ORIGINAL ARTICLE

Kinematics and Comfortability Analysis of Orthosis for Patients Associated With Anterior Cruciate Ligament Injury: Hinge Versus Sleeve

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ABSTRACT

Introduction: Every month, Sports National Institute (ISN) in Malaysia received around 3 to 4 cases associated with anterior cruciate ligament (ACL) injury involving athletes in hockey, kick volleyball and netball. Knee orthosis is one of treatment method and has been shown to support lower limb joint mechanics, which may protect the ACL injury for becoming worst. In this paper, an investigation was conducted to evaluate the performance of existing knee orthosis for treating ACL injury. **Methods:** Ten participants which have been grouped into two; six ACL patients (Group 1) and four healthy subjects (Group 2), where they took part in two bracing conditions; 1) with hinge (Brace 1) and 2) sleeve with bilateral hinges (Brace 2). A non-braced condition was included as a baseline measure. Three-dimensional kinematics data were used to calculate knee joint motions. **Results:** From the findings of ACL subjects, the knee flexion in non-braced condition (49.9°) has high value than others two braces, in which Brace 1 (40.9°) is less value than Brace 2 (44.6°). This shows the Brace 2 have higher degree of freedom than Brace 1. Other than that, the comfortability assessment found that Brace 2 is the most favourable options by participants in terms of less slippage and comfortless condition. **Conclusion:** In conclusion, the Brace 2 give best performance during dynamic balance activity in individuals who benefit from high degree of freedom and less slippage issue.

Keywords: ACL injury, Orthosis, Sleeve, Hinge, Kinematics

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INTRODUCTION

Anterior cruciate ligament (ACL) is a robust tissue band that binds with thigh bone and shin bone at the knee joint. Numerous biomechanical researches and investigations have been concentrated on the ACL injury treatment. The studies were including a large number about the structures of the human musculoskeletal system throughout the past few decades (1-4). The ACL is a significant knee stabiliser, and the primary roles is to prevent the tibia from moving forward to the femur. The ACL is also the utmost common orthopaedic injury that have been reported in literature (1, 5) also states that ACL is among the most common ligaments injury of the knee, and the frequency of injury is approximated to be 1 in 3000 in the United States. This makes the damage has more than 1920 000 cases annually. In Malaysia, Sports National Institute (ISN) received 3 to 4 cases monthly involving athletes in hockey, kick volleyball and netball (6). It should be noted that complete ligament tears could contribute to the foreseeable mechanical instability pattern and an inconstant level of functional instability (7). These injuries frequently caused accumulated fluid around the knee joint, altered movement, muscle weakness, and decreased functional performance (1, 3).

Knee orthosis were presented in the 1970's and at the outset masculine utilised for recovery (8). Bracing after ACL damage and recreation is continuously performed by numerous specialists and ought to be researched from a few points, as the clinical inquiry of its advantage is not clear (9). Nevertheless, knee supports are intended to decrease or avoid the severity of knee wounds (10). The knee orthosis ought to offer help, and in the meantime, it should not weaken the execution of the knee joint (8). They are typically made of neoprene with extra support, for example, metallic pivots to help

knee during development. In terms of mechanism, the orthosis must allow the knee joint to work ordinary and make it feasible for a person to partaking in their works, rather than decreasing their performance level (8-10). However, when the orthosis is applied on the joint, it might adjust the knee mechanism. Attempting to avoid diminishing performance levels, the heaviness of the orthosis, hinge friction, strap tightness and absence of physiologic kinematics are the factors that ought to consider when planning orthoses (11). Apart from that, this system is an excellent alternative for a secure and high-performance application.

