Effect of Anterior Tibiofemoral Glides on Knee Extension during Gait in Patients with Decreased Range of Motion after Anterior Cruciate Ligament Reconstruction

Michael A. Hunt, Stephen R. Di Ciacca, Ian C. Jones, Beverley Padfield, Trevor B. Birmingham

ABSTRACT

Purpose: The purpose of this preliminary investigation was to evaluate the effect of anterior tibiofemoral glides on maximal knee extension and selected spatiotemporal characteristics during gait in patients with knee extension deficits after anterior cruciate ligament (ACL) reconstruction.

Methods: Twelve patients with knee-extension deficits after recent ACL reconstructions underwent quantitative gait analyses immediately before and after 10 minutes of repeated anterior tibiofemoral glides on the operative limb, and again after a 10-minute seated rest period.

Results: Maximum knee extension during stance phase of the operative limb significantly increased immediately after the treatment (mean increase: $2.0^\circ \pm 4.1^\circ$, 95% CI: 0.6° – 3.3°). Maximum knee extension decreased after the 10-minute rest period (mean decrease: $0.9^\circ \pm 1.8^\circ$, 95% CI: -0.1° – 1.8°), although the decrease was not statistically significant. Small increases in operative limb step length, stride length, and gait speed were observed after the rest period compared to baseline values only.

Conclusions: A single session of anterior tibiofemoral glides increases maximal knee extension during the stance phase of gait in patients with knee-extension deficits. Increases in knee extension are small and short-lived, however, suggesting that continued activity is required to maintain the observed improvements.

Key Words: anterior cruciate ligament, biomechanics, gait, knee, manual therapy

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RÉSUMÉ

Objectif : L'objectif de cette recherche préliminaire était d'évaluer l'effet du glissement du fémoro-tibial antérieur sur l'extension maximale du genou et sur des caractéristiques spatiotemporelles choisies au cours de la marche chez les patients affectés d'un déficit de l'extension du genou après une reconstruction du ligament croisé antérieur (LCA).

Méthode : Douze patients aux prises avec un déficit de l'extension du genou à la suite d'une récente reconstruction du LCA ont subi des analyses de la démarche immédiatement avant et après 10 minutes de glissements répétés du fémoro-tibial antérieur sur le membre fonctionnel, et de nouveau après une période de repos de 10 minutes, en position assise.

Résultats : L'extension maximale du genou au cours de la phase d'appui du membre fonctionnel s'est accrue considérablement immédiatement après le traitement (augmentation moyenne : $2,0^\circ \pm 4,1^\circ$, 95 % IC : $0,6^\circ$ – $3,3^\circ$). La capacité maximale d'extension du genou après un repos de 10 minutes a diminué (baisse moyenne : $0,9^\circ \pm 1,8^\circ$, 95 % IC : $-0,1^\circ$ – $1,8^\circ$), mais cette baisse n'est pas significative sur le plan statistique. On a observé de légères augmentations dans la longueur du pas, la longueur de la foulée et la vitesse de marche du membre fonctionnel après la période de repos comparativement aux valeurs de base seulement.

Conclusions : Une seule séance de glissement du fémoro-tibial antérieur accroît l'extension maximale du genou au cours de la phase d'appui de la démarche chez les patients qui souffrent de déficits d'extension du genou. Les augmentations de l'extension du genou sont toutefois minimes et de courte durée, ce qui semble indiquer qu'une activité continue est nécessaire pour assurer le maintien des améliorations observées.

Mots clés : biomécanique, genou, ligament croisé antérieur, marche, thérapie manuelle

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INTRODUCTION

Loss of knee-joint range of motion (ROM) is a common complication after anterior cruciate ligament (ACL) reconstruction.^{1–5} Reports indicate that between 4% and 34% of patients experience prolonged loss of ROM after this surgery, and some patients can require up to 3 months to regain full knee extension.^{1,5,6} Decreased active knee extension causes abnormal gait patterns.^{2,7–9} A lack of knee extension can contribute to decreased stride length and gait speed and increased demand on other lower-limb joints and muscles.^{2,8,10,11} Accordingly, much emphasis has been placed on physiotherapy interventions aimed at limiting knee-extension deficits early after ACL reconstruction.^{3,5,9,12–14}

