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Isokinetic moment curve abnormalities are associated with articular knee lesions

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ABSTRACT: The aim of this study was to test whether lesions of the medial meniscus (MM) and of the anterior cruciate ligament (ACL) are associated with specific abnormalities of isokinetic moment curves (IMCs). Fifty-four young adults (20 active healthy people, and 34 patients with unilateral knee injuries) were assessed through knee extensor and flexor isokinetic tests at 60°/s. Qualitative IMC analysis was performed using a novel classification system which identified three distinct abnormal shapes. The chi-squared (χ^2) test was used to determine the inter-individual and intra-individual differences between the groups. Quantitative IMC inter-group comparisons were performed by a one-way analysis of variance (ANOVA). Knees with MM and ACL lesions were consistently associated with IMC shape irregularities ($p<0.001$) and with abnormal quantitative scores ($p<0.001$). More specifically, knees with isolated ACL lesions and knees with combined ACL and MM lesions presented similar distribution of knee extensor and flexor IMC irregularities, which was not present in knees with isolated MM lesions. A possible association between specific knee pathologies and IMC irregularities was identified (all $p<0.05$). In conclusion, different knee pathologies may be associated with different qualitative IMCs, which could be used as an additional presentation tool in clinical settings.

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INTRODUCTION

Muscle strength testing has been identified to be of importance in clinical settings. An objective evaluation based on the best practice evidence can guide professionals in many medical contexts and throughout different clinical phases. Specifically, it could help in assessing whether medical clearance should be given for a full return to sport following an injury event. As an alternative it could assist in decision making concerned with rehabilitation programme planning, or to provide inputs for prevention strategies [1-4]. Commonly used in daily practice, isokinetic dynamometry represents a reliable tool for muscle strength assessment [3]. This evaluation offers good prospects for inter- and intra-individual control of the kinetic capacity which is assessed by the measurement of peak torque [5], total work and average power [2,6]. In addition, isokinetic assessment, through the graphical representation of the isokinetic moment curve (IMC) patterns, provides a mean to inspect the subject's ability to produce a normal and smooth isokinetic torque curve of a maximal effort, while the presence of limiting factors affects the torque curve by introducing interference within the curve pattern [1,2,7].

Previous studies showed that irregular torque outputs were associated with pathologies such as anterior knee pain [8], knee osteoarthritis [9,10], and anterior cruciate ligament (ACL) rupture [1,11,12]. It appears that the smoothness of torque generation is indicative of proper force control [13] and the quantification of isokinetic curve irregularities is clinically important for refined joint function assessment [14]. In fact, neuromuscular adaptations, consequences of the altered joint's biomechanics, may compromise the co-ordination of muscles crossing the knee [15] and present a possible reason for decreased smoothness of the torque-time curve pattern during maximal knee efforts. A clear interpretation of the irregular patterns associated with the IMC may add to the overall isokinetic assessment of the deficient knee. The accurate estimation of the degree of smoothness of the IMC and a clear classification of its profile may be useful for clinical practice. In this regard, previous investigations have used quantitative measures, obtained by means of mathematical processing, to quantify the IMC shape irregularities in both healthy and injured knees [7,16]. Cross-correlation functions [17], percent root mean square difference (%RMSD) [18] and frequency-domain analysis [16] have been used to complement the assessment of curve shape similarity and consequently identify differences between successive curves. However, in clinical contexts the sole reliance on quantitative scores may be disadvantageous, as it neglects curve characteristics that may contribute to the ability to differentiate between specific injuries. Previous qualitative evaluation methods so far have not provided a direct link between shape-related curve identification and specific pathologies, and thus relied exclusively on the subjective ability of clinicians. Therefore, there is a lack of objective evidence to determine the profile and the degree of irregularity with regard to the IMC. An accurate and accepted profile of these irregular patterns may help in improving the diagnostic accuracy of professionals currently based only on isokinetic strength outputs. Indeed, it is of clinical interest to investigate the connection between IMC and quantitative outcomes in knee injured subjects. The purpose of the current study was therefore to test whether qualitative and quantitative features of the IMC can be associated with specific knee lesions related to the medial meniscus (MM) and the ACL.