The ACL's main function is to avoid excessive tibial dislocation of the femur, enhancing the stability of the knee (2, 3). The ACL, in particular, secures the knee during rotation (7). Complete ligament injuries contribute to the foreseeable mechanical instability pattern and an inconstant level of functional instability (7). Contrary to popular belief, the ACL lesions are often caused by non-contact mechanisms. The non-contact mechanisms include rotational internal or external and translational pressure in the joint (7). Other than that, the ACL injuries take place in more than 70% of non-contact injuries which means the injury is not direct access to the knee joint and it is critical (1, 3). There are also different degrees of ACL injury until it is ruptured (2, 7). Most of the causes of the rupture are combined with knee compression, flexion and internal rotation. There are also three quarter of all ACL injuries including minimal or no contact (12).

In general, studies focusing on the environmental risk factors are required to have an advance understanding of biomechanical integration and epidemiologic knowledge (13). Consider the interaction of extrinsic and intrinsic elements would be ideally studying factors (14). Acuteness of the knee wounds can be reduced by the application of the knee orthosis (10). Regardless of this reduction, the knee orthosis did not completely restore common tibial rotation values. According to a previous study by Giotis et al. (15), knee bracing after ACL reconstruction has appeared to confine tibial revolution under low to moderate movements. Appraised peak knee extension and flexion torque and analysed considerable reductions in strength when functional knee braces (FKB) were used (16). In addition, a prevalent problem concerning FKB in the published literature is its susceptibility to migration or slip distally during motion (17). These researches have concentrated on the effect of FKB on intramuscular weight, knee joint kinematics and the related energy cost (18). Bracing after ACL damage and rehabilitation is continuously performed by numerous specialists and ought to be researched from a few points, as the clinical inquiry of its advantage is not quite clear (9). Therefore, in this paper, two types of FKBs (hinge and sleeve-type orthosis) have been biomechanically evaluated to assess kinematics and comfortability elements while walking.

MATERIALS AND METHODS

Subject Selection

Two groups of subjects have been selected which are Group 1 (6 patients with ACL injuries) and Group 2 (4 normal subjects). For the reference purpose, the normal subjects were included in this study (19). In this study, the age of all subjects was in between 20 and 24 years old. Amongst these subjects, two subjects have undergone anterior cruciate ligament reconstruction (ACLR) between 1-4 months. In addition, the rest of ACL patients/subjects did not go through surgery previously and claimed that the severity of the ligament is partially tear (n=4). For the subjects who had no earlier history of knee damage, some information such as pathological problem and history of health was gathered from them (19, 20).

Kinematics Analysis

Two non-vigorous tasks (walking and turning) have been done by all subjects. They were required to walk at their comfortable pace on 3 metres runaway with 6 metres of total walking distance. At the end of the runaway, they were asked to turn to the left side and returned back to the starting point. This turning task was conducted to generate high translational and rotational forces to the knee joint. These tasks were accomplished under two conditions for the rehabilitation of ACL injury. The subjects required to wear two types of the functional knee braces (FKB), which are hinged (Brace 1) and sleeve type (Brace 2) on the injured leg as shown in Fig. 1. Prior to testing, placement of markers was done according to a study by Giotis et al. where a total of 16 markers were used (15). The markers were placed at each of the lower limb include left heel (LHEE), right heel (RHEE), left toe (LTOE), right toe (RTOE), left ankle (LANK), right ankle (RANK), left tibia (LTIB), right tibia (RTIB), left knee (LKNE), right knee (RKNE), left thigh (LTHI)

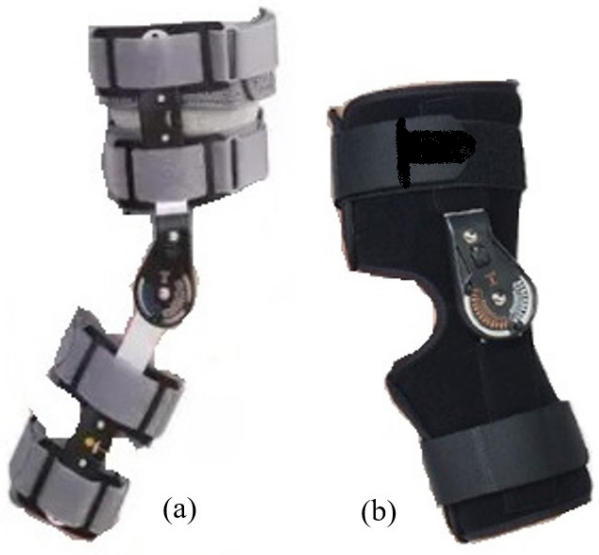

Figure 1: The design of functional knee brace (FKB); a) hinge (Brace 1) and b) sleeve (Brace 2)

