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The effects of bracing and knee flexion angle on hamstring activity during crutch walking: A preliminary study for post-operative care

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Abstract: *Objectives:* To determine if immobilization of the knee at varying degrees of knee flexion will limit the surface electromygraphical (sEMG) activity of hamstring muscles during crutch-assisted ambulation. *Methods:* Ten healthy participants walked with crutches with the knee maintained at 0, 30, 60 and 90° of knee flexion, both with and without a brace. The leg was non-weight bearing for all trials except for those with the knee at 0° of flexion, when subjects performed a 'toe-touch' gait. sEMG was used to record activity of the biceps femoris and semitendinosus during trials. *Results:* For the semitendinosus, there were no differences between braced and unbraced conditions at 0° (22.5 vs. 23.2%), 30° (37.5 vs. 28.7%), 60° (47.2 vs. 44.6%), and 90° (32.7 vs. 51.8%) of knee flexion (all, $p > 0.05$). Similarly, for the biceps femoris, there were no differences between braced and unbraced conditions at 0° (22.5 vs. 23.2%), 30° (44.5 vs. 28.7%), 60° (47.2 vs. 44.6%), and 90° (32.7 vs. 51.8%) of knee flexion (all, $p > 0.05$). Finally, there were no differences between braced at 90° of knee flexion and unbraced at 0° of knee flexion with regard to semitendinosus (32.7 vs. 23.2%) and biceps femoris (32.6 vs. 23.2%) activity ($p > 0.05$). *Conclusions:* The use of a brace to limit knee extension did not decrease activation of the hamstrings during crutch-assisted ambulation in healthy participants. More research is needed to determine if the use of a knee brace is necessary following surgical repair of the hamstring tendon.

ABOUT THE AUTHORS

The authors are an interdisciplinary group of physicians, surgeons, athletic trainers, physical therapists, and researchers whose interests include improving the lives of athletes and patients through evidence-based practice.

PUBLIC INTEREST STATEMENT

Knee immobilization with bracing is a commonly used protective strategy to prevent strain on the surgical repair site in patients following repair of a proximal hamstring tear. This postoperative protection approach, however, is largely based on individual clinician experience rather than clear research evidence. As such, we are unaware of any previous studies that have examined the effect of knee bracing on hamstring muscle activation during normal activities, such as walking. Notably, this article finds that bracing the knee in various positions of knee flexion was ineffective in decreasing the electromyographical (EMG) activity of the hamstrings during crutch-assisted walking in a sample of healthy participants. More research though is needed, particularly in patients having undergone surgical hamstring repair, to explore the impact of bracing (or no bracing) on hamstring muscle activation as well as key clinical patient outcomes.

Subjects: Orthopedics; Reconstructive Surgery; Sports Medicine

Keywords: ischial tuberosity; immobilization; EMG

1. Introduction

Hamstring muscle injuries are common in athletes across all levels of competition and often result in extensive time loss from sport. In collegiate athletes, the hamstring injury rate has been reported to be as high as 0.31 per 1,000 athlete exposures, with the highest rates in football, and men's and women's soccer (Dalton, Kerr, & Dompier, 2015). Epidemiological studies of professional athletes across various sport leagues have reported hamstring injury rates in game play to range from 0.6–4.0 per 1,000 athlete exposures (Ahmad et al., 2014; Drakos, Domb, Starkey, Callahan, & Allen, 2010; Feeley et al., 2008). Furthermore, authors of a recent study indicated that hamstring injuries accounted for 17% of all injuries in athletes competing in international athletics competitions (Edouard, Branco, & Alonso, 2016). Alarmingly, these injuries often result in extensive time loss from sport, with an average time loss of 8–24 days (Ahmad et al., 2014; Feeley et al., 2008; Hallén & Ekstrand, 2014), and have a high incidence of reinjury following return to play (Gibbs, Cross, Cameron, & Houang, 2004; Hallén & Ekstrand, 2014; Malliaropoulos, Isinkaye, Tsitas, & Maffulli, 2011; Orchard & Seward, 2002).

