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MYOELECTRIC STIMULATION ON GLUTEUS MEDIUS OR BICEPS FEMORIS REDUCED KNEE VALGUS TORQUE DURING A FORWARD LANDING TASK

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Anterior cruciate ligament injury can be caused by excessive knee valgus torque. This study demonstrated the effect of myoelectric stimulation to the gluteus medius and biceps femoris on the reduction of knee valgus torque. Twelve females performed a forward drop landing task in a biomechanics laboratory. A 130V myoelectric stimulation was delivered to either or both the gluteus medius and biceps femoris through electrodes of different size (38 or 19 cm^2) when the subject landed. A motion analysis system was used to obtain the normalized knee valgus torque data. Results showed a significant drop from 15.7 Nm to 11.0-11.4 Nm in stimulating either one muscle with the big electrodes. The technology could be a new option to be implemented as active functional sport apparel for the prevention of sport-related injury induced by knee valgus spraining motion.

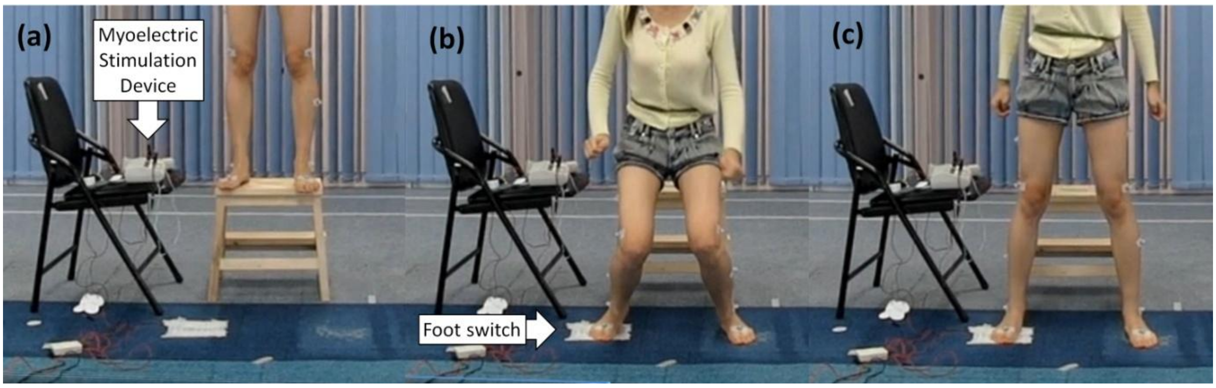
KEY WORDS: Anterior cruciate ligament, sports injury, injury prevention, prophylactic device.

INTRODUCTION: The anterior cruciate ligament (ACL) is a commonly injured structure at the knee joint during sport-related injuries. Kobayashi et al. (2010) concluded from a 20-year study on ACL injury mechanisms of 1,700 athletes that around half to 75% of these injuries were caused by a knee-in and toe-out mechanism. Clinically, the mechanism was presented to be the occurrence of sudden excessive valgus motion at the knee joint. Quantitatively, previous studies reported that the knee valgus angle had reached 12-15 degrees within 30-40ms after foot strike in injury incidents causing ACL rupture in basketball and handball sports (Krosshaug, Slauterbeck, Engebretsen, & Bahr, 2007). In addition, Koga et al. (2010) further suggested that the valgus plus an excessive internal rotation as the cause, which have caused excessive external rotation as the consequent.
The Fédération Internationale de Football Association (FIFA) has been promoting the “11” program which was proven effective in reducing lower limb injury in football, by bringing the incorrect “knee-in toe-out” alignment back to a correct lower limb orientation (Soligard et al., 2008). There were also prophylactic knee braces for the purpose; however, these braces would also inhibit sport performance, cause early fatigue, increase energy expenditure and oxygen consumption, and others (Najibi & Albright, 2005). Another type of thin neoprene knee sleeve was also commonly used, but such may have enhanced the proprioception of the knee joint instead of provided mechanical support (van Tiggelen, Coorevits, & Witvrouw, 2008).
Recently there was an invention to deliver myoelectric stimulation to shank muscles to prevent ankle sprain injury when such a hazard appeared (Fong, Chu, & Chan, 2012). The device only gives mechanical support by assisting the muscle reaction to generate muscular forces when in need, and allows the athlete to have an agile ankle joint for most of the time for the best performance. We believe that a knee sprain injury could be prevented by the same way, by externally stimulating certain muscles, i.e. gluteus medius, to abduct the hip joint to change the “knee-in” or valgus orientation back to a neutral straight alignment. In addition, to tackle the excessive internal rotation which was suggested to be a cause of ACL rupture, stimulating knee joint internal rotator muscle, i.e. biceps femoris, may also help preventing the injury. This study investigated the effect of gluteus medius and biceps femoris stimulation on the reduction of knee valgus torque during a forward drop landing task. We hypothesized that

the stimulation delivered right after foot strike during a forward drop landing task would significantly reduce the knee valgus torque.

