worst pattern. With arch support orthosis, the excursion was effetely reduced (Fig 5).

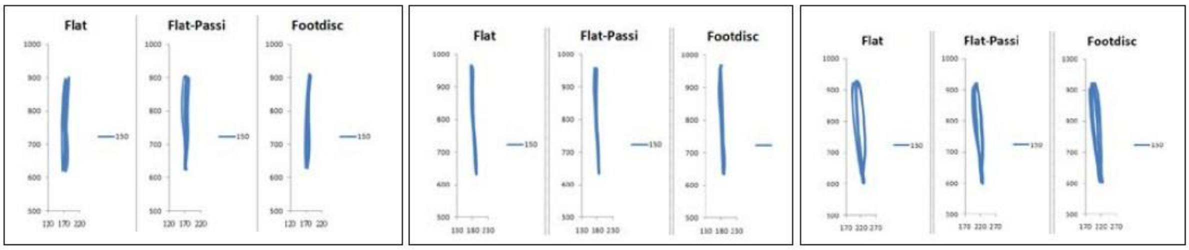

Fig 5: excursion reduction with arch support orthosis, left: straight leg-high arch foot, mid: straight leg-normal foot, right: genu valgum-flatfoot

VL, VM, GM are the major muscles produce the pedal power especially in an upper-hill cranking. The overuse injury is most likely occurred in these muscles. If the muscle activity time reduces but muscle power increase should reveal more effective riding. With arch support orthosis intervention, it significantly shortened the muscle activity duration in 45°~135° crank stroke but increased the muscle peak power as shown in Fig 6.

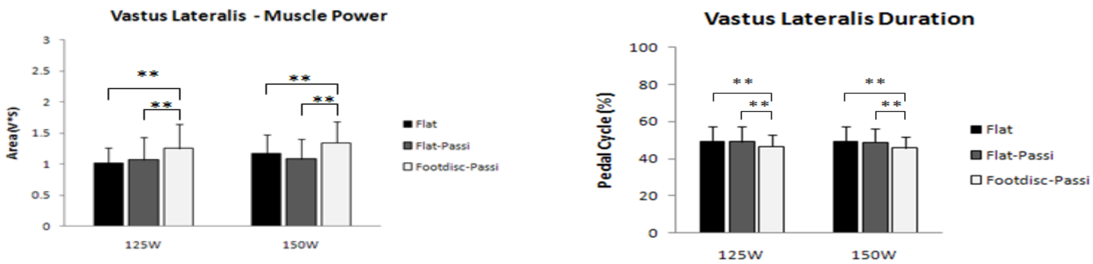

Fig 6: significant increase of muscle power but decrease of activation time with arch support insoles

CONCLUSION: over-pronated foot with genu valgum would produce maximum knee excursion which resulted in inefficient muscle activity, the arch support insoles could effectively provide knee and ankle dynamic stability during the power phase of cycling which resulted in increasing the muscle power and reducing the muscle fatigue.

Orhtosis alone doesn't provide foot motion control and foot dynamic stability. To perform its best function, it must be shod with a pair of good footwear. It is particular useful in preventing musculoskeletal injury and excelling the sports achievement for the subject with malalignment leg-axis and over pronated foot or high arch foot.

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