Hamstring muscle strains range in severity from grade I to grade III. Grade I injuries are defined by minimal tearing of the muscle or tendon while grade II injuries signify partial or incomplete tears. Grade III injuries are a complete rupture of the musculotendinous unit (Ahmad et al., 2013; Ali & Leland, 2012). Hamstring injuries can be further characterized by the location of injury, such as the proximal or distal musculotendinous junction, muscle belly, or the attachment site of the proximal or distal tendons (Askling, Koulouris, Saartok, Werner, & Best, 2013). Although rare, tendon avulsions are the most severe type of hamstring injuries and typically occur at the proximal site of attachment (Koulouris & Connell, 2003; Sarimo, Lempainen, Mattila, & Orava, 2008). Notably, a previous study reported that proximal tendon-bone avulsion injuries accounted for roughly 9% of all hamstring injuries in a predominantly athletic population (Koulouris & Connell, 2003).

Grade I and II strains are typically treated non-operatively, whereas surgical treatment is often recommended for grade III injuries when either all three tendons are avulsed or two hamstring tendons are avulsed with less than two cm of retraction (Cohen & Bradley, 2007; Harris, Griesser, Best, & Ellis, 2011). Although there is broad agreement that post-operative care following repair of proximal hamstring avulsions should include the use of crutches for two to six weeks accompanied by appropriately progressed physical therapy to regain hip and knee flexibility and strength, as well as sport-specific training (Cohen & Bradley, 2007; Cohen, Rangavajjula, Vyas, & Bradley, 2012; Konan & Haddad, 2010), there is a lack of consensus regarding the need for post-operative bracing (Askling et al., 2013; Chahal et al., 2012; Cohen & Bradley, 2007; Cohen et al., 2012; Konan & Haddad, 2010; Sallay, Friedman, Coogan, & Garrett, 1996; Sarimo et al., 2008; Skaara, Moksnes, Frihagen, & Stuge, 2013). Advocates of bracing suggest the need for limitation of active contraction of the hamstring muscle group to prevent distraction of the surgical repair. Consequently, several postoperative bracing strategies have been described including the use of hip orthoses that restrict hip flexion to ranges of only 15–40° (Ahmad et al., 2013; Cohen & Bradley, 2007; Cohen et al., 2012), immobilization of the knee in 30 –90˚ of flexion (Chahal et al., 2012; Chakravarthy, Ramisetty, Pimpalnerkar, & Mohtadi, 2005; Cross, Vandersluis, Wood, & Banff, 1998; Klingele & Sallay, 2002), and combination hip-knee orthoses that stabilize both the hip and knee in varying degrees of flexion (Blasier & Morawa, 1990; Brucker & Imhoff, 2005; Sallay et al., 1996; Thomsen & Jensen, 1999). Others have reported favorable outcomes with no use of post-operative immobilization (Askling et al., 2013; Sarimo et al., 2008; Stradley, Backs, Grosel, & Kaeding, 2008), suggesting that braces are unnecessary, uncomfortable and may make ambulation more difficult (Askling et al., 2013; Stradley et al., 2008).

To our knowledge, it is presently unclear whether bracing accomplishes the goal of limiting active contraction. Therefore, the purpose of this study was to identify differences in hamstring surface electromyography (sEMG) activity between braced and unbraced conditions at varying degrees of knee flexion: 0, 30, 60 and 90° of knee flexion. Of particular interest is the difference between braced at 90° of knee flexion (standard of care) and unbraced at 0° of knee flexion (toe-touch weight bearing). We hypothesized decreased hamstring muscle activity during braced conditions at each tested knee flexion angle because of the need to actively stabilize the knee in unbraced conditions. Likewise, we inferred that decreased hamstring muscle activity would be seen in the braced condition at 90° of knee flexion in comparison to unbraced at 0° of knee flexion. The results of this research may contribute to the decision-making process relative to the use of bracing as a standard of care immediately following surgical repair of proximal hamstring tears.

2. Methods

2.1. Participants

Ten healthy participants (six males, four females) aged 22–28 years were recruited to participate in this study. All the subjects were graduate students who reported no neurological impairment resulting from pathology of the lumbar spine or brain. Subjects all had BMI values of 24.9 or less to facilitate capture of sEMG signals. The study was approved by the University's Institutional Review Board, and written informed consent was obtained for all participants prior to testing.