METHODS: Females demonstrated greater knee valgus torque during a forward drop landing task (Pappas & Carpes, 2012). Therefore, this protocol was employed in this study. Data from a previous study (Dempsey, Elliott, Munro, Steele, & Lloyd, 2012) were used to determine the number of subjects required, assuming a difference of 0.218 Nm/kg to be clinically relevant. A sample size calculation revealed a minimum of 11 subjects would be required with the adoption of alpha of 0.05 and a power of 0.80, and therefore we invited 12 young healthy female adults (age = 22.3 ± 3.6 years, height = 1.62 ± 0.02 m, body mass = 50.2 ± 4.7 kg) with right limb dominance to perform the above-mentioned task from a height of 40 cm in a biomechanics laboratory, as shown in Figure 1. The university ethics committee approved the study, and informed consent was obtained from every subject before the study.

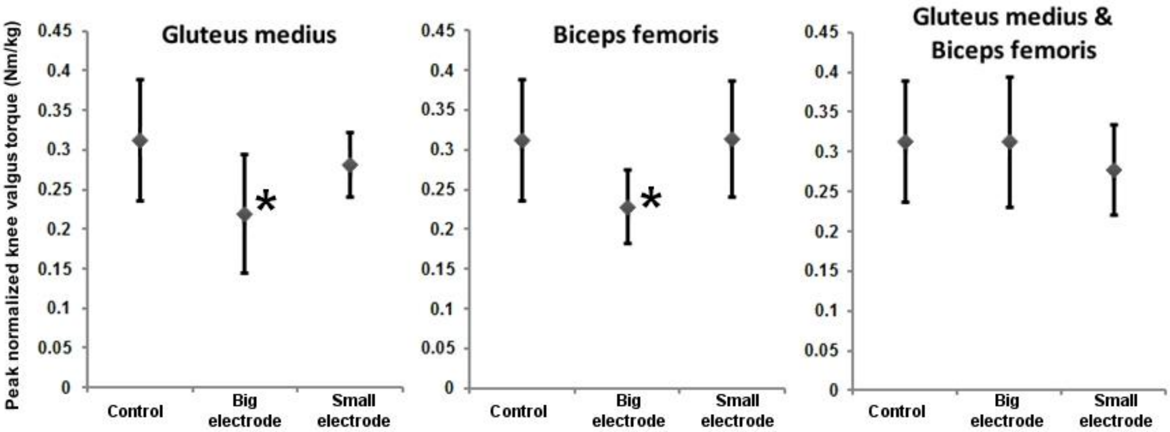
Figure 1: The forward drop landing task in this study. (a) Subject equipped with the myoelectric stimulation device standing at a height of 40cm; (b) Subject jumping off and landing on a footswitch on top of a force plate; (c) Subject returned to a standing position.



A battery-powered device fabricated by the university electronics services unit (Fong et al., 2012) was used to deliver a 130V myoelectric stimulation for 500ms when a foot switch (Force Sensitive Resistor Model 406, Interlink Electronics, USA) was activated by the subject during the landing task, as shown in Figure 1(b). The stimulation was delivered to the right limb through a pair of electrode pads (Panasonic EW4312P, Japan). The original size of the electrode pads (38 cm^2) was used, together with a half size (19cm^2) which was suggested to be effective and comfortable in muscle stimulation in a previous study (Lyons, Leane, Clarke-Moloney, O'Brien, & Grace, 2004). The stimulation was delivered to either one or both of the two muscles (3 conditions), namely the gluteus medius which abducts and laterally rotates the hip joint, and the biceps femoris which flexes and externally rotates the knee joint (Hermen, Freriks, Disselhorst-Klug, & Rau, 2000). These muscles may correct the "knee-in" lower limb alignment, reduce tibial anterior translation, and internal rotation, and may ultimately prevent an ACL rupture. In the case with stimulations to both muscles, the stimulations were delivered by two identical device triggered on by the same foot switch, in order to ensure that each muscle received adequate amount of stimulation instead of portion of the stimulation strength. The sequence of the tests was randomized, and each subject performed 3 jumps for obtaining the average data on each condition (including the control). Fifteen reflective markers were attached to the lower limb following the instructions from a biomechanics textbook (Vaughan, Davis, & O'Conner, 1992). A motion analysis system (Vicon, UK) and a force plate (AMTI, USA) synchronized with the foot switch were used to collect the 3D coordinates of the markers at 500Hz and the ground reaction force data at 1000Hz. The valgus torque of the right knee was calculated by a customized Matlab program. The data were normalized to the subject's body mass, and the peak normalized knee valgus torque within one second after the foot strike in each condition was collected. Sharpiro-Wilk test was conducted and it suggested normality of the parameter. Two-way analysis of variance (ANOVA) with repeated measured was conducted. If interactive effect of electrode size and location of muscle stimulation were found, stratified ANOVA was conducted to demonstrate the effect of electrode size on each of the three conditions of muscle stimulation, with Tukey pairwise comparisons conducted between each pair of conditions. If not, ANOVA on each main effect would be conducted. Statistical significance was set at 95% level of confidence.