MATERIALS AND METHODS

Experimental Design

Our study used an observational design with between-group comparisons to evaluate differences in quantitative measures and qualitative features of the IMC between injured subjects, with clinical diagnosis of knee injuries, and a matched counterpart represented by uninjured physically active subjects. Then, we evaluated the relationships between the profiles of the irregular patterns in the injured legs and specific knee lesions. All participants completed one laboratory setting assessment where maximal knee extension-flexion muscle torque of both legs was assessed by an isokinetic dynamometer; in addition, only the injured subjects were appointed for a standard clinical examination followed by an MRI scan with the final confirmation of the knee injury diagnosis made during the arthroscopic surgical procedure.

Participants

The study involved 54 male subjects divided into two matched groups: the injured group (n = 34; age 36.8±3.6 years; body mass: 72±5.6 kg; height: 1.74±0.08 m; BMI: 23.2±1.4 $kg \cdot m^{-2}$ (Table 1)) included patients diagnosed by MRI and physical examination as having one of the following injuries: ACL rupture, isolated medial meniscus tear (MM), or combination of ACL rupture and meniscal tear (ACL + MM). Injured participants were recruited through direct contact from a patient list awaiting surgical intervention. Inclusion

TABLE 1. Percentage distribution of IMC pattern for both injured and control group

IMC Pattern	Injured group (n=34)				Control group (n=40)
	MM (n=19)	ACL (n=6)	ACL+MM (n=9)	Uninjured leg (n=34)	
Knee extensors					
Normal pattern (%)	0	0	0	85.3	92.5
Valley pattern (%)	$47.4^{\#}$	$50^{\#}$	$33.3^{\#}$	4.3	2.5
Drop pattern (%)	$52.1^{\#}$	50*	44.4*	3.4	5
Shaking pattern (%)	0.5	$16.7^{\#}$	$22.3^{\#}$	7	0
Knee flexors					
Normal pattern (%)	5.3	0	5.5	42.5	35
Valley pattern (%)	26.3	33.3	33.3	18.5	20
Drop pattern (%)	31.6	0	5.6	23.5	22.5
Shaking pattern (%)	36.8	$66.7^{\#}$	55.6*	15.5	22.5

Note: the values are expressed as percentage distribution (%). IMC: isokinetic moment curve; MM: medial meniscus; ACL: anterior cruciate ligament; ACL+MM: combined anterior cruciate ligament and medial meniscus injury. * indicates significant difference comparing the injured leg of injured group and both legs of control group with $p \leq 0.05$; $^{\#}$ indicates significant difference comparing the injured leg of injured group and both legs of control group with $p \leq 0.01$.

criteria were identified using a self-report medical questionnaire and by physician consultation. These criteria included: absence of current or previous musculoskeletal injury to the contra-lateral knee; the ability to perform an isokinetic test on the injured side without pain limitation, and normal blood pressure. Knee injuries were diagnosed by the same orthopaedic surgeon in all patients using standard clinical examination and MRI findings, while final confirmation of the specific knee injury diagnosis was made during an arthroscopic surgical procedure which was performed later than the isokinetic test. The control group (*n* = 20; age 39.8±2.1 years; body mass: 73±10 kg; height: 1.76±0.06 m; BMI: 23.2±1.1 $kg \cdot m^{-2}$ (Table 1)) included uninjured, physically active subjects. The exclusion criteria for uninjured subjects were: symptomatic knee due to any articular or muscle injury, any previous knee surgery, other ligament instability or history of significant injury to the lower limbs which could impair function. The study procedures were reviewed for ethical compliance and received approval by the Research Ethics Committee according to the Declaration of Helsinki. The participants were fully informed about the procedures to be used and gave their voluntary written consent to participate.

