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No significant improvement in neuromuscular proprioception and increased reliance on visual compensation 6 months after ACL reconstruction

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Abstract

Purpose: To determine the contributions of proprioceptive and visual feedbacks for postural control at 6 months following ACLR, and to determine their associations with knee laxity, isokinetic tests and clinical scores.

Study design: Level IV, Case series.

Methods: Fifty volunteers who received ACLR between May 2015 and January 2017 were prospectively enrolled, and at 6 months following ACLR, postural stability was assessed. Somatosensory ratios (somatic proprioception), and visual ratios (visual compensation), were calculated to evaluate the use of sensory inputs for postural control. Univariable regression analyses were performed to determine associations of somatosensory and visual ratios with knee laxity, isokinetic tests and clinical scores.

Results: At 6 months following ACLR, the somatosensory ratio did not change, while the visual ratio decreased significantly from 5.73 ± 4.13 to 3.07 ± 1.96 ($p = 0.002$), indicating greater reliance on visual cues to maintain balance. Univariable analyses revealed that the somatosensory ratio was significantly lower for patients who performed aquatic therapy ($\beta = -0.50$; $p = 0.045$), but was not associated with knee laxity, muscle strength or clinical scores. An increased visual ratio was associated with patients who received hamstrings tendon autografts ($\beta = 1.32$; $p = 0.049$), but was not associated with knee laxity, muscle strength or clinical scores.

Conclusion: At 6 months following ACLR, visual ratios decreased significantly, while somatosensory ratios did not change. This may suggest that there is little or no improvement in neuromuscular proprioception and therefore greater reliance on visual cues to maintain balance. The clinical relevance of this study is that posturography can provide useful information to help research following ACLR and to predict successful return to play.

Keywords: ACLR, Posturography, Proprioception, Postural control, Rehabilitation, Clinical evaluation

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Introduction

Postoperative rehabilitation strategies and timing of return to play (RTP) are crucial to avoid graft failure following anterior cruciate ligament reconstruction (ACLR) [11, 15, 21, 24, 25, 36]. For this reason, residual laxity is sometimes assessed at different timepoints, to help clinicians finetune rehabilitation and RTP [13, 22, 28, 29, 32], although anterior tibial translation (ATT) measurements do not reflect conditions during physical activities [20].

Knee proprioception, which contributes to dynamic stability, is often impaired in ACL-deficient knees [19, 23, 26, 27], but starts to recover in the first 6 months following ACLR [3, 33]. Impaired knee proprioception can increase the risk of ACL re-tears [15, 24], as it affects both voluntary and involuntary movements [10] as well as dynamic balance [11, 14, 20]. Methods previously used to assess knee proprioception seldom provide objective and accurate measurements to detect subtle impairments, because they are performed without weight-bearing [6] or vision deprivation [8].

Reliable analysis of postural control can be achieved with modern posturography platforms [25], which can be combined with vision deprivation methods to determine the contributions of proprioceptive and visual feedbacks [8]. The utility of such devices has not yet been demonstrated for research on ACLR. The purpose of this study was therefore to determine the contributions of proprioceptive and visual feedbacks for postural control at 6 months following ACLR, and to determine their associations with knee laxity, isokinetic tests and clinical scores. The hypothesis was that proprioceptive feedback improves at 6 months after ACLR, irrespective of knee laxity, muscle strength and clinical scores.

Methods

The authors prospectively enrolled 50 volunteers who received ACLR, between May 2015 and January 2017, by the senior surgeon (FW). All participants were amateur or professional athletes and provided written informed consent for participation in the study, which was approved by the National Ethics Committee (C.H.U. de Montpellier, # 2019_IRB-MTP_03-09) and registered at ClinicalTrials.gov (NCT02225613). Exclusion criteria were: (i) history of hypertension or neurological disease, (ii) use of psychotropic medication, or (iii) concomitant lower limb injuries that could interfere with postural control in the previous 3 months.

