

Knee Orthosis for Anterior Cruciate Ligament Injuries - Kinematics and Comfortability Study

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Abstract. Knee orthosis is commonly used in supporting the knee movement and protecting the anterior cruciate ligament (ACL) injuries from worsening. In clinical practices, there are many types of ready-made orthoses that available in the market. However, different types of orthoses may provide different performances for patient's knee joint. Therefore, this paper attempt to investigate the performance of knee orthoses for ACL-injured knee. Two groups took part in the study; (Group 1) six ACL-injured, (Group 2) four healthy participants, where two types of knee orthoses were adopted; (Brace 1) hinge brace, (Brace 2) sleeve brace with bilateral hinges. The knee joint motions were calculated using kinematics data while comfortability was conducted through surveys. From the findings, Brace 1 produced normal range of motion (ROM) for internal rotation at 5.47° while Brace 2 fall outside of the normal range at 2.165°. Meanwhile, the external rotation for Brace 1 (-13.25°) was lower than Brace 2 (-33.25°). Furthermore, the comfortability analysis suggested that Brace 1 (60%) was more effective than Brace 2 (40%). To conclude, Brace 1 portrayed optimal performance than Brace 2 during dynamic balance activities with reduction in ROM to prevent excessive knee rotation.

1. Introduction

Injuries of anterior cruciate ligament (ACL) are the most common lower limb injuries with approximately 1,920,000 cases every year reported in the United States [1, 2]. Likewise, there were around three to four reports on ACL injuries received by the Sports National Institute (ISN), Malaysia monthly that involved sports such as netball, kick volleyball and hockey [3]. It is worth noting that a complete tear of ACL could lead to poor mechanical stability pattern and irregular level of functional stability [4] which would alter the knee movement and reduce the functional performance of knee due to the accumulation of fluid around the knee joint [1, 5]. In the early 1970s, knee orthoses were introduced and utilized for knee recovery and functionality [6]. Knee bracings after ACL injuries and



reconstructions have been continuously practiced by many specialists although their advantages in clinical inquiries are still unclear and should be investigated [7]. Nonetheless, knee orthoses could provide supports with the purpose to prevent and reduce the severity of knee wounds [8] without weakening the knee joints' executions [6]. Normally, the knee orthoses are made of neoprene with additional support such as metallic pivots that assists knee movement. However, it should be noted that the knee orthoses ought to allow the knee to execute ordinarily and practical for people to participate in their activities instead of reducing their level of performance. Nevertheless, the mechanisms of knees might be adjusted when the orthoses are used on the knee joints. In order to prevent the decrease in performance level, several factors need to be taken into considerations when scientist or specialist wanted to design orthoses. Those abovementioned factors including the weight of the knee orthoses, hinge frictions, strap tightness and absence of physiological kinematics [9]. On the other hand, the knee orthosis system is an excellent alternative for a secure and high-performance applications for ACL-injured knee.

The main function of ACL is to prevent excessive tibial translation from the femur while maintaining the knee stability and securing the knee during rotation [4, 5, 10]. Thus, injuries to the ACL contributed to recurrent knee instabilities [4]. In contrast to the popular opinions, the ACL injuries are commonly caused by non-contact mechanisms that involve internal or external rotational and translational pressure in the knee joint [4]. Besides that, more than 70% of the non-contact injuries contributed to the tears of ACL which implied with the injuries are not directly accessed to the knee and they are critical [1, 5]. The most common reasons of ACL injuries are often incorporated with knee compression, flexion and internal rotation while there are also three quarter of ACL injuries that include minimal or no contact [11].

Generally, our study focused on the risk factors of environments in order to understand the biomechanical integration and epidemiologic knowledge [12]. The use of knee orthoses could reduce the acuteness of the ACL-injured knee [8]. However, they could not completely restore common tibial rotation values by which the knee orthoses after ACL reconstruction were observed to restrict rotation of tibia under low to moderate movements [13]. When functional knee braces (FKB) were applied in a study by Lowe et al. [14], the peak knee extension, flexion torque and considerable reductions in strength were analysed. Apart from that, application of FKB showed that it is susceptible to migration and distal slip during knee movement [15]. The aforementioned literatures studied the influence of FKBs on intramuscular weight, kinematics of knee and related energy cost [16]. To date, there are still unclear advantages in clinical views regarding the bracing after ACL injuries, reconstructions and rehabilitations although they have been practiced widely by numerous specialists [7]. There are many type of FKB that available in the market for clinical use, however, not much literature discussing about the effect of different design for the use of ACL injury. Therefore, this paper is attempted to biomechanically evaluate two different types of FKBs; (1) hinge knee brace and (2) sleeve brace with bilateral hinges in order to assess knee kinematics and comfortability during walking condition.