Procedures

Concentric unilateral maximal knee extension-flexion muscle torque of both legs was assessed by an isokinetic dynamometer (Biodex system 3, Biodex Medical Systems Inc., Shirley, NY, USA). Prior to testing, participants performed a standardized 5-minute warm-up on a cycloergometer (50 W) and 5 minutes of active range of motion exercises of subsequently involved muscles [19]. The assessments were carried out in the Biomechanics Laboratory from 1:00 p.m. until 6:00 p.m., at an average temperature of 23±1°C and relative humidity of 60±4.5% [20]. Testing was performed in a seated position, with the back rest of the chair set at 85° (Figure 1). The participants were secured to the chair by two straps across the chest and a single strap at the abdomen and distal thigh of the tested limb in order to avoid compensations [7,21]. Knee range of motion (ROM) was set at 95° with 0° indicating full knee extension. Adequate familiarization with the dynamometer was provided in the form of further warm-up isokinetic repetitions at various angular velocities. Specifically, the familiarization protocol included 15 continuous repetitions at a self-perceived low effort level. This was followed by three repetitions at a self-perceived medium effort level, and 2-3 practice sets consisting of 2-3 maximal repetitions [7]. Following 3-5 min of passive rest, the participants performed 1 set of 5 maximal repetitions of concentric knee extension and flexion at 60°/s [22].The choice of this angular velocity was based on previous investigations that described the typical isokinetic curve shapes for the knee extensors and flexors [1,23]. Testing was performed and data further analysed by two different examiners, each with about 20 years of experience in isokinetic assessment.

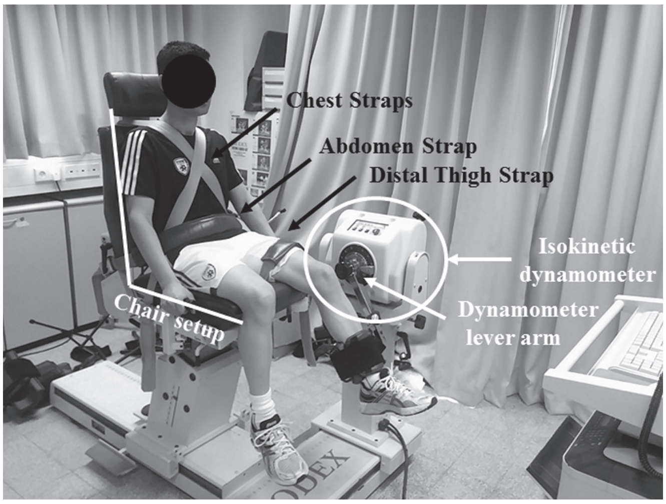

FIG. 1. Isokinetic dynamometer and experimental setup.

Outcome measures

IMC qualitative analysis

Isokinetic moment curves (IMCs) of both extensor and flexor muscles were qualitatively analysed through visual inspection. Firstly, the output data were exported from the Biodex software as cvs. files and opened in an Excel spreadsheet (Microsoft Excel). Then, the curves were normalized to peak moment prior to presentation to the examiners as previously proposed by Ayalon et al. [1]. For this purpose only the 2nd, 3rd and 4th repetitions were examined [16]. The analysis of IMCs was based on the criteria of irregularity and consistency, as previously described by Ayalon et al. [1]. Irregularity refers to the possible presence of break points, defined as IMCs' deviations from prevalent patterns that are commonly observed in the shape of either the extensor or the flexor muscle curves; consistency refers to the number of repetitions in which the same irregularity appears. Accordingly, only irregular patterns that were displayed in all three repetitions were judged as consistent and representative of abnormal IMCs. The criteria for classification were: location of peak torque deviating from normal, minor or major disruptions of the smoothness of the IMC, concavity of the curve during force development or decrease, sudden reduction in force development followed by a sharp increase in force, rapid changes in slope direction, double-humped curve, and plateau during mid-range of motion. Following the above criteria, two blinded examiners were asked to qualitatively classify specific patterns of the IMCs based on the location, shape, amplitude and frequency of the irregularities. The analysis of the break point via visual inspection of the IMCs led to the following classification of the curves:

1) Normal pattern: represented by a continuous and smooth curve with no interferences, having a parabolic shape and displayed with its peak around the mid-point of the curve (Figure 2a);

