ORIGINAL ARTICLE

Isometric quadriceps pressure difference: A simple and cost-effective tool to identify and regain quadriceps muscle strength following anterior cruciate ligament reconstruction - A case series

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ABSTRACT

Introduction: Quadriceps weakness and extension deficit of the knee following anterior cruciate ligament (ACL) reconstruction (ACLR) can threaten rehabilitation, and isometric quadriceps exercise is the usual prescription. However, the outcome depends more on the individual's re-learning process. Identification of this lacuna and focussed attention to the isometric strength of quadriceps are lacking in the current practice, and developing a tool can lead to optimal outcomes in ACLR. The objective of this study was to assess the role of 'isometric quadriceps pressure difference' (IQPD) in regaining quadriceps strength following the ACLR using a simple tool.

Patients and Methods: Eight patients who underwent post-operative ACL rehabilitation between March 2016 and May 2018 were analysed retrospectively. A 'progressive isometric training protocol (PITP)' based on IQPD was prescribed along with the standard protocol. Data were collected from the case records of the patients. IQPD, thigh muscle girth and heel height difference (HHD) were noted pre-operatively, immediately following surgery and 3 months post-operatively. A non-parametric test was used to compare the outcomes before and after surgery.

Results: Based on the analysis, the inclusion of IQPD-based PITP in regaining the terminal extension had a significant statistical difference in the IQPD, HHD and girth ($p < 0.007$, $p < 0.005$ and $p = 0.027$, respectively).

Conclusion: IQPD can be a simple, cost-effective strategy to identify subtle quadriceps weakness. Further, PITP can improve the isometric quadriceps strength in the acute post-operative period and reduce the incidence of knee extension deficit in post-ACLR.

Key Words: Anterior cruciate ligament reconstruction, isometric quadriceps pressure difference, knee extension deficit, rehabilitation

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INTRODUCTION

Quadriceps weakness and knee extension deficit following anterior cruciate ligament (ACL) reconstruction (ACLR) is a universal phenomenon. These factors can be detrimental and may harm the functional and sport-specific outcomes in the long term. In the present scenario, isokinetic equipment or pressure sensitiser is used to measure the isometric quadriceps strength, which is costly, needs expertise and is not patient-friendly. Hence, a simple and cost-effective technique is required to overcome this issue.

Quadriceps inhibition can have a significant adverse effect following ACLR. Hence, quadriceps re-education and achieving symmetrical extension become the primary goal (Palmieri-Smith et al., 2013). Since quadriceps physiology, morphology and the mode of innervation demand adequate attention, therapists must incorporate the correct technique to identify quadriceps deficits and prescribe a comprehensive individualised exercise prescription. Hence, an appropriate learning methodology should be adopted and tailored depending on patient abilities (Draper and Ballard, 1991).

The motor learning process involves acquiring a new or modifying an existing movement. In contrast, a re-learning strategy focusses on a repeated task that involves an internal reorganisation leading to permanent changes in the capability of an individual. The neuromuscular concept of re-learning plays an essential role in regaining the deficient quadriceps function. It involves feedback of special senses in augmenting and perfecting the art of movement control (Giggins et al., 2013).

The principle of biofeedback (BFB) may sound primitive, but the basic physiological principles make it an effective and conceptual approach in rehabilitation. The use of electromyographic (EMG) BFB has proven effective in re-educating quadriceps function following ACL injuries and ACLR (Snyder-Mackler, 1994). Augmenting the quadriceps contractions through neuromuscular stimulation and BFB has gained enough attention following reconstruction procedures in the acute post-operative period. Apart from EMG, visual, auditory, pressure, tactile and kinesthetic feedback can be utilised to identify and re-educate quadriceps function following ACLR (Giggins et al., 2013). The use of pressure BFB (PBFB) is straightforward and may prove cost-effective in these circumstances. The modified sphygmomanometer can effectively identify subtle quadriceps weakness and reactivate normal quadriceps function in post-ACLR patients (Mohanakrishnan et al., 2016).