Surgical technique

All patients were operated under general anaesthesia, in the supine position, using a tourniquet. The femoral

tunnels (10 mm diameter) were drilled blind-ended, from the inside-out, using the anteromedial portal. Twenty-six patients (58%) received bone-patellar-tendon-bone (BTB) autografts, and 19 patients (42%) received hamstring tendon (HT) autografts fixed with femoral endobuttons and tibial screws (Smith and Nephew, Andover, MA). Patients returning to non-contact sports with predominant quadriceps involvement received HT grafts, while patients returning to contact sports received BTB grafts. Meniscal repair or meniscectomy were performed in 16 medial (36%) and 4 lateral (9%) compartments, and extra-articular tenodesis was performed in 22 knees (49%) that had high-grade pivot-shift.

Clinical assessment

All patients were evaluated clinically before surgery and at a minimum follow-up of 6 months using the Lysholm score [34], International Knee Documentation Committee score (IKDC) [16], and Knee injury and Osteoarthritis Outcome Score (KOOS) [31]. Absolute and side-to-side difference of anteroposterior laxity were recorded using the GnRB device (Genourob, Laval, France), at a force of 200 N [7, 18]. Isokinetic testing was performed at 180°/s during 3 repetitions to assess muscle strength deficit at peak torque between the ipsilateral and contralateral leg [17].

Postoperative rehabilitation

Patients were randomized to follow a conventional rehabilitation protocol, with or without additional aquatic therapy, 5 times per week, for a period of 3 weeks. In the first phase, the goal was to obtain full extension and 90° of flexion, and at 6 weeks, 120° of flexion. Partial weight-bearing (50% body weight) was allowed during the first 3 postoperative weeks if the preoperative static anterior tibial translation (ATT) was < 5 mm [13] and progressive full weight-bearing was allowed between 3 and 6 weeks. At 6 to 12 weeks, the goal was to get full range of motion, increase muscular strength and knee stability. At the end of this phase, the patient was expected to walk quickly and climb stairs. At 3–6 months, the goal was to regain the normal muscle strength and prepare for gradual return to sport. This phase consisted of heavy resistance strength training and exercises depending on type of sport practiced.

Posturography measurements

As part of the rehabilitation program to enable patients to achieve specific goals for RTP, a posturography platform (Medicaptureurs, Balma, France) [25] was used to

assess postural stability at 6 months following ACLR. Adequate testing preparation was provided to the patients to ensure their familiarity and understanding of the exercise. During the final measurement the patients stood barefoot, with their legs abducted 30°, and their arms along the body, for one minute on the posturography platform, facing a visual cue on the wall. The platform recorded the center of foot pressure (CoP) and its sway path, and calculated the surface area of the ellipse that covers 90% of the data points (Fig. 1). Posturography was evaluated in 3 conditions:

- Platform stable with eyes open (PsEo,)
- Platform stable with eyes closed (PsEc)
- Platform unstable (foam surface) with eyes open (PuEo)

Two ratios were calculated to indicate the use of somatosensory and visual cues for postural control. The somatosensory ratio, calculated by dividing the surface area of the ellipse in PsEc by that in PsEo, represents the use of somatosensory input when vision is impaired. A lower somatosensory ratio indicates better neuromuscular proprioception. The visual ratio, calculated by dividing the surface area of the ellipse in PuEo by that in PsEo, represents the use of visual input when somatosensory input is impaired [25]. A lower visual ratio indicates more

efficient use and/or greater reliance on visual cues to maintain balance.

Statistical analysis

A priori sample size calculation was performed to determine whether somatosensory ratios would improve (decrease) by at least 25% following ACLR. A recent study indicated a mean preoperative somatosensory ratio of 1.46 ± 0.8 [25]. Assuming equal standard deviations, a minimum of 40 patients is required to determine a statistical significance, with a power of 0.80 and alpha of 0.05. Descriptive statistics were used to summarize the data. Shapiro–Wilk tests were used to assess the normality of distributions. Comparisons between non-parametric data were evaluated using Wilcoxon rank-sum or Mann–Whitney U tests. Univariable linear regression analyses were performed to determine associations of somatosensory and visual ratios with twelve variables (age, sex, BMI, graft type, extra-articular tenodesis, time between injury and surgery, rehabilitation protocol, and postoperative leg strength deficit, anteroposterior laxity, as well as Lysholm, IKDC and KOOS scores). Multivariable analyses were not performed due to the limited cohort size. Statistical analyses were performed using R version 3.3.2 (R Foundation for Statistical Computing, Vienna, Austria). *P*-values < 0.05 were considered statistically significant.