Manual therapy interventions are believed to result in improvements in joint function through a combination of mechanical and neuromuscular mechanisms. In particular, some techniques are believed to increase collagen extensibility and joint lubrication and to reduce muscle tone, resulting in improved movement and function. Directed mobilizations, often termed “joint glides,” are a frequently used type of manual therapy that can be applied to joints in specific planes of movement and are intended to restore specific joint movements.^{15,16} For example, a glide of the tibia on the femur directed anteriorly is commonly performed with the intent of improving knee extension. Although the use of glides at various joints has been shown to result in direction-specific increases in joint ROM,^{17–20} we are unaware of any previous research that has evaluated the effect of an anterior tibiofemoral glide on knee-extension ROM. There is also evidence to suggest that improvements in joint ROM after manual therapy interventions can translate to changes in characteristics of walking gait. For example, Green et al.²¹ reported increases in pain-free dorsiflexion, gait speed, and step length after an anterior glide of the tibia on the talus. We are also unaware, however, of any previous research that has evaluated the effect of an anterior tibiofemoral glide on knee kinematics and spatiotemporal characteristics during walking.

Although early postoperative passive and active ROM, muscle strengthening, and gait retraining are advocated in patients with knee-extension deficits after ACL reconstruction, little emphasis has been placed on the potential benefits of specific manual therapy interventions. Therefore, this investigation was designed to evaluate the effect of anterior tibiofemoral glides on maximal knee extension and spatiotemporal characteristics during gait in patients with knee-extension deficits after ACL reconstruction.

METHODS

Participants

Twelve participants were recruited from a single sport medicine physiotherapy clinic using purposive sampling.

To be included in the study, participants had to be able to walk unassisted without a gait aid and demonstrate a deficit in maximal knee extension in the operative limb compared to the non-operative limb—first identified using passive ROM measurement with a universal goniometer, and later confirmed during quantitative gait analysis. All participants had undergone a unilateral ACL reconstruction using a four-strand hamstring tendon ipsilateral autograft performed by one of four orthopaedic surgeons at the clinic. Patients with concomitant surgical treatment(s) for posterior cruciate ligament, medial collateral ligament, chondral, meniscal, and/or articular injury were included. Although such patients may require a more conservative postoperative rehabilitation protocol related to weight-bearing and return-to-sport activities, anterior glides would still be appropriate in the presence of a knee-extension deficit. Patients followed a standard postoperative physiotherapy protocol that included passive and active knee ROM exercises, strengthening, and proprioception retraining. Gait retraining with the use of crutches and physiotherapist assistance as required began immediately upon commencement of physiotherapy. All participants provided informed consent prior to testing; the study was approved by the institution's Ethical Review Board for the Study of Human Subjects.

Experimental Design and Intervention

Maximum knee extension during gait was assessed bilaterally during three consecutive gait analyses separated by 10 minutes. Tests were completed at baseline (Test 1), immediately after the operative limb was treated with a single 10-minute bout of repeated anterior tibiofemoral glides (Test 2), and after a 10-minute rest period (Test 3). During the rest period, patients remained in a seated position; no activity was permitted, and no treatment was provided. Test 1 was used to assess the initial extent of the knee-extension deficit during gait, Test 2 to assess the immediate effects of the anterior tibiofemoral glides, and Test 3 to assess the duration of any improvements observed following treatment.

Immediately after completing the baseline gait analysis (Test 1), participants were positioned prone, lying on a standard wooden plinth, with their lower legs extending over the plinth's edge. The physiotherapist then performed an anterior tibiofemoral glide to the participant's operative limb, as described by Kaltendorf¹⁶ (see Figure 1). Specifically, the physiotherapist (SD) grasped the dorsal aspect of the participant's proximal lower leg with one hand and held it firmly against his body while placing his other hand over the dorsal lateral aspect of the participant's tibia just distal to the knee joint. He passively moved the knee joint to the maximum available knee-extension ROM. He then glided the participant's tibia in an anterior direction parallel to the surface

Figure 1 Patient and therapist positioning for the application of the anterior tibiofemoral glide at end-range knee extension.

of the femoral condyle to the point where the resistance provided by the knee limited further anterior movement (R2). The tibia was held in this position for 10 seconds and released for 5 seconds. This was repeated for a period of 10 minutes. Participants were instructed to remain as relaxed as possible during the movement and to notify the physiotherapist if they experienced any discomfort. All participants were treated by the same clinician, who at the time of the study had been practising physiotherapy for 4 years and was completing the Canadian Physiotherapy Association's Orthopaedic Division manual therapy intermediate exam process.