Even though PBFB has gained maximum attention in neurological and urogenital conditions, it has not gained enough recognition in musculoskeletal rehabilitation. Progressive resisted exercise (PRE) forms an integral part of musculoskeletal rehabilitation, which involves muscular activation on an incremental basis to achieve the target (Kg/Pound). Both 'Delorme' and 'Oxford' protocols involve resistance in incremental and regressive fashion to achieve the target. Similarly, based on this principle in our study, the target pressure (IQPD) was identified and achieved in a progressive incremental pattern using a modified sphygmomanometer.

PATIENTS AND METHODS

Participants

This was a retrospective study done on patients who underwent ACLR followed by rehabilitation between March 2016 and May 2018 from the department of orthopaedic surgery. Patients who had bilateral knee injuries, avulsion fractures, associated multi-ligament injuries, symptomatic meniscal injuries and radiological signs of osteoarthritis were excluded. Data of eight patients with isolated unilateral ACL tear were collected after obtaining institutional ethical committee approval. Among these patients, three had bone–patellar tendon–bone grafts, and five of them had hamstrings grafts. Physical therapists did the physical therapy evaluation and intervention with expertise in orthopaedic physical therapy for more than two decades [Figure 1].

Outcome measures

Standard outcome measures such as muscle girth difference of quadriceps (Kovačev et al., 2015), heel height difference (HHD) (Schlegel et al., 2002) and isometric quadriceps pressure difference (IQPD) (Mohanakrishnan et al., 2016) were used. These measurements were taken before surgery, immediate post-operative period and 3 months later.

Muscle girth evaluation

Patients were positioned in a relaxed long sitting posture on a couch. Muscle girth was measured 10 cm above the patella

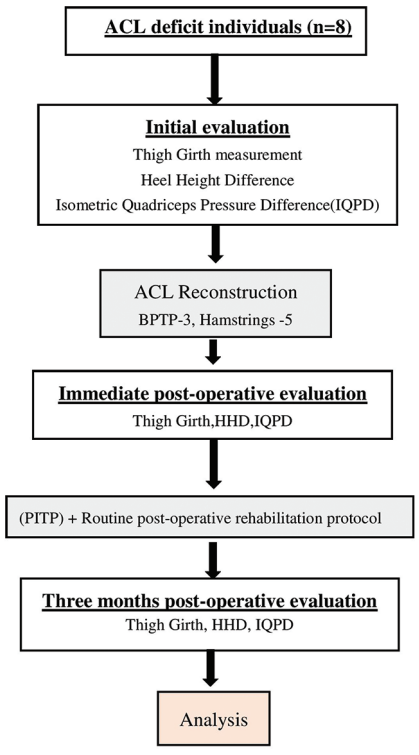

Figure 1: Flowchart showing the methodology

(Kovačev et al., 2015) using an inch tape on both sides, and the difference in muscle wasting was documented.

Heel height difference

Patients were made to lie prone with their knees out of the couch and thigh well supported. The difference in the heel height was measured using a scale on the posterior margins of the calcaneum (Schlegel et al., 2002).

Isometric quadriceps pressure difference

'Modified sphygmomanometer' was used to measure the isometric strength of quadriceps on both sides (affected and unaffected). The apparatus consisted of a cuff wrapped over a sand-filled pet bottle and pressure gauge [Figure 2]. This unit was placed on the hard couch beneath the knee with the patient in long sitting. When a maximum quadriceps contraction is initiated, the cuff measures the pressure proportional to the applied force. Care was taken to maintain the contact of the hip and ankle to the couch [Figure 3]. Three trials were repeated on both sides, and the best reading was documented. The trunk was inclined to 60°–70° and supported by hands during the procedure. The difference (uninvolved − involved) was recorded as IQPD (Mohanakrishnan et al., 2016).