2.2. Equipment and procedures

Surface EMG sensors (Model MA-411, Motion Lab Systems, Inc., Baton Rouge, Louisiana) were used to measure the activation of the semitendinosus and biceps femoris muscles. The application of surface electrodes followed standardized laboratory procedures and the exact location of electrode placement was in accordance with SENIAM guidelines (Recommendations for sensor locations in hip or upper leg muscles, xxxx). Specifically, the placement of the electrodes for the biceps femoris and semitendinosus was 50% of the distance between the ischial tuberosity and the lateral and medial epicondyles of the tibia, respectively. Prior to electrode placement, the skin surrounding the placement site was vigorously cleaned with gauze soaked with isopropyl alcohol. Pre-wrap and athletic tape were used to ensure electrode and cable placement. Participants were fitted with and instructed in the use of crutches to perform a non-weight-bearing gait, or a toe-touch gait when necessary, on the right leg. They were also fitted with a post-surgical brace that could be adjusted to limit right knee range of motion (Post-Op Lite Knee Brace, Breg Inc.). Then, subjects were instructed to walk under eight different conditions. They walked with the knee maintained voluntarily, or with the assistance of the brace, at 0, 30, 60, and 90° of flexion. The order of testing for conditions (brace versus unbraced, and knee angle) was randomized with a standardized rest period of two minutes between all trials.

Prior to each unbraced trial, the participants' knee angles were measured using a handheld goniometer. Participants were instructed to hold that position as best as they could to mimic real world conditions. They were further instructed to keep their hips as neutral as possible in order to limit hip flexion and, once again, to mimic real world conditions. Participants were instructed to ambulate ten meters using crutches with their right knee kept at each specified angle with and without the brace. After a practice trial, sEMG was captured during three trials of walking under each condition.

2.3. Data processing

Surface EMG data were recorded at 1,200 Hz. Trials were cut to isolate one full gait cycle that spanned one crutch strike to the next. Data were exported to Visual 3-D (C-Motion Inc; Germantown, MD), where the signals for each trial were high pass filtered at 50 Hz, and low pass filtered at 300 HZ.

Then, the root-mean-squared (RMS) voltage was computed and a displayed as a linear envelope (moving average) with a time-constant of 0.33 s. The RMS amplitude was first calculated for the entire length of each stance phase separately and RMS values were then averaged across trials. Surface EMG values were normalized for each subject by dividing the peak value during any of the activities by the intra-session peak value (peak dynamic method). The peak dynamic method is commonly used to normalize sEMG during gait (Jacobson, Gabel, & Brand, 1995; Lyytinen et al., 2016; Prilutsky, Gregor, & Ryan, 1998). The mean normalized sEMG amplitudes of the trials from each condition were used for statistical analysis.

2.4. Statistical analysis
Descriptive statistics were calculated for all variables. Paired t-tests were used to detect differences in muscle activation between braced and unbraced conditions at each knee angle of interest. Statistical significance was established at 0.05. Data analyses were performed using Statistical Package for the Social Sciences version 20.0 (SPSS, Inc., Chicago, IL).

3. Results
Tables 1 and 2 present the sEMG values of the semitendinosus and biceps femoris muscles for braced and unbraced conditions at various angles of knee flexion. As shown, the EMG recordings did not demonstrate significantly decreased semitendinosus or biceps femoris activation during crutch-assisted ambulation with braced as compared to unbraced conditions at knee flexion angles varying between 0–90° (all, $p > 0.05$). In addition, there were no significant differences in the sEMG activity of these muscles when braced at 90° of knee flexion (standard of care) in comparison to unbraced 0° of knee flexion, or toe-touch weight bearing (both, $p > 0.05$).

Table 1. Semitendinosus sEMG activity during ambulation with and without a brace at specified knee flexion angles

Knee flexion angle	Normalized peak signal amplitude per condition[a]		*p*-value
	Braced	Unbraced	
0°	19 ± 17.0	18 ± 11.3	0.686
30°	35 ± 26.6	25 ± 21.2	0.182
60°	41 ± 21.2	37 ± 24.5	0.713
90°	29 ± 16.4	42 ± 25.0	0.181

[a]Data are expressed as percentage of peak dynamic sEMG and presented as mean ± SD.

Table 2. Biceps femoris EMG activity during ambulation with and without a brace at various knee flexion angles

Knee flexion angle	Normalized peak signal amplitude per condition [a]		*p*-value
	Braced	Unbraced	
0°	23 ± 15.4	23 ± 16.8	0.818
30°	29 ± 20.5	44 ± 35.1	0.210
60°	47 ± 18.0	45 ± 28.5	0.088
90°	32 ± 14.2	52 ± 30.4	0.100

[a]Data are expressed as percentage of peak dynamic sEMG and presented as mean ± SD.