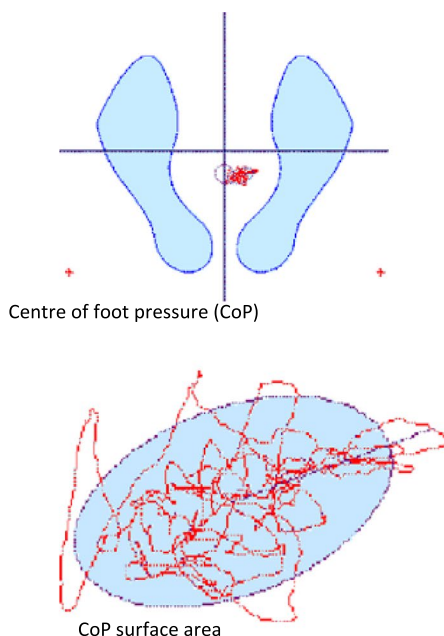
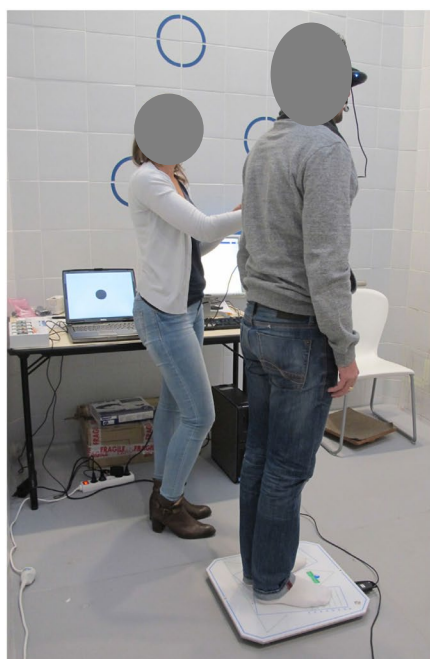
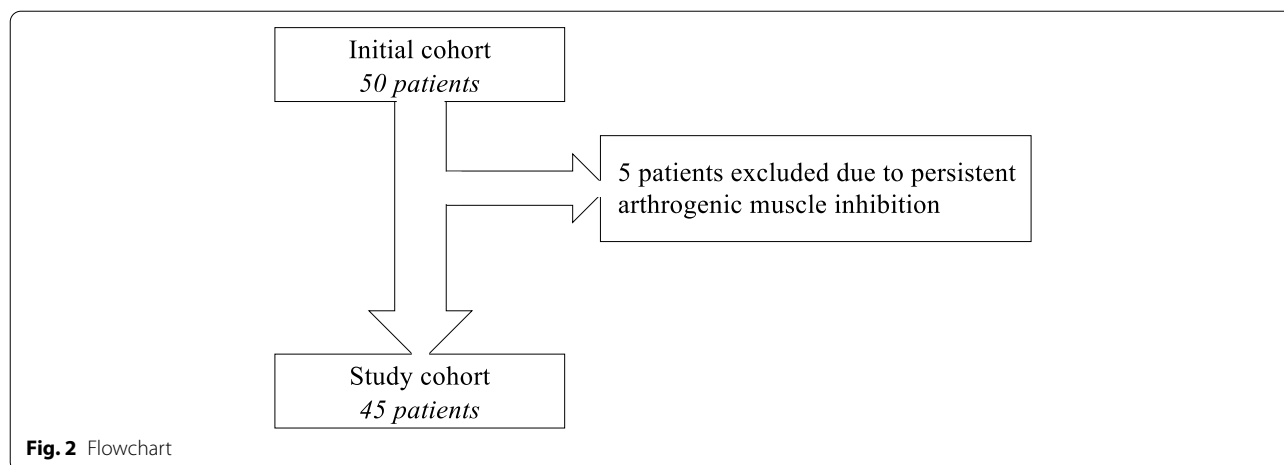