2) "Valley" pattern: represented by a continuous and smooth curve with one main interference characterized by an interruption of the

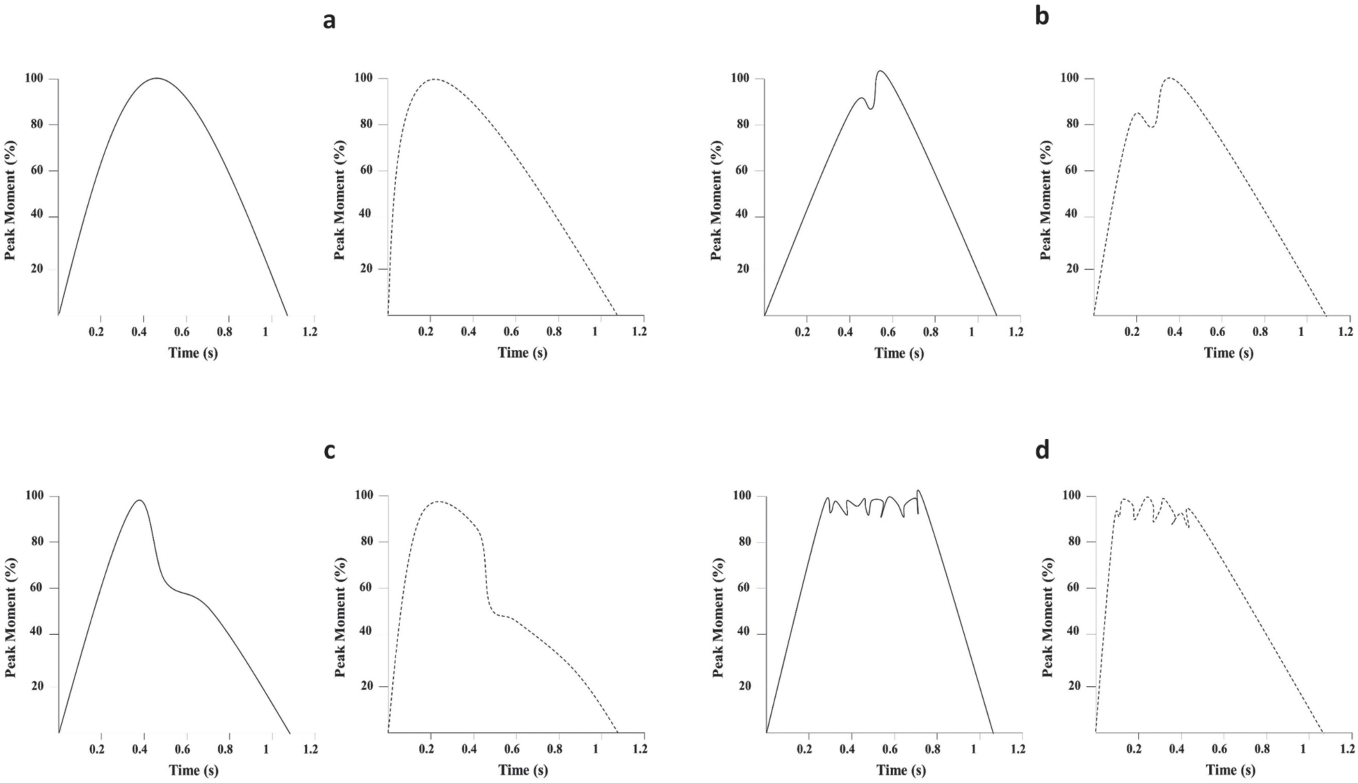

FIG. 2. (a) "Normal pattern" of isokinetic moment curves (IMCs) for knee extensor (solid line) and flexor (dotted line) muscles. **(b)** "Valley" pattern of isokinetic moment curves (IMCs) for knee extensor (solid line) and flexor (dotted line) muscles. **(c)** "Drop" pattern of isokinetic moment curves (IMCs) for knee extensor (solid line) and flexor (dotted line) muscles. **(d)** "Shaking" pattern of isokinetic moment curves (IMCs) for knee extensor (solid line) and flexor (dotted line) muscles.

moment curve associated with a slight and sudden reduction of the torque output, occurring immediately before or at the peak point (Figure 2b);
3) "Drop" pattern: represented by a continuous and smooth curve with one main interference characterized by an interruption of the moment curve associated with a sharp and sudden reduction of the torque output, occurring immediately after the peak point (Figure 2c);
4) "Shaking" pattern: represented by a curve with a sequence of irregularities assuming the shape of a tremble, occurring along the mid-range of the moment curve including the peak point (Figure 2d).