4. Discussion

The main objective of this study was to measure the effect of knee immobilization at varying degrees of knee flexion on hamstring muscle activity during crutch-assisted ambulation. We found no significant differences between braced and unbraced conditions at several knee flexion angles ranging from 0–90°. Consequently, our results suggest that the use of a brace to limit knee extension does not significantly decrease the level of hamstring muscle activation during crutch-assisted gait. Although preliminary, these findings may contribute to the decision-making process relative to the use of bracing as a standard of post-operative care immediately following surgical repair of proximal hamstring tears.

The research literature on surgical repair of proximal hamstring tendon ruptures is comprised of numerous case studies and series describing post-operative rehabilitation guidelines including the use of bracing to protect the repair site following surgery (Blasier & Morawa, 1990; Brucker & Imhoff, 2005; Chahal et al., 2012; Chakravarthy et al., 2005; Cohen & Bradley, 2007; Cohen et al., 2012; Cross et al., 1998; Klingele & Sallay, 2002; Sallay et al., 1996; Sarimo et al., 2008; Stradley et al., 2008; Thomsen & Jensen, 1999). Immobilization strategies include the use of an orthosis to immobilize either the hip (Cohen & Bradley, 2007; Cohen et al., 2012) or knee only (Chahal et al., 2012; Chakravarthy et al., 2005; Cross et al., 1998; Klingele & Sallay, 2002), orthoses that immobilize both the hip and knee (Blasier & Morawa, 1990; Brucker & Imhoff, 2005; Sallay et al., 1996; Thomsen & Jensen, 1999), and the use of no brace to immobilize or limit motion in either joint (Askling et al., 2013; Sarimo et al., 2008; Stradley et al., 2008). Importantly, favorable patient outcomes have been reported in all studies using any one of these immobilization strategies as part of the overall rehabilitation process. In separate case series, Cohen and Bradley (2007), Cohen et al. (2012) described the use of a hip orthosis that restricted hip flexion to ranges between 15 and 40° for up to eight weeks following surgery to limit the stress at the proximal reattachment site. In contrast, others have described immobilization of the knee at 90° of flexion for either two or eight weeks after surgery (Chakravarthy et al., 2005; Cross et al., 1998). Additional knee immobilization strategies include bracing the knee in 30˚ of flexion for six weeks (Chahal et al., 2012) and the use of a harness-suspension device to maintain the knee in an unspecified degree of flexion for up to 4 weeks (Klingele & Sallay, 2002). Alternatively, some authors have described the use of a hip-knee orthosis that limits the movement of both the hip and knee (Blasier & Morawa, 1990; Brucker & Imhoff, 2005; Sallay et al., 1996; Thomsen & Jensen, 1999). For instance, Thompson and Jenson (Thomsen & Jensen, 1999) described bracing the knee at 60° of flexion and limiting hip flexion to 0–45° for the initial three weeks following surgery. Others have described stabilizing the hip in extension while bracing the knee in 90° of flexion for six weeks post-surgery (Brucker & Imhoff, 2005; Sallay et al., 1996). Finally, authors have also described successful patient outcomes with no use of a brace to immobilize or limit the degree of flexion in either the hip or knee (Askling et al., 2013; Sarimo et al., 2008; Stradley et al., 2008). As expected, protocols have been primarily based on surgeon preference and experience as we are unaware of any clinical evidence comparing the various protection strategies on either limiting hamstring activation and strain or their association with patient outcomes independent of other facets of the overall rehabilitation program. Despite this lack of evidence, it is reasonable to suggest that any type of immobilization strategy at the hip and/or knee will be met with some patient resistance, as immobilization can make ambulation and performance of activities of daily living more difficult, thus potentially impacting patient compliance.

To date, we are aware of only one biomechanical study that investigated the effect of either hip or knee hip flexion angle on the displacement of a surgically repaired proximal hamstring muscle-tendon unit under load. In a recent study using cadaveric hemipelvis specimens, Harvey, Singh, Obopilwe, Charette, and Miller (2015) found that increasing hip flexion from 0–90° augmented the degree of gap formation across proximal hamstring repairs when loaded. Although the authors concluded that no determination could be made regarding the influence of knee position on repair site strain, they suggested that post-operative immobilization of the hip to limit the degree of hip flexion was an appropriate recommendation. However, further research may be warranted given the *in vitro* nature of this initial study.