Fig. 1 Representation of the posturography measurements used in the study. The patient stands on the posturography platform (left), and the center of foot pressure of both feet (CoP) is recorded (top right). The area covered by the CoP sway path (confidence ellipse covering 90% of the points; bottom right) is then calculated



Results

At a minimum follow-up of 6 months, no surgical or postoperative complication was reported; however, 5 patients were excluded due to persistent arthrogenic quadriceps muscle inhibition (Fig. 2). The remaining 45 patients comprised 34 men (76%) and 11 women (24%), aged 27 ± 6 years, with a BMI of 23 ± 3 kg/m² (Table 1).

The sway surface area using posturography did not change following ACLR (Table 2). In addition, the somatosensory ratio did not change, while the visual ratio decreased significantly from 5.73 ± 4.13 to 3.07 ± 1.96 ($p=0.002$), indicating greater reliance on visual cues to maintain balance.

Univariable analyses revealed that the somatosensory ratio was significantly lower for patients who performed aquatic therapy ($\beta = -0.50$; $p = 0.045$) (Table 3), but was not associated with knee laxity, muscle strength or clinical scores. The visual ratio was significantly higher in patients who received HT autografts ($\beta = 1.32$; $p = 0.049$), but was not associated with knee laxity, muscle strength or clinical scores.

Discussion

The most important finding of the present study was that, following ACLR, visual ratios decreased significantly, while somatosensory ratios did not change. This may suggest that there is little or no improvement in neuromuscular proprioception and therefore greater reliance on visual cues to maintain balance. Neither ratio was associated with leg strength, knee laxity and functional scores. These findings refute the hypothesis that proprioceptive feedback improves at 6 months after ACLR, irrespective of knee laxity, muscle strength and clinical scores. It is worth noting that there was little or no change in sway surface area after ACLR, indicating that at 6 postoperative months, the intervention did not improve overall patient balance. Proprioception,

knee laxity and muscle strength all contribute to postural control [1] and posturography can provide useful additional information on the functional recovery of patients after ACLR. Combined with laximetry and isokinetic testing, posturography allows a holistic assessment of patient ability to return to sports. However, to the authors' knowledge, there are no recommended balance thresholds governing return to sport after ACLR.

Table 1 Pre- and intra-operative data

	Total cohort (n = 45)	
	Mean \pm SD	(Range)
Sex		
Men	34 (76%)	
Women	11 (24%)	
Age (years)	27.0 \pm 6.2	(18 – 43)
BMI (kg/m ²)	23.0 \pm 2.7	(18 – 30)
Time between injury and surgery (weeks)	23.6 \pm 32.6	(2 – 171)
Graft type		
HT	19 (42%)	
BTB	26 (58%)	
Medial meniscal treatment		
None	29 (64%)	
Meniscectomy	7 (16%)	
Suture	9 (20%)	
Lateral meniscal treatment		
None	41 (91%)	
Meniscectomy	4 (9%)	
Suture	0 (0%)	
Extra-articular tenodesis	22 (49%)	
Rehabilitation protocol		
Land-based therapy	21 (47%)	
Aquatic therapy	24 (53%)	