2. Methodology

In this study, two group of participants comprising of six ACL-injured patient (Group 1) and four healthy subjects with no pathological knee conditions (Group 2) have been chosen [17]. The injured patients were using the same design of braces before joining (approximately between one until six months during the rehabilitation period) as a subject in this study. Our study involved a total of ten participants (n=10) with age ranges of 20 to 24 years old where all of them have signed consent forms to allow this study to be conducted. Two out of ten participants underwent ACL reconstruction (ACLR) between 4-16 weeks. Meanwhile, the remaining four ACL-injured patients did not undergo ACLR and claimed that their ligaments were partially tear (n=4). Similar activity of walking was carried out by all participants in the assessment where a non-braced knee condition was used as a baseline measure. Data on three-dimensional (3D) kinematics of the orthotic knees were gathered by which posterior directed force was applied to the anterior tibia at upper and lower part of straps with

two developments of FKBs associated with daily activities [17]. From the clinical side of view related to efficiency of the FKBs, several standardized and controlled studies were evaluated [18].

2.1. Analysis of kinematics

Two non-vigorous activities were done by the participants under protocol observations. The participants performed walking activities at their comfortable and natural pace on 300 cm runaway with a total walking distance of 600 cm by which at the end of the runaway, they turned to the left and returned to the starting position. The turning activity was carried out to exert high translational and rotational forces to the knee. The accomplishments of the activities were done under two conditions for rehabilitation of ACL injuries where the participants were required to wear two types of FKBs; (Brace 1) hinged knee brace and (Brace 2) sleeve brace with bilateral hinges as illustrated in Figure 1. The subjects were only wearing the knee braces at the injured side of left knee joint.



Figure 1. Functional knee braces (FKB) used in the experiment; (a) Hinge knee brace (Brace 1), (b) Sleeve knee brace with bilateral hinges (Brace 2). The figures were captured and edited from Google search engine.

Five motion capture cameras (Vicon Motion System, United Kingdom) were utilized in recording the kinematics of the lower limbs motions of the participants. The placement of markers on the lower limbs were made on particular bony landmarks of inferior extremities [13] as illustrated in Figure 2. A total of 16 markers were used in the study where 6 markers were placed at each of the lower limb as shown in the figure; right thigh (RTHI), left thigh (LTHI), right knee (RKNE), left knee (LKNE), right tibia (RTIB), left tibia (LTIB), right ankle (RANK), left ankle (LANK), right toe (RTOE), left toe (LTOE), right heel (RHEE), and left heel (LHEE).

The markers were detected by five working infrared cameras by which the motion data were displayed on the Vicon Nexus software. Every walking condition was done 2 times for each session that include walking with non-braced knee, walking with Brace 1 and walking with Brace 2 [19]. Data on the result outcomes of knee extensions, internal and external knee rotations of the participants were recorded and evaluated.

2.2. Comfortability analysis

The comfortability analysis was conducted through surveys with all participants before and after the kinematics assessments. This survey aims to investigate the comfortability of FKBs among participants with ACL injuries without reconstructions, ACL injuries with reconstructions and without ACL injuries. The effectiveness of FKBs and slippage issues during the kinematic assessment were analysed [20]. Development and revisions of part of our survey were assisted by 4 orthopaedic surgeons at Fowler Kennedy Sports Medicine Clinic, 6 physiotherapists and an epidemiologist [20, 21].



Figure 2. Markers' placements on lower limbs of participants for kinematic analysis; (a) without FKBs, (b) with FKBs. Pictures taken from [32].