and right thigh (RTHI). Then, the kinematics behaviour of lower limb movement was recorded using six motion capture cameras (Vicon Motion System, United Kingdom). Each session contained two trials for each walking conditions which are walking without brace, walking with hinge knee brace, and walking with sleeve brace with bilateral hinges. As for the walking condition with braces, 60 degrees of knee flexion was set up, the subject's knees were sustained symmetrically to ensure that they had sufficient comfortability wearing knee brace (21). From the experiment, results of knee flexion, extension, adduction and abduction were recorded for all ten subjects. All angle of those parameter has been automatically calculated from the Vicon Motion System software (ProCalc, United Kingdom) based on the markers placement on the subject's skin.

Comfortability Assessment

Comfortability assessment has been carried out by distributing a survey form to all ten subjects before and after the kinematics experiment. The survey form comprised with thirteen questions. The objective of this survey is to document the conformity of the functional knee brace (FKB) wear between individuals that associated with anterior cruciate ligament (ACL) injury followed by reconstruction, and without ACL injury. The survey evaluated discomfort (cause skin irritation) and slippage (22). Part of this survey was developed and revised by four orthopedic surgeons at the Fowler Kennedy Sports Medicine Clinic, as well as six physiotherapists, and an epidemiologist (22, 23).

RESULTS

Kinematic Analysis

As showed in Fig. 2, the maximum peak angle of knee joint between non-braced and with braced experienced at least 5.4% difference. Apart from non-braced knee joint, the highest knee flexion angle was demonstrated at Brace 2 (47.75°) for normal subjects followed by Brace 2 (44.57°) for ACL subjects. The worst value was obtained for Brace 1 in both ACL (40.98°) and normal subjects (40.73°). While walking with the FKB, minimum knee flexion was preserved in both ACL and normal subject due to the untreated ACL condition of the subjects. However, in individuals with ACL reconstruction, the angle of flexion of the knee was risen initial foot contact and their peak reaction force was reduced during the gait analysis. In general, the use of FKB causes the knee to be restricted in movement.

Fig. 3 shows the maximum peak angle of knee adduction and abduction for patients with ACL and without injury. From the figure, when the subjects did not wear the brace, it showed that the peak angle for adduction (26.4° and 26.2°) was much lower than the knee with hinge and sleeve braces by at least 2.1% difference. For adduction, the highest peak angle was found at

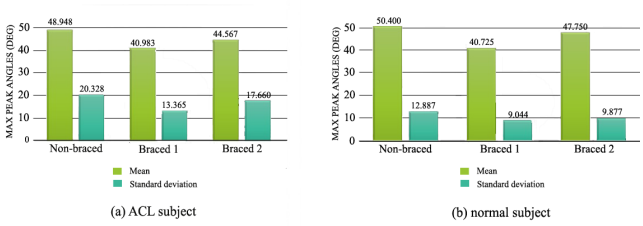

Figure 2: Maximum peak angle of knee flexion for subjects (a) with ACL injury and (b) without injury