One week after the first evaluation, both examiners were required to perform a second round of evaluation in order to assess the intra-tester and inter-tester reliability of the qualitative analysis of the IMCs.

IMC quantitative analysis

The following IMC quantitative parameters for both extensor and flexor muscles were analysed [1,8,16]:

– Inter-limb difference (%): expressed in terms of percentage difference between the peak torque scores (highest torque for each lower limb's muscle group) between the two lower limbs' muscle groups according to the following equations:

$$\text{Inter limb difference} = \frac{\text{stronger} - \text{weaker}}{\text{stronger}} \text{ x } 100 \text{ for the control group}$$

and

$$\text{Inter limb difference} = \frac{\text{uninvolved} - \text{involved}}{\text{uninvolved}} \text{ x } 100 \text{ for the injured group}$$

– Variability (%): namely the coefficient of variation (CV) of the peak torque scores for both extensor and flexor muscles obtained during the 2nd, 3rd and 4th repetitions.

Sample size

To calculate a sample size, it was necessary to establish what would be a clinically detectable change in outcome and be of clinical significance. Keays et al. [24] examined the physical characteristics in ACL-insufficient subjects and included the calculation of peak torque bilateral asymmetries as a measure to discriminate between the involved and uninvolved legs. Based on the assumption that between-legs asymmetries in knee extensors and flexors torque of 12.1±1.1 and 10.3±0.7%, respectively, are meaningful (Keays et al. [24]) and considering within-subject standard deviations (typical error) of

TABLE 2. Percentage distribution of IMC pattern for both injured and control group.

IMC Pattern	Injured subjects (*n*=34)						Control subjects (*n*=20)
	MM Injury		ACL Injury		ACL+MM Injury		
	Involved legs	Uninvolved legs	Involved legs	Uninvolved legs	Involved legs	Uninvolved legs	Uninvolved legs
	n=19		*n*=6		*n*=9		*n*=40
Knee extensors							
Normal pattern (%)	0%	84.2%	0%	100%	0%	77.8%	92.5%
Valley pattern (%)	47.4%*$^{\#}$	10.5%	50%*$^{\#}$	0%	33.3%*$^{\#}$	0%	2.5%
Drop pattern (%)	47.4%*$^{\#}$	0%	33.3%*$^{\#}$	0%	44.4%*$^{\#}$	11.1%	5%
Shaking pattern (%)	5.2%	5.2%	16.7%$^{\delta}$	0%	23.3%$^{\delta}$	11.1%	0%
Knee flexors							
Normal pattern (%)	5.2%	47.3%	0%	50%	0%	33.5%	35%
Valley pattern (%)	36.8%	10.7%	33.3%	33.3%	33.3%	22.2%	20%
Drop pattern (%)	31.8%	21.0%	0%	16.7%	11.1%	22.2%	22.5%
Shaking pattern (%)	26.2%	21.0%	66.7%*$^{\#\delta}$	0%	55.6%*$^{\#\delta}$	11.1%	22.5%

Note: the values are expressed as percentage distribution (%). IMC: isokinetic moment curve; MM: medial meniscus; ACL: anterior cruciate ligament; ACL+MM: combined anterior cruciate ligament and medial meniscus injury. * indicates significant differences in the comparisons between the involved leg of injured group and both legs of control group with $p \leq 0.05$; $^{\#}$ indicates significant differences in the comparisons between the involved and the uninvolved leg of the injured group with $p \leq 0.05$; $^{\delta}$ indicates significant differences in the comparisons with the involved leg of the MM pathology with $p \leq 0.05$.