HT Hamstring autograft, BTB Bone-patellar-tendon-bone autograft

Table 2 Clinical outcomes

	Total cohort (n = 45)				p-value
	Preoperative		Postoperative		
	Mean ± SD	(Range)	Mean ± SD	(Range)	
Surface area (mm²)					
Platform stable, Eyes open (PsEo)	152 ± 112	(47 – 782)	199 ± 180	(56 – 1087)	0.105
Platform stable, Eyes closed (PsEc)	195 ± 115	(34 – 603)	214 ± 114	(45 – 555)	0.308
Platform unstable, Eyes open (PuEo)	470 ± 246	(103 – 1459)	430 ± 166	(212 – 844)	0.547
Somatosensory ratio (PsEc / PsEo)	1.43 ± 0.71	(0.46 – 3.21)	1.39 ± 0.78	(0.27 – 3.74)	0.967
Visual ratio (PuEo / PsEo)	5.73 ± 4.13	(0.95 – 14.72)	3.07 ± 1.96	(0.58 – 9.52)	<u>0.002</u>
Lysholm score	66.2 ± 18.9	(19.0 – 97.0)	83.6 ± 12.8	(50.0 – 100.0)	<u>0.001</u>
IKDC	41.1 ± 11.4	(17.0 – 65.5)	56.8 ± 9.6	(39.0 – 79.0)	<u><0.001</u>
KOOS					
Symptoms	69.2 ± 17.0	(32.1 – 96.4)	75.6 ± 12.2	(42.9 – 92.9)	0.098
Pain	71.9 ± 15.2	(33.3 – 94.4)	83.2 ± 13.5	(47.2 – 100.0)	<u><0.001</u>
ADL	80.8 ± 16.1	(44.1 – 100.0)	92.8 ± 9.6	(64.7 – 100.0)	<u><0.001</u>
Sports	38.3 ± 22.5	(0.0 – 85.0)	68.6 ± 16.1	(35.0 – 100.0)	<u><0.001</u>
QoL	29.3 ± 20.4	(0.0 – 87.5)	57.8 ± 20.0	(12.5 – 100.0)	<u><0.001</u>
Isokinetic tests					
Extension deficit (%)			17.2 ± 17.5	(-12.6 – 82.9)	
Flexion deficit (%)			-4.8 ± 28.9	(-54.3 – 65.9)	
Flexion/Extension (F/E) ratio			-0.8 ± 0.24	(-2.06 – 0.47)	
Anteroposterior laxity					
Absolute (ipsilateral, mm)			5.2 ± 1.2	(3 – 8)	
Differential (side-to-side difference, mm)			0.7 ± 0.6	(0 – 3)	

The finding that sway surface area does not improve after ACLR is consistent with previous studies [25], although while using a different posturography platform and protocol, 2 studies did find balance improvements at 6 and 12 months following ACLR [4, 5]. Nevertheless, patients who had ACLR demonstrate significantly greater sway surface area than control patients [4, 5, 12], suggesting that postural control is not fully restored. Furthermore, somatosensory and visual ratios are greater than those reported for control patients in a different study [9] using a similar device and protocol, suggesting that ACL tears may impair the ability of patients to use somatosensory and visual cues for balance.

In the present study, the somatosensory ratio did not change after ACLR, but the visual ratio significantly decreased. Univariable analysis revealed that patients who performed aquatic therapy had significantly lower somatosensory ratios. This improvement could be due to limited reliance on visual cues in water, which stimulates reliance on proprioceptive and/or vestibular cues. This is supported by recent findings that somatosensory and cerebellar systems have reduced activity after ACLR, while the visual and nigrostriatal systems have a stable increase in activity [4]. These observations are coherent

with a model where the brain balances input from several sources, including somatosensory and visual inputs. A reduction in one input can thereby be compensated for by an increase in reliance on other inputs [2]. Thus, after ACLR, patients may become more dependent on visual input for balancing. These findings contradict older observations, that reliance on visual input during single-leg stance increases only in ACL-deficient patients, but not in patients who had ACLR [35].

In the present cohort, patients who had the addition of aquatic therapy instead of only the conventional rehabilitation protocol had lower somatosensory ratios, suggesting that the aquatic therapy may improve the recovery of somatosensory contribution to postural control [25]. By impairing visual postural correction while exercising, aquatic therapy may increase somatosensory reliance [25]. This is consistent with the recent finding that training-induced structural plasticity in brain regions associated with proprioceptive postural control were associated with improved balance in blind individuals [30]. Further, aquatic therapy was shown to provide faster recovery, allowing for an earlier return to social, sporting and professional activities [25]. Rehabilitation strategies may therefore play an important role in how patients adapt their postural control mechanisms after ACLR, who

Table 3 Univariable linear regression analyses to identify factors associated with postoperative posturography measurements