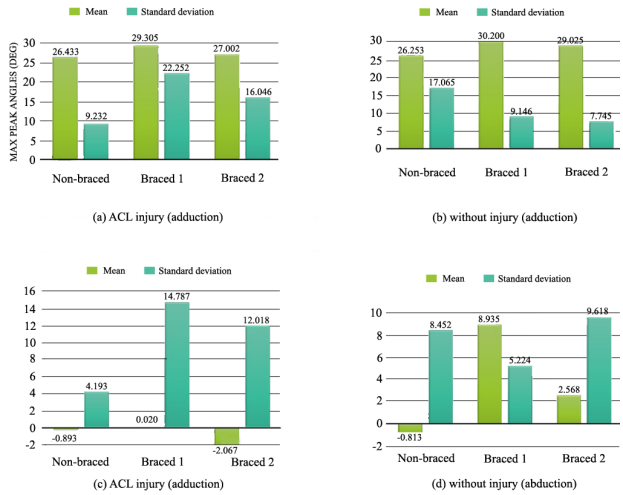

Figure 3: Maximum peak angle of knee adduction for subjects (a) with ACL and (b) without injury, and knee abduction for subjects (c) with ACL and (d) without injury.

the Brace 1 (29.3°) than Brace 2 (27°) for subject that associated with ACL injury (Figure 3(a)). Meanwhile, the highest peak angle value for normal subject (Figure 3(b)) was demonstrated at Brace 1 (30.2°) than Brace 2 (29°) design. From this condition, it showed that the Brace 2 was not allowed the knee joint to rotate more, in which more rigid than Brace 1.

Comfortability Analysis

Fig. 4 shows the findings of comfortability analysis for the slippage and discomfort brace from the survey. It was found that 60% of subjects said Brace 1 having slippage condition while wearing the brace during the experiment. The rest, 40% of them said no slippage for Brace 2. Due to big size of hinge orthosis (Brace 1), this could be a reason why the slippage condition happened. Surprisingly, 75% of subjects response discomfort for Brace 1 as compared to Brace 2. Again, the size and mechanism of hinge orthosis (Brace 1) is the main reason of the discomfort condition.

DISCUSSION

In this research, we explored whether sleeve knee braces with bilateral hinges can promote knee flexion capacity and impact operational efficiency relative to other knee braces. The advantage of the knee braces with extension support was only noted in the walking cadence. While

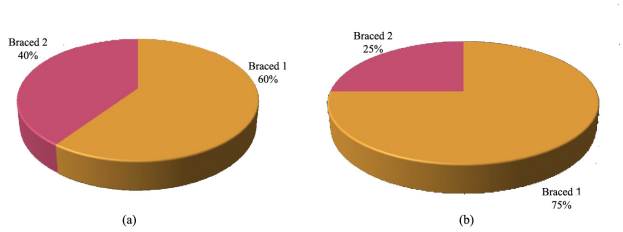

Figure 4: Percentage of (a) slippage brace and (b) discomfort brace from the survey.

walking with knee support, minimum knee flexion was preserved in both ACL and normal subject due to the untreated ACL condition of the subjects (24). However, in individuals with ACL reconstruction, the angle of flexion of the knee was risen initial foot contact and their peak reaction force was reduced during the gait analysis. This findings was supported by previous study by Brandsson et al. (25), where similar condition of peak reaction force was reduced during the gait activity. In the contrary, knee stability for both group of participants has increased, and this can be determined by evaluating the value of standard deviation. It is shown that the standard deviation was higher in Brace 2, rather than Brace 1 for both ACL and normal subjects.

For assisting ACL injury patients using orthosis technique, it may improve proprioception where the effects of orthosis (like bracing) could improvise stability during normal daily activity and cope with injury (24, 26). From our study, it shows that Brace 2 can provide adequate stability for assisting ACL patients to perform activity. Other than that, the ultimate goal of the ACL-deficient is to make sure the orthosis is comfort, light weight, easy to handle and optimum alignment to the joint during performing daily activities (15, 21). Therefore, a scholar must consider above mentioned elements in order to provide a finest treatment and assistive device for ACL patients. On top of that, the use of orthosis is found to be sufficient in assisting ACL patients to conduct rehabilitation at home (7, 9). It is a home-based rehabilitation where all patients and wear braces, not only to assist them in doing daily activities but could also motivate patients to perform rehabilitation with minimally supervised by care takers, doctors and nurses (27).