3. Result and discussion

Fabrication The maximum peak angle of knee extension among the participants (n=10) for the non-braced knee and FKBs (Brace 1 and Brace 2) are shown in Figure 3. For the ACL-injured participants (n=6), the highest peak angle for knee extension was observed for Brace 2 at 4.597° which was 7.529° higher than Brace 1 at -2.932°. Meanwhile, the baseline measure for the knee extension was -1.577° during the non-braced condition which was lower than Brace 2 and slightly higher than Brace 1. With similar trend for the healthy participants (n=4), Brace 2 recorded 12.08° knee extension that was higher than Brace 1 at -0.425° with angle difference of 12.505° between them. The baseline measure for healthy participants for the non-braced (0.96°) was slightly higher than Brace 1 and greatly lower than Brace 2. Based on the figure (Figure 2), the highest peak angle was portrayed by Brace 2 for both healthy and ACL-injured participants (n=10) while the worst value for knee extension was during Brace 1 condition where all participants exhibited negative peak angle that indicates hyperextension of knee. From the findings, Brace 2 was found to be more flexible as it allows higher range of motions (ROM) during knee extensions than the other two conditions (non-braced and Brace 1). Besides that, Brace 2 also managed to prevent hyperextension of knee during walking gait while Brace 1 exhibited slight hyperextension of knee for both ACL-injured and healthy knee.

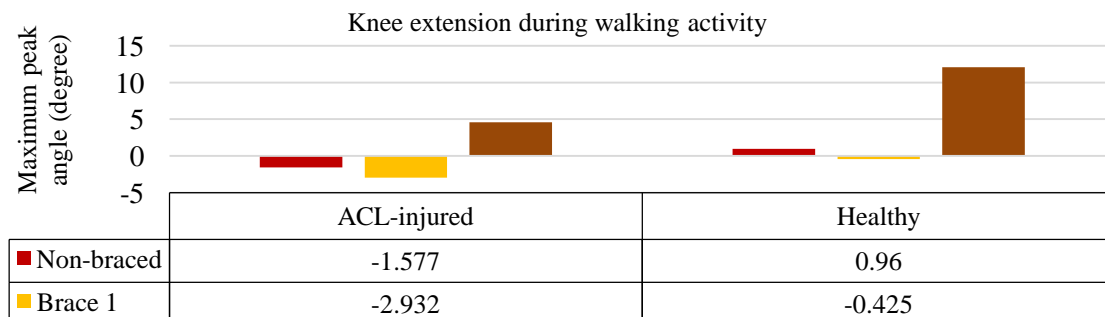


Figure 3. Maximum peak angles during knee extensions among ACL-injured and healthy participants under three conditions; (1) non-braced knee, (2) Brace 1 (hinge brace) and (3) Brace 2 (sleeve brace with bilateral hinges).

On the other hand, the peak angle for internal knee rotations were presented in Figure 4. The baseline measures (non-braced condition) for the all participants (n=10) were recorded at negative values; -9.76° (ACL-injured) and -2.45° (healthy). The FKBs for ACL-injured participants demonstrated higher peak angles than their baseline measure. Meanwhile, the peak angle of non-braced conditions for healthy participants was lower than Brace 1 but greatly higher than Brace 2. In contrast to the results of knee extension (Figure 2), Brace 1 showed higher peak angle for internal knee rotation than Brace 2. Maximum value of 8.33° was found in Brace 1 for the healthy participants (n=4) and 5.47° for the ACL-injured (n=6). Meanwhile, Brace 2 conditions recorded lower peak angles at -26.77° (healthy) and 2.165° (ACL). Among the ACL-injured participants, a difference of 3.305° was found between Brace 1 and Brace 2 while the healthy participants exhibited 35.1° peak angle difference between the two braces. From these comparisons, Brace 2 conditions portrayed higher rigidity since their peak angles during internal knee rotations were lower than Brace 1 conditions among healthy knee. Meanwhile, Brace 1 among ACL-injured participants possessed adequate value of peak angles that reflect its flexibility while still being able to limit the ROM of knee to minimize the risk of injuries.