Gait Analysis

Participants underwent three-dimensional gait analyses using an eight-camera motion-capture system (Eagle cameras, Motion Analysis Corp., Santa Rosa, CA). Passive-reflective markers were placed on the patient using a modified 22-marker Helen Hayes marker set.²² Extra markers were placed bilaterally over the medial knee-joint line and medial malleolus during an initial static standing trial to determine relative marker orientation and positions of joint centres of rotation for the hip, knee, and ankle. After removal of the four additional markers, patients were instructed to walk barefoot across the laboratory at their self-selected typical walking speed while kinematic data (sampled at 60 Hz) were collected during the middle of several strides. Five trials were obtained for each limb during each gait test. Participants were asked to verbally rate their knee pain prior to Test 1 and after Test 3, using an 11-point scale (0 = no pain, 10 = extreme pain).

Centres of rotation for the knee and ankle were calculated as the midpoint of the medial and lateral markers at each joint. The centre of the hip was located based on the inter-ASIS distance in the frontal plane. Specifically, the centre of the hip was deemed to be located

22% of this distance posteriorly, 32% of this distance medially, and 34% of this distance inferiorly to the ipsilateral ASIS.²³ Joint angles about the knee were calculated as an ordered series of rotations of the shank coordinate system with respect to the thigh coordinate system (x -axis = abduction/adduction; y -axis = flexion/extension; z -axis = internal/external rotation).²⁴ Flexion/extension about the knee was calculated by rotating the shank coordinate system about the z -axis of the thigh until the y -axis of the shank fell in the XY plane of the thigh. Full knee extension was defined as 0°, while positive and negative values for the knee angle in the sagittal plane corresponded to flexion and hyperextension respectively. Therefore, the minimum knee angle observed during the gait cycle corresponded to the maximum amount of knee extension, and this was identified for each trial (see Figure 2). We confirmed test-retest reliability of this measure on a sample of 27 individuals with knee pathology tested twice at least 24 hours apart and within 1 week ($ICC_{2,1} = 0.89$; 95% CI = 0.76–0.95).²⁵ To minimize potential bias, the treating physiotherapist conducted neither the gait analyses nor any post-processing of data. However, given the experimental design, the assessor could not be blinded to trial order.

Step length was measured as the horizontal distance in the line of forward progression between the location of heel strike from one limb to the location of the subsequent heel strike of the contralateral limb. Stride length was defined as the horizontal distance in the line of forward progression between subsequent heel strikes of the same limb. Lastly, gait speed was defined as the average walking speed between subsequent heel strikes of the same limb. All post-processing of data was done using commercially available software (Orthotrak, Motion Analysis Corp., Santa Rosa, CA).

Data Analysis

The primary outcome measure was the maximum knee-extension angle during stance. Secondary outcome measures were step length, stride length, and gait speed. Measures from each participant, including the gait test, were calculated as the average of the five trials for each limb. Each outcome measure was then used as the dependent variable in a two-factor (2 limbs $\times$ 3 gait tests) repeated-measures analysis of variance (ANOVA). Following significant effects ($p < 0.05$), Tukey post hoc tests were used to further evaluate observed differences. All statistical analyses were performed using a commercially available statistical software package (Statistica version 5.1, StatSoft Inc., Tulsa, OK).

RESULTS

Demographics and clinical characteristics of the 12 participants are reported in Table 1. All patients underwent testing within 8 weeks of ACL reconstruction. Each

Table 1 Participants' Demographic and Clinical Characteristics ($n = 12$)

Characteristic	Mean (SD)	Min, Max
Age (yrs)	21.3 (4.5)	17, 33
Mass (kg)	69.9 (14.5)	55.9, 98.0
Height (m)	1.73 (0.11)	1.58, 1.95
Sex (M:F)	5:7	
Operative limb (R:L)	7:5	
Knee-extension deficit ($^{\circ}$)*	7.0 (5.4)	1.5, 16.5
Days after surgery	30.8 (12.2)	19, 54

* Passive ROM in supine was measured prior to gait testing using a universal goniometer. Positive values represent a passive extension deficit compared to the non-operative limb.

Figure 2 Plots of a representative participant's average sagittal-plane knee kinematics throughout gait for the baseline (a) and post-treatment (b) walking trials. The figure illustrates the knee ROM values throughout a walking stride based on the mean of five separate walking trials for the operative (solid line) and non-operative (dotted line) limbs. The vertical lines denote the transition from stance to swing phases of gait. Note that in this case the maximum knee extension (indicated by arrows) in the operative limb occurred immediately after initial contact in both tests and was improved by approximately 3° following the mobilizations.

participant completed all three gait tests without incident, and only one participant reported an increase in pain during walking after the testing (0/10 prior, 1/10 post). No patient reported any pain at any time during the intervention period.

