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EMG biofeedback assisted KT-1000 evaluation of anterior tibial displacement

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Abstract Two studies were undertaken to evaluate the use of EMG biofeedback to encourage hamstring relaxation during KT-1000 measurement of anterior tibial displacement. In study 1, 60 ACL-deficient patients were studied in three groups using 15 lb and 20 lb in each group: in group 1 the patients were simply retested 15 min after the initial test sequence, in group 2 they were initially retested with EMG biofeedback and then again without, and in group 3 they were retested twice with EMG biofeedback. No significant difference in mean anterior tibial displacement was seen between the initial measurements and retest measurements when no EMG biofeedback was used. A significant increase in mean anterior tibial displacement was seen when the retesting was performed with EMG biofeedback. No further increase was seen with repeated retesting with EMG biofeedback. In study 2, 40 patients were evaluated 4–12 months following ACL reconstruction. KT-1000 measurements of anterior tibial displacement of both the operated and non-operated knees were made at 15 lb and 30 lb with and without the use of EMG biofeedback. EMG biofeedback was associated with a significant increase in unilateral measurement of anterior tibial displacement. When side-to-side differences were compared, there was a small but statistically significant increase in anterior tibial displacement with the use of EMG biofeedback. Although the use of EMG biofeedback to encourage hamstring relaxation does increase unilateral measurements of anterior tibial displacement, it does not appear to have a clinically significant effect on measurement of side-to-side difference. It may have a role in testing patients who have difficulty achieving hamstring relaxation or in aiding inexperienced examiners.

Keywords Knee arthrometry · Electromyographic biofeedback · Anterior cruciate ligament

Introduction

The KT-1000 arthrometer is frequently used to measure anterior displacement of the tibia in relation to the femur, either to detect rupture of the anterior cruciate ligament (ACL) or to measure laxity following ACL reconstruction surgery. Although KT-1000 arthrometric assessment reliably detects ACL rupture [1, 9], there are a number of factors that may affect the absolute measurements of anterior tibial displacement. These include the angle of force application [1, 7], alignment of the device relative to the joint [1, 7], muscle relaxation [1, 5], and rotation of the trochlear groove and patellar stabilization within the trochlear groove [1]. Apart from muscle relaxation, these factors are essentially operator dependent, and their effect should be able to be minimized by attention to detail and by adequate and regular practice.

Muscle relaxation requires the cooperation of the patient and is less easy to control. The effect of poor relaxation can be significant, and hamstring contraction significantly reduces the anterior displacement of the tibia in ACL-deficient knees [6]. Conversely, KT-1000 measurements of ACL-deficient knees in unconscious patients (under general anaesthesia) have been shown to be significantly greater than when the patients are conscious [5]. The ability of an individual patient to relax the thigh musculature and an examiner's ability to encourage relaxation can vary considerably. It would be useful to have a simple method of ensuring satisfactory relaxation.

Biofeedback is a principle that is widely used in muscle rehabilitation and strengthening programmes and significantly increases peak torque measurements for both quadriceps and hamstring muscle groups [4]. Biofeedback is more effective than electrical stimulation in facilitating recovery of peak torque of quadriceps following ACL reconstruction [3], better than exercise alone in recovery of quadriceps function following ACL reconstruction [2], and better than exercise alone in quadriceps strengthening in normal subjects [8].

The principle of electromyographic biofeedback is that the patient has a visual or auditory representation of the quality of muscle contraction. The patient then tries to enhance the level of the visual or auditory output by contracting the muscle group in or over which the EMG electrodes have been placed.

The sensitivity of modern EMG biofeedback units can be adjusted considerably. It was postulated that by using such a unit at its maximum sensitivity and with the electrodes over the hamstring compartment, it should be possible to achieve the opposite effect to that which is usually sought. The goal of the patient would then be to keep the visual or auditory representation of muscle activity to a minimum in order to reduce hamstring activity.

The purpose of this investigation was to test the hypotheses that (a) the use of EMG biofeedback to encourage hamstring muscle relaxation results in larger KT-1000 measured anterior tibial displacements than without the use of EMG biofeedback, and (b) the use of EMG biofeedback in this way results in larger side-to-side differences in anterior tibial displacement in ACL-reconstructed knees.