TABLE 3. Quantitative scores for both extensor and flexor muscle actions for all conditions.

Variable	Group	Mean ± SD	95% CI	
Inter-limb difference Q60°/s (%)	C	7.5 ± 4.6	5.3	9.6
	ACL + MM	39.3 ± 23.0*	21.6	57.0
	ACL	20.2 ± 9.1	10.6	29.9
	MM	32.6 ± 19.4*	23.3	42.0
Inter-limb difference H60°/s(%)	C	7.5 ± 5.0	5.2	9.9
	ACL + MM	23.9 ± 16.5	11.1	36.6
	ACL	27.7 ± 19.9	6.7	48.6
	MM	20.0 ± 21.6	9.6	30.5
Variability Q (%)	C	5.6 ± 2.7	5.0	6.3
	ACL + MM	11.6 ± 3.6*	9.1	14.1
	ACL	14.3 ± 4.3*	9.8	18.9
	MM	12.7 ± 4.5*	10.5	14.9
Variability H (%)	C	5.3 ± 2.4	4.7	5.8
	ACL + MM	12.2 ± 3.4*	9.6	14.9
	ACL	13.4 ± 7.5*	5.5	21.4
	MM	12.8 ± 5.6*	10.1	15.6

Note: the values are expressed as percentage distribution (%). C: control; ACL+MM: combined anterior cruciate ligament and medial meniscus injury; ACL: anterior cruciate ligament; MM: medial meniscus. "*" indicates significant difference with the control group with $p \leq 0.05$.

1.2 and 2.5% [24], a sample size of > 33 participants would provide maximal chances of 0.5 and 25% of type I and type II errors, respectively.

Statistical analysis

The IMCs qualitative parameters are reported in Table 2 and presented as distribution percentages. All the IMC quantitative measures, reported in Table 3, are presented as means ± standard deviation (SD). For inter-tester and intra-tester reliability, Cohen's kappa coefficient (κ) with 90% confidence interval (CI) was calculated. According to Landis et al. [25], $\kappa > 0.80$ was defined as almost perfect, 0.60–0.80 as substantial, 0.40–0.60 as good, 0.20–0.40 as fair and <0.20 as poor. The chi-squared (χ^2) test was used to analyse the non-parametric data produced from the classification of the IMCs, in order to test for differences in the frequencies of observed irregular patterns between involved and uninvolved legs in the injured group. This analysis was applied to evaluate how likely it is that any of the observed irregular patterns of the IMCs is associated with specific knee pathology as ultimately diagnosed during the arthroscopic surgical procedure. Specifically, three separate 2 × 4 contingency analyses (control vs. ACL, control vs. ACL+MM, control vs. MM) were performed for this purpose. Additionally, the same non- parametric statistical procedure was applied to identify differences between either the involved or uninvolved legs in the injured group and both legs in the control group. A one-way analysis of variance (ANOVA) with Bonferroni post-hoc analysis was implemented to examine the inter-group differences of the IMC quantitative data. The independent variables included one between-subjects factor (group) with 4 levels (control, ACL, ACL + MM, MM). The alpha test level for statistical significance was set at $p<0.05$. Statistical analysis was performed using SPSS Statistics 21 software (SPSS Inc., Chicago, IL, USA).

RESULTS

Classification of abnormal IMCs associated with the injured knees ($n = 34$) reveals substantial inter-tester reliability ($\kappa = 0.73$; 90% CI=0.69-0.74) while the inter-tester reliability for the IMCs of the uninvolved knees of the injured group and both healthy legs of the control group ($n = 34$ and 40, respectively) was almost perfect ($\kappa = 0.93$; 90% CI=0.90-0.95). As for the intra-rater consistency, both demonstrated almost perfect reliability ($\kappa = 0.95$ and $\kappa = 0.92$, respectively) for the classification of the IMCs of uninjured knees and substantial reliability ($\kappa = 0.78$ and $\kappa = 0.76$) for the abnormal IMCs of the injured knees. Percentage distributions (%) of all bilateral IMCs patterns reported from both groups are shown in Table 2. Between-group comparison showed no significant differences for the IMC patterns between the uninvolved leg of the injured group and both legs of the control group. The comparison of irregularities occurring in the IMC patterns between the involved and uninvolved legs of the injured group showed significant differences, as shown in Table 2 ($p<0.05$). Similarly, significant differences between the occurrence of irregularities in the IMC patterns were found when comparing the involved leg of the injured group and both legs of the control group (Table 2) ($p<0.05$).