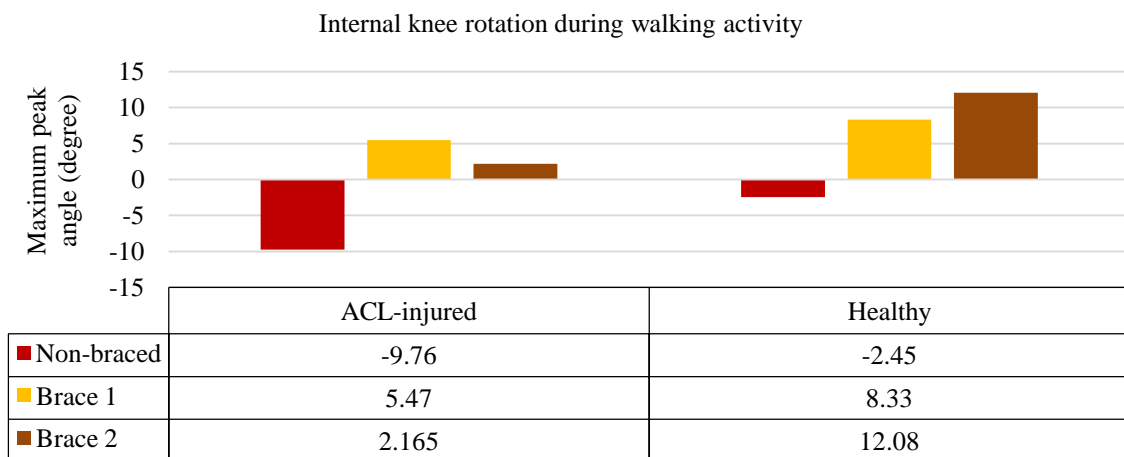


Figure 4. Maximum peak angles during internal knee rotations among ACL-injured and healthy participants under three conditions; (1) non-braced knee, (2) Brace 1 (hinge brace) and (3) Brace 2 (sleeve brace with bilateral hinges).

Figure 5 illustrates the peak angle of external knee rotation for the participants where the negative values represent the angles in external rotation motion. The baseline measure of ACL-injured participants (n=6) was -34.63° which is lower than the healthy participants (n=4) at -42.6° . Higher peak angles were observed in Brace 2 at -33.25° and -49.7° for ACL-injured and healthy participants, respectively as compared to Brace 1. As for the Brace 1, both groups of participants (n=10) demonstrated lower peak angles at -13.25° (ACL) and -10.7° (healthy) with 21% difference between the ACL-injured and the healthy participants. From the figure (Figure 5), it was observed that Brace 2 demonstrated larger peak angles during external knee rotations that were closer to the baseline measures (non-braced) for all ten participants. In contrast to that, the knee rotations with Brace 1 were greatly lower in peak angle values than the other two conditions which implied that Brace 1 exhibited higher rigidity than Brace 2. Thus, Brace 1 was expected to be able in providing better stability and supports for knee motions besides restraining the knee rotations to avoid the ACL acuteness.

The comfortability analysis related to effectiveness of FKBs are shown in Figure 6. Based on the surveys done by all participants (n=10), 40% of them experienced effectiveness for Brace 2 while the remaining 60% preferred Brace 1 as an effective FKB. It should be noted that, higher percentage from this survey did not represent significant effectiveness in this study. However, it is worth noting that participants complied with medical device when it made sense to them and 'seemed effective' [20].

Meanwhile, another comfortability analysis related to slippage issues involving FKBs are presented in Figure 7. Based on the figure, there were 6 out of 10 participants encountered slippage issues with the FKBs during experiments while the rest 4 participants did not experience any slipping. From the 60% of participants (n=6), 50% of them (n=3) experienced slippage with Brace 1 (hinge) while another 33% (n=2) experienced slippage with Brace 2 and the remaining 17% (n=1) did not state which FKB that he or she experienced the slippage with. Based on the results, it could be said that bigger size of Brace 1 might be the reason for more slippage issues than Brace 2.

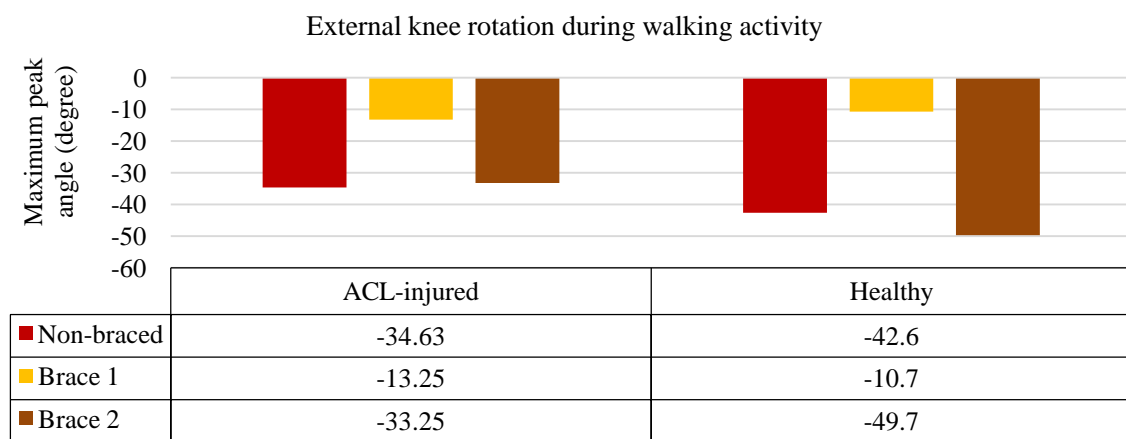


Figure 5. Maximum peak angles during external knee rotations among ACL-injured and healthy participants under three conditions; (1) non-braced knee, (2) Brace 1 (hinge brace) and (3) Brace 2 (sleeve brace with bilateral hinges).