Materials and methods

Two studies were undertaken. The first was to evaluate the effect of EMG biofeedback on anterior tibial displacement in ACL-deficient knees. ACL-deficient knees were chosen for the initial study because the absolute measurements of anterior knee laxity are greater in this group than in normal and ACL-reconstructed knees. The second was to evaluate the effect of EMG biofeedback on the side-to-side differences in anterior tibial displacement in patients who had undergone unilateral ACL reconstruction.

Study 1

We investigated 60 patients scheduled for ACL reconstruction, in whom the injury had occurred more than 6 weeks previously. In all patients the diagnosis of ACL rupture was subsequently confirmed at arthroscopy. We felt that by excluding patients in whom the injury was less than 6 weeks old, the influence of pain-related muscle spasm would be minimized. There were 50 males and 10 females with a mean age of 24±4.7 years. The same examiner (C.H.), who had extensive experience with the technique prior to the study, performed all KT-1000 assessments.

The patients were sequentially allocated to one of three groups: patients 1, 4, 7, etc. to group 1, patients 2, 5, 8, etc. to group 2 and so on. There were four, three and four women in groups 1, 2 and 3, respectively. The respective group mean ages were 25, 24, and 23 years. All patients in each group initially underwent a KT-1000 arthrometric assessment of the affected knee using 15 lb (67 N) and 20 lb (89 N). They were given a standardized set of instructions, including instructions to relax the limb as much as possible. Three measurements of anterior tibial displacement were made at both testing forces and the mean of the three values was used for subsequent analysis. Patients in group 1 were retested 15 min later using the same protocol. Patients in group 2 were retested 15 min later using the same protocol but with the addition of a MyoTrac Plus (Thought Technology, Montreal, Canada) EMG biofeedback unit. The skin electrodes were placed in the midline over the hamstring compartment half-way between the knee joint and the ischial tuberosity. No electroconductive gel was used, and hair was not removed from the skin. The patients were given a standardized set of instructions regarding the use of this unit. Specifically, they were instructed to relax the limb as much as possible and to keep the number of lights showing on the unit to a minimum. The patients were then retested another 15 min later but this time without the EMG biofeedback. Patients in group 3 were also retested 15 min after the initial test sequence using EMG biofeedback, as described above. They were retested a further 15 min later using the same protocol, that is, with the use of EMG biofeedback.

Two analyses were conducted. First, data from the initial KT-1000 assessment were analysed using two-way analysis of variance (ANOVA) with test force (15, 20 lb of force) as a repeated factor and group (group 1, 2 or 3) as a between-subjects factor. This was to ensure that there were no initial differences in terms of anterior tibial displacement between the three patient groups. Second, repeated-measures ANOVA was used to assess for the effect of test sequence and force used. This was performed separately for each group. For groups 2 and 3 planned comparisons were made between the initial test sequence and test sequence 2 and between test sequence 2 and test sequence 3. For groups 2 and 3 the number of patients who showed an increase, decrease or no change with biofeedback between the first and second test sequences was determined. A minimum 0.5-mm change in anterior tibial displacement was required to indicate an effect of biofeedback.

Study 2

Forty patients (26 men, 14 women) were evaluated 4–12 months following unilateral isolated ACL reconstruction (20 patellar tendon graft, 20 semitendinosus/gracilis graft). The non-operated knee had not previously been injured in any of the patients.

Three KT-1000 measurements of anterior tibial displacement were made for each knee at both 15 lb (67 N) and 30 lb (134 N) by a single experienced examiner (K.W.). Here 30 lb was used rather than 20 lb in keeping with the change in clinical practice which occurred between the two studies. Testing was then repeated with the EMG biofeedback to enhance hamstring relaxation. The testing technique was the same as in study 1.