Figure 3 Maximum values for knee extension during stance for the operative and non-operative limbs exhibited during three consecutive gait tests. Values are means $\pm$ standard deviation; positive and negative values correspond to extension deficit and hyperextension respectively. Tests were completed at baseline (Test 1), immediately after the operative limb was treated with an anterior tibiofemoral glide (Test 2), and after a 10-minute rest period (Test 3). Note that the only significant difference (*) occurred between Tests 1 and 2 for the operative limb.

Plots of a representative participant's sagittal-plane knee kinematics throughout gait for the baseline and post-treatment walking trials are illustrated in Figure 2. Means and standard deviations for maximum knee extension during stance for the three gait tests are illustrated in Figure 3. There was a significant main effect for limb ($F(1,11) = 23.42$; $p < 0.001$), with the operative limb demonstrating significantly less maximum knee extension ROM. There was no significant main effect for test condition ($F(2,22) = 4.92$; $p = 0.29$). However, there was a significant ($F(2,22) = 6.67$; $p = 0.04$) limb by test condition interaction, indicating that the difference between limbs depended on the test condition. Post hoc tests indicated that maximum knee extension on the operative limb during Test 2 (i.e., after the anterior tibiofemoral glide) was significantly ($p = 0.008$) greater than during Test 1 (i.e., the baseline value). However, the operative limb demonstrated significantly less maximum knee-extension ROM than the non-operative limb during all three tests ($p = 0.005$), which suggests that even though knee extension improved in the operative limb after treatment, it did not reach the value of the non-operative limb. Also, although maximum knee-extension ROM on the operative limb appeared to decrease after the rest period, this difference did not reach statistical significance ($p = 0.13$).

Means and standard deviations for spatiotemporal gait characteristics are reported in Table 2. Comparisons showed a significant main effect for limb only for step length ($F(1,11) = 18.02$; $p = 0.01$). There were significant main effects for test condition for all three variables ($p < 0.05$). No limb by test condition interactions were observed for any spatiotemporal variable. While very

Table 2 Spatiotemporal Gait Characteristics for the Non-operative and Operative Limbs over Each of the Three Gait Tests

	Test 1 Mean (SD)		Test 2 Mean (SD)		Test 3 Mean (SD)	
	Non-operative	Operative	Non-operative	Operative	Non-operative	Operative
Step length (m)	0.65 (0.06)	0.62 (0.06)*	0.65 (0.06)	0.63 (0.06)	0.66 (0.06)	0.64 (0.05)**
Stride length (m)	1.26 (0.13)	1.26 (0.12)	1.29 (0.11)	1.29 (0.11)	1.30 (0.11)**	1.30 (0.10)**
Gait speed (m/s)	1.09 (0.18)		1.11 (0.15)		1.14 (0.15)**	

* Significantly different from non-operative limb ($p < 0.05$)** Significantly different from Test 1 ($p < 0.05$)

small increases in each variable were observed with successive gait tests for the operative limb, post hoc tests indicated that significant differences ($p < 0.01$) existed only between Test 1 and Test 3 (i.e., baseline and after the 10-minute rest period). For the non-operative limb, significant differences between gait tests were found only for stride length (greater during Test 3 than during Test 1).

DISCUSSION

Results from the present study suggest that anterior tibiofemoral joint glides can increase knee extension during gait in patients with extension deficits after ACL reconstruction. These findings are consistent with Kaltenborn's theory that joint glides can improve physiologic ROM and extend to improved functional ability during activities such as walking.¹⁶ Selected spatiotemporal characteristics of gait increased with repeated walking tests after the glides, which suggests that more global improvements in overall lower-limb function can potentially be achieved with as little as 10 minutes of glide mobilizations.

The mean increase in maximum knee extension during gait was 2° (95% CI: 0.6° – 3.3°). Although this improvement was statistically significant, it is unclear whether it was clinically important. Since the mean difference between limbs in maximum knee extension during gait before mobilization was 8° , the mean increase of 2° after mobilization could be described as an average improvement of 25%—a substantial improvement for a single treatment session. On the other hand, individual patient responses were quite variable, and only half of participants increased knee extension beyond our estimate of a minimal detectable change (MDC) of approximately 3.0° ($\text{MDC}_{90} = \text{SD} \cdot (\sqrt{1 - \text{ICC}}) \cdot 1.64 \cdot \sqrt{2}$).²⁶ Two participants actually exhibited *less* knee extension after the tibiofemoral glide. One of these participants was the oldest in the group, and the other had had the most recent surgery. Although these findings do not imply causation, they may highlight the influence of individual patient differences in factors such as age, pain level, and time since surgery on the effect of glides. It should

be noted that anterior glides are applied up to the point where resistance provided by the knee limits further movement (R2)²⁷ and should not be considered an overly aggressive mobilization. Although we suggest early treatment, including anterior glides, for knee-extension deficits after ACL reconstruction (e.g., one patient in the present sample was treated 19 days post surgery), manual therapy techniques must be applied with caution early in the postoperative rehabilitation period.