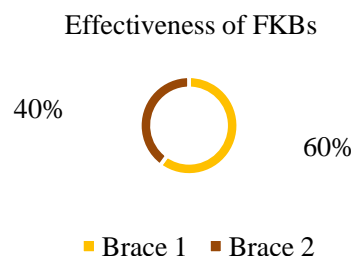


Figure 6. Effectiveness of FKBs during experiments among ten participants under two bracing conditions; Brace 1 and Brace 2.

Functional knee brace (FKB) adoptions among ACL-injured patients are one of the common treatments and clinical solution in supporting knee mobilities and movements during daily activities [7]. The use of knee orthoses or FKBs could minimize the acuity of ACL injuries [8] although they could not fully restore the functionality of knee after the injuries and ACL-reconstructions [13]. To the best of our knowledge, there were unclear clinical data on knee orthoses after ACL injuries and reconstructions despite the facts that the orthoses have been applied widely by many specialists [7]. Therefore, we aim to evaluate two different types of FKBs namely, hinge knee brace and sleeve brace with bilateral hinges in terms of biomechanical aspect. This study provided kinematic data on knee extension, internal and external knee rotations as well as comfortability analyses related to the FKBs. Outcomes from our study could provide list of evidences on the choices of available FKBs and quantitative data for medical practitioners and researchers which are vital in evaluating the influences of FKBs towards the knee kinematics. Nevertheless, due to low number of participants in this recent study, the future study should consider to utilise more subjects with different ages. It should be noted

that the goals of FKBs are to provide knee stabilities [22], preventing knee hyperextension [22], aiding in correct knee alignment [23] and limiting excessive movements of knee to prevent further damage towards the ACL [24, 25] during activities. Thus, the results of kinematics in this study that complied with the aforementioned objectives would be able to preserve the knee with ACL injuries. In general, Brace 1 portrayed better performance as the peak angles during walking gait were lower than Brace 2 for knee extensions and external knee rotations while the values during internal knee rotations were comparable between the two braces for ACL-injured participants.

Slippage Issue with FKBs

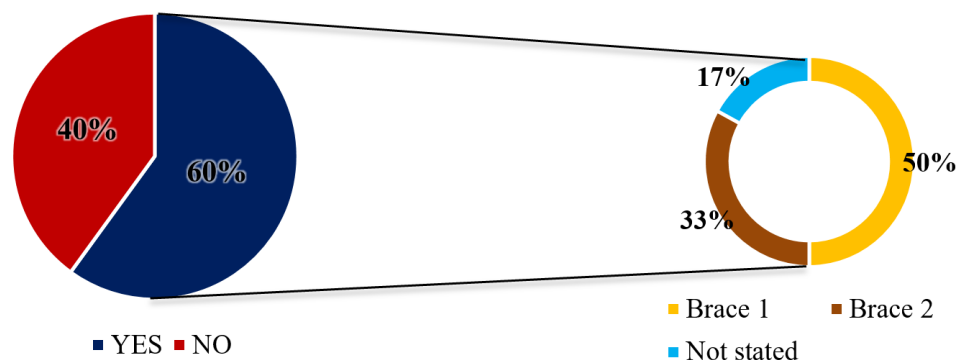


Figure 7. Slippage issues of FKBs during experiments among ten participants under two bracing conditions; Brace 1 and Brace 2.

4. Conclusion

The influences of FKBs towards knee kinematics have been studied in this paper where they were found to lessen the ROM of knee joint in order to limit excessive motions that might worsen the condition of ACL injuries. Our findings suggested that the use of FKB is an efficient way to cope and protect the ACL-injured knee. Based on the results, Brace 1 would be suggested as an optimum FKB to be used as one of the treatments for ACL injuries since it demonstrated sufficient support and stability to the knee during walking.

Acknowledgments

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