In this study, due to the current resources, some limitations have been considered to conduct the kinematics analysis. One of them is the number of patients. We were only secured to get six patients that associated with ACL injury, meanwhile another four is normal subjects. Nevertheless, the current number of subjects were considered an acceptable option for preliminary results as shown in kinematics studies by other scholars (27-29). As far as the research studies are concern, it is good to conduct such study with a larger number of patients as demonstrated by others (21, 22). The second limitation is regarding the design of orthosis where only two types of braces were considered in this study. To be noted, there are many available designs of braces in the market. It is suggested that future study could consider the other choices as well to conduct kinematics analysis of ACL patients while wearing knee braces. With larger number of patients and different design of orthosis, it is expected that the results could give more insight to the users and practitioners.

CONCLUSION

The findings of the study highlighted the importance of choosing the correct brace even though it is off-the-shelf. There was a research claimed that wearing of hinge knee brace escalates proprioception in the knees of patients with ACL injuries. The sleeve design (Brace 2) with bilateral hinges has been investigated and added knee brace extension (KBE) which allowed a significantly greater flexion angle and comfort when compared to hinge brace (Brace 1).

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REFERENCES

1. Kiapour A and Murray M. Basic science of anterior cruciate ligament injury and repair. Bone & Joint Surgery. 2014; 3(2): 20-31.
2. Zainal Abidin N and Ramlee M. A short review on anatomy, biomechanics and treatment for anterior cruciate ligament injury. Proceedings of 7th International Graduate Conference of Engineering, Science and Humanities. 2018: 270-73.
3. Zainal Abidin N, Abdul Wahab A, Ramlee M, and Abdul Kadir M. A Mini Review on Graft Fixation Devices for Anterior Cruciate Ligament Reconstruction – Techniques, Materials and Complications. IEEE Explore. 2018: 93-98.
4. Zainal Abidin N, Ramlee M, and Abdul Kadir M. Biomechanical effects of different lengths of cross-pins in anterior cruciate ligament reconstruction: A finite element analysis. Journal of Mechanics in Medicine and Biology. 2020; 20(7): 2050047.
5. Mpatswenumugabo B, Bukara E, Semakula M, Nzayisenga A, Mukezamfura R, et al. A case report of anterior cruciate ligament and posterolateral corner reconstruction using tendon graft preserved in situ. International Journal of Surgery Case Reports. 2018; 44: 42-46.
6. Anon. Risiko Tinggi ACL buat atlet. 2017; Available