Intervention

Patients underwent post-operative rehabilitation with progressive isometric training protocol (PITP), which focussed on the terminal extension and routine ACL post-operative physical therapy.

Progressive isometric training protocol

A modified training protocol based on De Lorme's PRE model was followed. This protocol had a gradual and progressive resistance to quadriceps activity with an initial target of 25% of the IQPD for 25–50 repetitions, 2–3 sessions per day for the 1st week. The target was increased to 50% in the 2nd week followed by 75% in the 3rd–4th week and 100% in the 4th–6th week [Appendix 1].

Figure 2: The modified sphygmomanometer apparatus for measuring isometric quadriceps pressure difference

Statistical analyses

Data collected were cleaned for paucity before the analysis and checked for normality using the Shapiro–Wilk test. A Kruskal–Wallis non-parametric test and a *post hoc* test were used to compare the outcomes before and after surgery (n = 8). Data were analysed using IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp. Statistical significance was set at $p < 0.05$ (two-tailed).

RESULTS

Among the eight patients, six were male, and two were female. Five of them had right-sided ACLR. Based on the analysis, the inclusion of PITP in regaining the terminal extension had a statistically significant difference in the IQPD, HHD and girth scores ($p < 0.007$, $p < 0.005$ and $p = 0.027$, respectively) [Table 1 and Figure 3]. A *post hoc* analysis between the time intervals showed a significant result for IQPD, HHD and thigh girth measurements. However, the girth scores had no significant change in the follow-up visits [Table 2].

DISCUSSION

The present study was conducted to assess the role of IQPD in regaining quadriceps strength during the early rehabilitation phase of ACLR. Pain and weakness of the quadriceps can lead to extension deficit of the knee following any surgery around the

Table 1: Mean and standard deviations of outcome measures (n=8)

Outcome measures	Mean (SD)		
	Pre-operative	Immediate post-operative	Follow-up
HHD	1.12 (1.74)	3.06 (2.06)	0.50 (0.53)
IQPD	8.12 (7.52)	18.75 (9.16)	3.12 (4.58)
Girth	0.56 (0.32)	1.12 (0.44)	0.75 (0.37)

SD: Standard deviation, HHD: Heel height difference, IQPD: Isometric quadriceps pressure difference

Figure 3: Apparatus placement and measurement procedure

Table 2: *Post hoc* analysis between the time measurements

Outcome measures	Between time measurements	Mean difference	Significance (*P*)
IQPD	Immediate post-operative to pre-operative	10.62	0.026
	Follow-up to immediate post-operative	−15.62	0.001
HHD	Immediate post-operative to pre-operative	1.93	0.071
	Follow-up to immediate post-operative	−2.56	0.012
Girth	Immediate post-operative to pre-operative	0.562	0.024
	Follow-up to immediate post-operative	−0.37	0.192

HHD: Heel height difference, IQPD: Isometric quadriceps pressure difference

knee (Adams et al., 2012). Loss of extension can be a devastative outcome following ACLR (Ektas et al., 2019) and can have a detrimental effect on long-term outcomes.

Our study had two observations. First, PITP based on IQPD significantly improved the terminal extension in the post-operative period. Second, PBFB in the form of a modified sphygmomanometer can be used to identify and measure the subtle weakness of isometric quadriceps strength as IQPD following ACLR procedures.

While EMG BFB occupies the centre stage in rehabilitation, other forms of BFB also facilitate the learning process in regaining movement control and strengthening programmes. Biomechanical BFB is a procedure that measures movement pattern, posture and force. They are measured by inertial sensors, force plates, electro goniometers, visual capturing and pressure units (Giggins et al., 2013). A PBFB unit is a tool consisting of an inflatable pouch connected to a pressure gauge. PBFB can accurately transfer the force produced by the muscle activity through visual representation during training (Cairns et al., 2000). This PBFB can also be used to strengthen the weakened musculatures in cervical dysfunctions (Hudswell et al., 2005). In the past, the use of sphygmomanometer for PBFB was applied to validate handgrip strength measurement (Silva et al., 2015; Hamilton et al., 1992). PBFB can be safe and easy to apply even to elderly patients to evaluate the strength (Kaegi et al., 1998). A systematic review recommends a sphygmomanometer as a valuable tool for measuring isometric strength in the hip (Toohey et al., 2015).