We expected that bracing would have a significant effect in decreasing the sEMG level of the semitendinosus and biceps femoris at varying degrees of knee flexion during crutch-assisted ambulation. Consequently, our finding that there were no differences between conditions at any knee angle was surprising. In all tested angles but 90° of knee flexion, semitendinosus muscle activation was slightly higher in the braced condition in comparison to unbraced condition. Similarly, biceps femoris activation was either equal to or slightly greater at both 0 and 60° of flexion for the braced condition. One potential explanation for this finding is that despite bracing, participants were unable to restrict from activating their hamstring muscles to decelerate knee extension during the second half of the swing phase of gait, which is typical of normal adult walking (Levangie, 2011). Our finding that both semitendinosus and biceps femoris muscle activation was greater for the braced condition at 90° of flexion in comparison to unbraced condition was expected; however, the differences in activation levels were less than projected. Since participants were instructed to actively maintain 90° of knee flexion during the unbraced condition, increased hamstring activation in comparison to the braced condition was expected. Nevertheless, it was somewhat surprising that the differences in activation levels were only 13 and 20% for the semitendinosus and biceps femoris muscles, respectively. Increased activation during the unbraced condition could be attributed to the increased length in the moment arm of the lower leg in 90° of flexion. This is supported by our finding that increasing levels of muscle activation corresponded to increasing knee flexion angles in all unbraced conditions.

Our most noteworthy finding was that there were no differences in hamstring muscle activation when participants were braced at 90° of knee flexion in comparison to being unbraced and maintaining the knee in approximately 0° of flexion, which is consistent with toe-touch ambulation. Importantly, this comparison has the most clinical relevance since patients are typically kept toe-touch weight bearing on crutches when no hip and/or knee orthosis is prescribed.

In is important to note several limitations of this study. First, we utilized a small sample size. Because the design of the experiment, it was not possible to select a sample size based on an a priori power analysis. It is possible that a difference existed among conditions, but that our sample size was too small to detect it. Secondly, we investigated healthy participants, which may make it difficult to draw conclusions about unhealthy populations. However, we utilized the peak dynamic methods to assess differences in sEMG and not the isometric maximum voluntary contraction method. By normalizing to the intra-session maximum we likely reduced intra-subject variability and increased the sEMG reliability as this technique eliminates the effects of pain and inhibition (Burden, Trew, & Baltzopoulos, 2003). Finally, in an attempt to mimic real-world conditions, we did not brace the hip the limit hip flexion. Some post-operative protocols may call for this type of brace. Future research should further investigate the added effect of mechanically limiting hip flexion on hamstring activity at different braced and unbraced positions.

5. Conclusion

In conclusion, knee immobilization at varying degrees of knee flexion was ineffective in decreasing semitendinosus and biceps femoris muscle activation during crutch-assisted ambulation in healthy participants. We also found no differences in hamstring muscle activation when patients were braced at 90° of knee flexion in comparison to unbraced at 0° of knee flexion. Previous studies have described several postoperative bracing strategies, each placing the hip, knee, or both in varying degrees of flexion, used to minimize strain on the surgical repair site of patients undergoing proximal hamstring tendon repair. However, our results suggest that immobilizing the knee in varying positions of 0–90° of flexion may be an ineffective strategy to minimize active contraction of the hamstring muscle group during crutch-assisted ambulation. These findings have potential clinical implications since other authors have reported favorable postsurgical outcomes without the use of post-operative bracing and noted that braces are uncomfortable and may hinder crutch-assisted ambulation. Nonetheless, it is important that our study results are interpreted within the context of the aforementioned limitations. These findings document preliminary evidence of the effect of knee bracing on hamstring muscle activation, albeit in a healthy population. Future research should examine the effect of immobilizing the knee at varying degrees of flexion on hamstring activation of patients following surgical repair of proximal hamstring tears. Future studies may also consider comparing the effect of various hip and/or knee immobilization protective strategies to an unbraced approach on key clinical outcome measures in patients undergoing this surgery.

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