	Somatosensory ratio			Visual ratio		
	(PsEc / PsEo)			(PuEc / PsEo)		
	β	C.I	<i>p</i> -value	β	C.I	<i>p</i> -value
Male sex	-0.13	(-0.70 – 0.44)	0.638	-0.18	(-1.63 – 1.28)	0.805
Age	0.03	(-0.07 – 0.01)	0.088	0.03	(-0.07 – 0.13)	0.547
BMI (kg/m²)	-0.05	(-0.14 – 0.04)	0.264	-0.11	(-0.37 – 0.14)	0.376
Graft type						
<i>BTB</i>	REF			REF		
<i>HT</i>	0.19	(-0.35 – 0.72)	0.478	1.32	(0.01 – 2.64)	<u>0.049</u>
Extra-articular tenodesis	-0.26	(-0.78 – 0.25)	0.305	0.54	(-0.79 – 1.87)	0.411
Time from injury to surgery (weeks)	0.01	(-0.00 – 0.01)	0.138	0.00	(-0.02 – 0.01)	0.621
Rehabilitation protocol						
<i>Land-based therapy</i>	REF			REF		
<i>Aquatic therapy</i>	-0.50	(-1.00 – -0.01)	<u>0.045</u>	-0.34	(-0.99 – 1.66)	0.610
Isokinetic testing						
<i>Extension deficit (%)</i>	0.00	(-0.02 – 0.01)	0.563	0.00	(-0.04 – 0.04)	0.973
<i>Flexion deficit (%)</i>	0.01	(-0.02 – 0.00)	0.171	0.01	(-0.04 – 0.02)	0.501
<i>F/E ratio</i>	-0.08	(-1.44 – 1.28)	0.904	0.17	(-3.36 – 3.71)	0.921
Laximetry						
<i>Absolute laxity (mm)</i>	0.07	(-0.14 – 0.29)	0.480	0.21	(-0.33 – 0.75)	0.434
<i>Side-to-side difference (mm)</i>	0.15	(-0.27 – 0.57)	0.474	0.09	(-0.98 – 1.16)	0.869
Lysholm	0.03	(-0.35 – 0.40)	0.889	0.04	(-0.92 – 1.00)	0.933
IKDC	0.01	(-0.02 – 0.04)	0.586	0.01	(-0.06 – 0.08)	0.785
KOOS						
<i>Symptoms</i>	0.01	(-0.01 – 0.03)	0.317	0.00	(-0.06 – 0.05)	0.895
<i>Pain</i>	0.00	(-0.02 – 0.02)	0.829	0.01	(-0.06 – 0.04)	0.815
<i>ADL</i>	0.01	(-0.02 – 0.03)	0.710	0.00	(-0.07 – 0.07)	0.929
<i>Sports</i>	0.00	(-0.01 – 0.02)	0.788	0.02	(-0.06 – 0.02)	0.404
<i>QoL</i>	0.00	(-0.01 – 0.01)	0.849	0.01	(-0.03 – 0.04)	0.715

β Regression coefficient, C.I. 95% confidence interval

could benefit further from proprioceptive training with limitation or deprivation of visual compensation. The clinical relevance of this is that posturography can provide useful information to help research following ACLR and to predict successful RTP.

This study evaluated the utility of a common method used to assess patient postural control in evaluating outcomes of ACLR. Posturography was independent from leg strength, knee laxity and functional scores. Furthermore, this study highlighted the importance of rehabilitation for somatosensory recovery after ACLR. Its main limitation is the lack of a control group of knees without ACL tears, which prevents comparison to normal posturography measurements. In addition, posturography is a bipedal exam and therefore the unaffected leg could compensate for the decreased proprioception of the affected leg. Another limitation was the absence of

preoperative laxity and isokinetic testing. Finally, the cohort was too small to evaluate the effect of meniscal lesions, or to perform multivariable analyses. Further comparative studies with larger cohorts and multiple follow-up evaluations would be beneficial to understand how proprioceptive and visual feedbacks contribute to postural control in the medium and long-terms.

Conclusion

At 6 months following ACLR, visual ratios decreased significantly, while somatosensory ratios did not change. This suggests that there is little or no improvement in neuromuscular proprioception and therefore greater reliance on visual cues to maintain balance. The clinical relevance of this study is that posturography can provide useful information to help research following ACLR and to predict successful RTP.

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Authors' contributions

The author(s) read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

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