The data were initially analysed using a 2 (biofeedback/no-biofeedback) by 2 (normal knee/operated knee) by 2 (15/30 lb

Table 1 Anterior tibial displacement (mm) in ACL-deficient knees for all test sequences 1–3 and groups 1–3, with and without EMG biofeedback

	Test sequence 1		Test sequence 2		Test sequence 3	
	Without	With	Without	With	Without	With
Group 1						
15 pound	6.8 ± 2.6	–	6.8 ± 2.8	–	–	–
20 pound	9.6 ± 3.3	–	9.6 ± 3.4	–	–	–
Group 2						
15 pound	7.4 ± 2.6	–	–	7.9 ± 2.8	7.4 ± 2.6	–
20 pound	10.1 ± 3.9	–	–	10.9 ± 4.3	10.5 ± 4.0	–
Group 3						
15 pound	5.8 ± 2.2	–	–	6.7 ± 2.2	–	6.6 ± 2.4
20 pound	8.3 ± 2.7	–	–	9.7 ± 2.4	–	9.4 ± 2.7

Table 2 Number of patients with no change, increase or decrease in anterior tibial displacement with biofeedback in study 1 (note that comparisons were between test sequence 1 and 2)

	No change	Increase	Decrease
Group 2			
15 pound	2	15	3
20 pound	2	15	3
Group 3			
15 pound	7	13	–
20 pound	8	12	–

force) repeated-measures ANOVA with a between-subjects factor of graft type (hamstring/patellar tendon). Side-to-side differences were then assessed using a 2 (biofeedback) by 2 (lb force) repeated-measures ANOVA with graft type as a between-subjects factor. The number of patients who showed an increase, decrease or no change with biofeedback was determined by the method described for study 1.

Results

Study 1

The mean and standard deviation of the anterior tibial displacement measurements for each test sequence are shown in Table 1. From this table it can be seen that an increase in application of force produced an increase in anterior tibial displacement ($F_{1,57}$ = 300.87, $P < 0.001$). At initial assessment there was no difference in anterior tibial displacement between the three groups. For group 1, there was also no significant difference in anterior tibial displacement between the first and second test sequence.

Both group 2 and group 3 showed significant effects of test sequence ($F_{2,38}$ = 3.78, $P < 0.05$; $F_{2,38}$ = 11.84, $P < 0.001$, respectively). Specifically, planned comparisons revealed in both groups a significant increase in anterior tibial displacement between test sequence 1 and test sequence 2 (group 2: $F_{1,19}$ = 10.77, $P < 0.01$; group 3: $F_{1,19}$ = 12.63, $P < 0.01$), indicating an effect of biofeedback. For group 2 there was a decrease in mean anterior tibial displacement between test sequence 2 and test sequence 3; however, this was not statistically significant. For group 3 there was no significant difference in anterior tibial displacement between test sequence 2 and test sequence 3. No group showed a significant interaction between force and test sequence.

The numbers of patients with no change, increase or decrease in anterior tibial displacement with biofeedback are shown in Table 2. From this table it can be seen that approximately 75% of patients in group 2 and 70% of patients in group 3 experienced an increase in anterior tibial displacement with the use of biofeedback.

To summarize, a statistically significant increase in anterior tibial displacement was seen between testing with EMG biofeedback and testing without EMG biofeedback at both forces. Further testing with EMG biofeedback did not result in a further increase in anterior displacement measurements, but retesting without EMG biofeedback resulted in a non-significant decrease back towards the levels of the initial test sequences.

Study 2

The means and standard deviations for the anterior tibial displacement measurements are shown in Table 3. The analysis of unilateral measurements revealed a significant biofeedback/no biofeedback effect ($F_{1,38}$ = 49.46, $P < 0.001$), a significant normal knee/operated knee effect ($F_{1,38}$ = 30.93, $P < 0.001$) and a significant pounds of force effect ($F_{1,38}$ = 63.29, $P < 0.001$). There were no significant interaction effects between any of the three independent variables, nor was there any effect of graft type.

Examination of Table 3 reveals that anterior tibial displacement measurements with biofeedback were greater that those without biofeedback. At 15 lb the mean increase in anterior tibial displacement with biofeedback was 0.5 ± 0.7 mm in the operated limb and 0.3 ± 0.5 mm in the non-operated limb. At 30 lb the mean increase was 0.5 ± 0.7 mm in the operated limb and 0.4 ± 0.7 mm in the

Table 3 Anterior tibial displacement (mm) in ACL-reconstructed and normal contralateral knees in study 2

	Operated knee	Non-operated knee	Side-to-side difference
15 pound			
Control	4.0 ± 1.3	3.4 ± 1.1	0.5 ± 1.0
Biofeedback	4.5 ± 1.4**	3.7 ± 1.0**	0.8 ± 1.0*
30 pound			
Control	6.4 ± 1.7	5.6 ± 1.6	0.8 ± 1.5
Biofeedback	6.9 ± 1.7**	6.0 ± 1.5**	0.9 ± 1.3