from: http://new.isn.gov.my/risiko-tinggi-acl-buat-atlet/.
7. Lamsam C. Anterior cruciate ligament injury. Siriraj Medical Journal. 2009; 61(2): 107-09.
8. Jensen M. Anterior cruciate ligament injury and knee braces – perspectives for prevention and treatment. A review. Sports Technology. 2014: 1-16.
9. Masini B and Owens B. Current recommendations for anterior cruciate ligament bracing: when to use. The Physician and Sports Medicine. 2013; 41(1): 35-39.
10. Rishiraj N, Taunton J, Lloyd-Smith R, Woollard R, Regan W, and Clement D. The potential role of prophylactic/functional knee bracing in preventing knee ligament injury. Sports Medicine (Auckland, N.Z.). 2009; 39(11): 937-60.
11. Greene D, Hamson K, Bay R, and Bryce C. Effects of protective knee bracing on speed and agility. The American Journal of Sports Medicine. 2000; 28(4): 453-59.
12. Boden B, Sheehan F, Torg J, and Hewett T. Noncontact anterior cruciate ligament injuries: mechanisms and risk factors. The Journal of the American Academy of Orthopaedic Surgeons. 2010; 18(9): 520-27.
13. Zainal Abidin N, Abdul Kadir M, and Ramlee M. Three Dimensional Finite Element Modelling and Analysis of Human Knee Joint- Model Verification. Journal of Physics: Conference Series. 2019; 1372: 1-7.
14. Griffin L, ALBOHM MJ, ARENDT EA, BAHR R, BEYNNON BD, et al. Understanding and preventing noncontact anterior cruciate ligament injuries: a review of the Hunt Valley II meeting, January 2005. The American Journal of Sports Medicine. 2006; 34(9): 1512-32.
15. Giotis D, Paschos N, Zampeli F, Pappas E, Mitsionis G, and Georgoulis A. Bracing can partially limit tibial rotation during stressful activities after anterior crucial ligament reconstruction with a hamstring graft. Orthopaedics & Traumatology, Surgery & Research. 2016; 102(5): 601-06.
16. Lowe W, Warth R, Davis E, and Bailey L. Functional Bracing After Anterior Cruciate Ligament Reconstruction: A Systematic Review. The Journal of the American Academy of Orthopaedic Surgeons. 2017; 25(3): 239-49.
17. Singer J and Lamontagne M. The effect of functional knee brace design and hinge misalignment on lower limb joint mechanics. Clinical Biomechanics. 2008; 23(1): 52-59.
18. Najibi S and Albright J. The use of knee braces, part 1: Prophylactic knee braces in contact sports. The American Journal of Sports Medicine. 2005; 33(4): 602-11.
19. LaPrade R, Venderley M, Dahl K, Dornan G, and Turnbull T. Functional Brace in ACL Surgery: Force Quantification in an In Vivo Study. Orthopaedics Journal of Sports Medicine. 2017; 5(7).
20. Paluska S and McKeag D. Knee braces: current evidence and clinical recommendations for their use. American Family Physician. 2000; 61(2): 411-18.
21. Mohseni S, Farahmand F, Karimi H, and Kamali M. Anthrometric evaluation of stabilizing effect of knee functional bracing at different flexion angles. Journal of Sports Science and Medicine. 2009; 8: 247-51.
22. Rankin A, A survey of functional knee brace usage following anterior cruciate ligament reconstruction- A pilot study, in Department of Physical Therapy1997, The University of Western Ontario: Canada.
23. Zainal Abidin S, Wan Jusoh W, and Beng G. Kinematic analysis on reaching activity for hemiparetic stroke subjects using simplified video processing method. Malaysian Journal of Fundamental and Applied Sciences. 2018; 14(3): 386-90.
24. Wright RW and Fetzer GB. Bracing after ACL reconstruction: A systematic review. Clinical Orthopaedics and Related Research. 2007; 455: 162-68.
25. Brandsson S, Faxen E, Kartus J, Eriksson BI, and Karlsson J. Is a knee brace advantageous after anterior cruciate ligament surgery? A prospective, randomised study with a two-year follow-up. Scand J Med Sci Sports. 2001; 11: 110-14.
26. Henriksson M, Rockborn P, and Good L. Range of motion training in brace vs. plaster immobilization after anterior cruciate ligament reconstruction: a prospective randomized comparison with a 2-year follow-up. Scand J Med Sci Sports. 2002; 12: 73-80.
27. Brown SR, Washabaugh EP, Mazumder AD, Wojtys EM, Palmieri-Smith RM, and Krishnan C. Functional Resistance Training to Improve Knee Strength and Function After Acute Anterior Cruciate Ligament Reconstruction: A Case Study. Sports Health. 2020.
28. Josipovic M, Vlaic J, Serdar J, Simunovic M, Nizic D, Schauperl Z, Bojanic I, and Jelic M. Plantaris tendon: a novel graft for anterolateral ligament reconstruction and additional reinforcement for anterior cruciate ligament autografts in combined reconstructive procedures. Knee Surgery, Sports Traumatology, Arthroscopy. 2020; 28: 2604-08.
29. Ismailidis P, Kernen R, Egloff C, Nuesch C, Mundermann A, and Muller SA. Clinical and Biomechanical Outcomes of One-Stage Treatment of a Simultaneous Ipsilateral Patellar Tendon and ACL Tear Combined with a Tibial Plateau Fracture: A Case Study. Case Reports in Orthopaedics. 2020: 579348.