PBFB by using a conventional sphygmomanometer during the acute phase of rehabilitation can improve the isometric quadriceps strength following ACLR (Mohanakrishnan et al., 2016). PBFB facilitates a precise re-learning process and may reduce the incidence of flexion deformity at the knee, which can be monitored by HHD (Mohanakrishnan et al., 2016; Schlegel et al., 2002). This study showed that improved isometric quadriceps strength reduced the extension deficits at the knee [Figure 4].

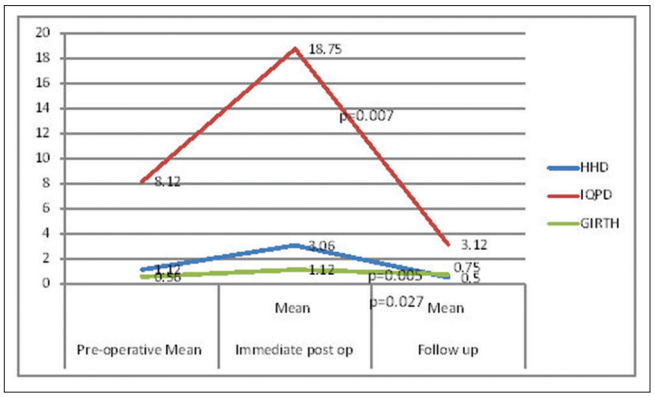

Figure 4: Comparison of outcomes before and after anterior cruciate ligament surgery ($n = 8$)

In our study, a 'modified sphygmomanometer' was used to measure the difference in the isometric strength of quadriceps. The identified value (IQPD) was used as a benchmark and was worked up to equalise the difference to achieve symmetry. Hence, identification and focussed attention to the isometric strength of quadriceps can provide an optimal and functional return to near-normal levels following ACLR.

Studies show that the thigh and calf girth can significantly reduce before and after knee surgeries, significantly affecting quadriceps strength (Ross and Worrell, 1998). Thigh girth is a predictive factor in determining quadriceps' strength and force production ability (Olagbegi et al., 2017). In our study, the thigh girth reduced significantly following surgery and improved with the PITP protocol.

The study's strengths are safety, simplicity, cost-effectiveness, assessment and intervention. The BFB principle incorporated in this study provides a better insight into the re-learning process. Moreover, the recommended protocol used in this study may be self-administered by patients without any difficulty; hence, it can serve as a suitable home exercise programme.

The limitations of our study are the small sample size and the pressure due to compensatory movements by the individual to the cuff, which can alter the actual values. Since the practical application of a modified sphygmomanometer in ACL rehabilitation needs validation, this technique may be applied to larger samples for diverse knee pathologies with the standard isokinetic gadgets.

CONCLUSION

It may be concluded that IQPD can be used as a simple and cost-effective strategy to identify the subtle weakness of the quadriceps. PITP can encourage a structured re-learning of quadriceps activation to improve the isometric quadriceps strength during the acute post-operative period, reducing the incidence of knee extension deficits among patients following ACLR.

Ethics approval and consent to participate

This study was carried out after obtaining approval from the institutional ethics committee. Written consent was given to

participate, and all images were taken with verbal and written permission.

Consent for publication

All patients included in this research gave written informed consent to publish the data contained within this study.

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Conflicts of interest

There are no conflicts of interest.

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Appendix 1: Progressive isometric training protocol

Period (weeks)	IQPD (%)	Repetitions	Sessions/day
1	25	25-50	2-3
2	50	25-75	3-4
3-4	75	50-75	4-5
4-6	100	75-100	6

IQPD: Isometric quadriceps pressure difference