* $P < 0.05$, ** $P < 0.01$, control vs. biofeedback conditions

Table 4 Number of patients with no change, increase or decrease in anterior tibial displacement with biofeedback in study 2

	No change	Increase	Decrease
Operated knee			
15 pound	10	28	2
30 pound	13	26	1
Non-operated knee			
15 pound	18	19	3
30 pound	17	19	5

non-operated limb. For both limbs taken together, the mean increase at 15 lb was 0.4±0.1 mm and 0.5±0.1 mm at 30 lb (see Table 3). The ACL-reconstructed knees had higher anterior tibial displacement than normal knees. Increased force produced increased anterior tibial displacement.

When the side-to-side differences in anterior tibial displacement were analysed, a small but significant main effect of biofeedback was seen ($F_{1,38} = 4.33$, $P < 0.05$). From the mean values in Table 3 it can be seen that the side-to-side increase with biofeedback was greater for the 15-lb test force (0.3 mm) than the 30-lb test force (0.1 mm). However, there was no significant interaction between pounds of force and biofeedback. Side-to-side difference values were also not affected by force used or graft type.

Table 4 shows the number of patients with no change, increase or decrease in anterior tibial displacement with the use of biofeedback. For the operated knee approximately 68% of patients show an increase with biofeedback compared with approximately 48% of patients for the non-operated knee.

Discussion

This study demonstrates that the use of EMG biofeedback to encourage hamstring relaxation does increase unilateral KT-1000 measurements of anterior tibial displacement in normal, ACL-deficient and ACL-reconstructed knees. However, the use of EMG biofeedback had little effect on side-to-side differences in anterior tibial displacement in the setting of a unilateral anterior cruciate ligament reconstruction. Although the increase in side-to-side difference associated with the use of EMG biofeedback was significant at 15 lb, this change was small and probably not clinically relevant. However, even a small change may become relevant in the setting of research in which patient groups are bracketed on the basis of side-to-side difference.

The absolute measurements of anterior tibial displacement in ACL-deficient knees in this study were similar to those reported in previous studies. In study 1, the initial anterior tibial displacement measurements at 20 lb were similar to those reported by Daniel et al. [1]. The measures obtained in ACL-deficient knees with the use of EMG biofeedback were similar to those in unconscious patients as reported by Highenboten et al. [5]. This suggests that the use of EMG biofeedback does indeed result in muscle relaxation.

The effect of EMG biofeedback did not appear to be a result of learning on the part of the patient, as there was no increase in anterior displacement associated with simply repeating the testing without the use of biofeedback and comparing the anterior displacements to the initial measurements. Further, when testing was repeated without biofeedback, but following testing with the use of biofeedback, the anterior displacement measurements returned towards the initial values. Interestingly, repeated testing with EMG biofeedback did not result in further increases in anterior tibial displacement.

Previous authors [1, 5] have stressed the importance of adequate muscle relaxation during KT-1000 arthrometric measurement. In this study we addressed only the issue of hamstring relaxation. However, adequate quadriceps relaxation is also important. Increased tone in the quadriceps muscle may result in anterior shift of the starting point for measurement of anterior tibial displacement, thereby decreasing the absolute values of anterior tibial displacement. Although we did not test the use of EMG biofeedback in this regard, it may be possible to achieve a similar effect of improved quadriceps relaxation using this technique. The use of dual-channel EMG biofeedback may even allow for simultaneous enhancement of both hamstring and quadriceps relaxation.

It was interesting to note that the response to the use of EMG biofeedback in patients who had undergone unilateral ACL reconstruction was not influenced by the graft type. The site of the surface electrodes was at the midthigh level. At this point the medial and lateral hamstring muscle bundles are closely related, and therefore use of the EMG biofeedback can be expected to influence the two bundles similarly.

In conclusion, although the use of EMG biofeedback to encourage hamstring relaxation does increase unilateral measurements of anterior tibial displacement, it does not appear to have a clinically significant effect on measurement of side-to-side difference in patients who have undergone unilateral ACL reconstruction. The technique may have a role in patients who have difficulty achieving hamstring relaxation or in training inexperienced operators.

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