RESULTS: Two-way ANOVA showed significant interactive (electrode size x condition of muscle stimulation) effect (p = 0.005) and electrode size effect (p = 0.017) but not condition of muscle stimulation effect (p = 0.077). Therefore, stratified ANOVA was conducted to demonstrate the effect of electrode size on each condition of muscle stimulation, as shown in Figure 2. In the control condition the peak normalized knee valgus torque was 0.312 ± 0.076 Nm/kg (or 15.7 Nm if not normalized) for this group of subjects. Significant drop was found in stimulating either the gluteus medius (0.219 ± 0.076 Nm/kg or 11.0 Nm, p = 0.001) or the biceps femoris (0.228 ± 0.046 Nm/kg or 11.4 Nm, p = 0.003) with the big electrodes. All other conditions recorded the value ranging from 0.277 to 0.314 Nm/kg, or 13.9 to 15.8 Nm, which did not differ significantly with the control condition.

Figure 2: The peak normalized knee valgus torque recorded in this study. (*p < 0.05).



DISCUSSION: The testing protocol is this test was a forward drop landing task from a height of 40cm. In the group of female subjects in this study, the recorded knee valgus torque ranged from 11.0 to 15.8 Nm. There was one previous study with male subjects performing overhead jumping catch and landing which recorded the value ranging from 51.0 to 60.9 Nm (Dempsey et al., 2012), and another study with female subjects performing vertical jumping and landing which recorded the value ranging from 43.4 to 60.4 Nm (Myer, Ford, Palumbo, & Hewett, 2005). The values in this study were lower, as the landing task did not include an upward jump, and the landing task were performed bilaterally. We especially employed this protocol as this was the first study to deliver a myoelectric stimulation as an external intervention to alter the landing biomechanics, and therefore a gentler landing task with both limbs would be safer. To date, there is no literature reporting the knee joint kinetics information during accidental sport-related knee sprain injury incidents. There were some studies reporting the estimated ground reaction force during ACL rupture injuries (Koga et al., 2010; Krosshaug et al., 2007), however, knee joint kinetics were not further estimated as it would not be reliable to calculated such from the estimated ground reaction force data. Therefore, we could hardly tell that if the 30.4% drop of knee valgus torque from 15.8 to 11.0 Nm is clinically significant or not, or if such a reduction would be enough to prevent an ACL rupture to occur.
The strategies employed in this study were to abduct the hip by gluteus medius and to externally rotate the tibia by biceps femoris, which were related to femur back to a straight alignment from an excessive “knee-in toe-out” landing posture. Another new strategy would

be to adduct the knee and bring the abducted tibia inward, and this could perhaps be done by assisting the function of the semimembranosus, semitendinosis or gracilis. These are also the choices of autograft in ACL reconstruction surgery, and we suspect that patients undergone ACL reconstruction with these tendons as autograft may have inferior ability to correct the lower limb orientation when an excessive "knee-in toe-out" landing posture occurs.
The small electrodes did not introduce an effect as they may be too small to recruit enough muscle fibres to generate the effect. A surprising result was on the condition with stimulation on both gluteus medius and biceps femoris, which did not show any significant drop of the peak knee valgus torque when compared to the control. In this condition, each muscle group was stimulated simultaneous but separately by two identical myoelectric stimulation devices with same settings. Therefore each muscle had received the same amount of full stimulation instead of sharing the same stimulation from one device. The condition was also not close to be having barely significant difference with the control, as it recorded a similar mean value and standard deviation (0.3117 ± 0.0082 Nm/kg) to that from the control condition (0.3123 ± 0.0076 Nm/kg). From the data, we could not give a suggestion on this surprising result.

CONCLUSION: Myoelectric stimulation through a pair of electrodes of 38cm^2 in size on either gluteus medius or biceps femoris delivered right after foot strike significantly reduced the knee valgus torque during a forward drop landing task performed by a group of young female adults in a biomechanics laboratory. The technology could be a new option to be implemented as active functional sport apparel for the prevention of sport-related injury induced by knee valgus sprain, including anterior cruciate ligament and meniscus rupture.

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