It is also important to note that all but one subject experienced a decrease in maximal knee-extension ROM, albeit not a statistically significant one, during gait on Test 3 (i.e., post-rest condition). This suggests that the positive effect of the glides was of relatively short duration and calls into question the long-term effects of a single intervention. However, joint mobilization is very rarely used as a single treatment, and it is likely that several treatments would be required to achieve longer-lasting changes. Similarly, we focused on the effect of an anterior glide because it is an extremely common mobilization and would most likely be an initial treatment option attempted in these types of patients; however, if less than desirable improvements in extension were obtained with the anterior glide alone, attempts to restore motion with additional manual therapy techniques, such as medial tibiofemoral or superior patellar mobilizations, might be attempted. We cannot comment on the effect of those additional treatments based on the present results.

The changes in knee-joint extension during gait observed in the present study did not necessarily translate directly into changes in global gait kinematics. For example, although knee extension tended to decrease after the 10-minute seated rest session (i.e., at Test 3), improvements in each of the spatiotemporal variables (step length, stride length, and gait speed) continued to be observed. In fact, in contrast to the findings for knee extension, the only differences between gait tests for these spatiotemporal variables occurred between Tests 1 and 3. The reasons for this are unclear, but the findings highlight the fact that these global measures of gait function rely on contributions from the ankle, knee, and hip.

In addition, stride length is measured based on the step lengths of both limbs, which explains why an improvement in this variable was observed in the non-operative limb after mobilization of the operative limb.

Alterations in the kinematic profiles of lower limbs after ACL reconstruction have been previously reported by many authors. Patients with ACL-reconstructed knees have been shown to exhibit decreased knee-joint extension during stance compared to healthy control subjects,^{1,28–30} as well as compared to the contralateral limb,³¹ for periods of more than 3 months post-surgery. In addition, reports of changes in the electromyographic activity profiles of many lower-limb muscles²⁸ indicate differences in the gait biomechanics of individuals after ACL reconstruction. These differences are likely precipitated by a combination of pain, weakness, and mechanical limitations; therefore, each of these issues should be addressed during postoperative rehabilitation.

Although joint mobilizations are believed to improve collagen extensibility, it is likely that, given the changes in collagen composition and orientation associated with pathology³² and, in particular, following ACL surgery, significantly more time and force are required to elicit permanent change in the mechanical composition of the joint. Indeed, the reduced knee-joint extension after a 10-minute rest period observed in the present study suggests that in the absence of an external force, tissues begin to return to near-baseline lengths rather quickly.

LIMITATIONS

The present sample size was sufficient to detect a statistically significant increase in knee extension, with narrow confidence intervals around its change. However, potential limitations in generalizing results from our sample of 12 patients to the greater population of patients with knee extension deficits after ACL reconstruction must be acknowledged. It should also be noted that some authors have suggested that biomechanical changes may occur in the contralateral limb after injury or surgery³¹ so as to maintain symmetry between limbs. If this is the case, it is possible that changes in spatio-temporal characteristics after the mobilization were masked in the present study. Future research comparing operative to non-operative limbs in larger groups of patients receiving different interventions, including repeated treatment sessions, alternative manual therapy techniques, and other treatment strategies, is warranted.

CONCLUSION

A single session of anterior tibiofemoral glides increased maximal knee extension during the stance phase of gait in patients with knee-extension deficits after ACL reconstruction. Increases in knee extension were

small and short-lived, however, which suggests that continued activity is required to maintain the observed improvements.

KEY MESSAGES

What Is Already Known on This Subject

Loss of knee-extension ROM is a common complication after ACL reconstruction. Glide mobilizations are a common physiotherapy treatment option for improving joint ROM; however, there is limited research evidence to support their efficacy. Little is known about the effects of anterior tibiofemoral glides in restoring knee extension during walking gait, especially after surgical interventions such as ACL reconstruction.

What This Study Adds

Our study is the first to quantify, using three-dimensional motion analysis, the effects of anterior tibiofemoral glide mobilizations on maximum knee extension during walking gait in patients who have recently undergone ACL reconstruction and exhibit an extension deficit. Results indicate that statistically significant improvements in knee extension during stance can be achieved immediately after a single session of joint mobilization; however, these positive effects are short-lived (less than 20 minutes), which suggests a need for continued mobilization therapy sessions to achieve longer-lasting improvements in knee extension.

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