ANOVA showed a larger mean extensor inter-limb difference (%) when comparing ACL + MM and MM with the control group ($F=36.568$, $p<0.001$ and $F=31.692$, $p<0.001$, respectively) (Table 3). ANOVA showed no significant differences in the group comparisons on mean flexor inter-limb difference (%) ($F=3.929$, $p=0.13$).

The means of the individual variability (%) of peak torque values were significantly higher in the ACL, ACL + MM and MM groups than in the control group for both extensor and flexor scores ($F=22.072$, $p<0.001$, $F=29.919$, $p<0.001$ and $F=32.397$, $p<0.001$ respectively for extensors score; $F=39.612$, $p<0.001$, $F=18.435$, $p<0.001$ and $F=30.661$, $p<0.001$, respectively for flexors score) (Table 3).

DISCUSSION

This study combined qualitative and quantitative IMC analysis with the aim to investigate whether a specific IMC profile may be associated with specific knee lesions. The results revealed that the presence of irregular pattern of the IMCs and the finding of abnormal isokinetic quantitative scores were associated with specific knee pathologies. Moreover, the qualitative evaluation of the IMCs indicated a possible link between knee pathologies and pattern irregularities, thus highlighting that the IMCs of injured knees are characterized by specific dysfunctional profiles compared to the uninjured side.

It is well known that the IMC is the functional end-point of a kinetic chain behaviour, whose outputs, in terms of qualitative torque-time patterns and quantitative mechanical variables, are attributed to both mechanical and/or neuromuscular factors [1,16]. Indeed, the contingent failure of such neurophysiological and biomechanical aspects during the attempt to develop force and generate movement around a single joint may produce an alteration of a normal IMC. Our results show that the presence of single or concurrent pattern irregularities in the IMCs of both the extensor and flexor muscles is likely different between knee pathologies. In fact, the comparison between the IMC patterns of pathologic knees with uninvolved ones of both the injured and control groups revealed differences in the occurrence of consistent irregularities. Specifically, the IMCs of the knee extensor muscle in the injured group were consistently affected by torque irregularities, displayed as one of the aforementioned irregular pattern shapes. Isolated ACL and combined ACL+MM injuries presented a similar distribution of pattern irregularities (Table 2). Conversely, the isolated MM tear differentiated from the previous injuries in the absence of the "Shaking" pattern during the knee extensor IMC development. In addition to the above qualitative-analysis findings, between-groups ANOVA showed significant differences for the extensor inter-limb difference and variability when comparing control vs. ACL + MM and MM. As for the IMCs of knee flexor muscles, only isolated ACL and ACL+MM injuries were associated with "Shaking" pattern irregularities when compared with the uninvolved contralateral leg of the injured group and both legs of the control group. However, between-group post-hoc analysis showed no significant differences for flexor inter-limb difference when comparing the control with all groups (Table 3). This point could be attributed to unaltered flexion phase functionality due to either the ACL + MM or isolated MM knee injuries [9]. Conversely, significant differences were found between the control group and all groups in terms of variability (Table 3). These outputs are in accordance with the results of previous studies suggesting that the variation in consistency of normal IMC patterns and quantitative scores was a consequence of knee biomechanical modification and/or neurophysiological dysfunction [1,16]. The neurophysiological causes underlying the above results may be related to the central-pattern-generator (CPG) mechanism, which highlights that altered common movement types, occurring due to neurological or mechanical causes, are commonly associated with high variability of cyclic tasks such as walking, cycling, and extension-flexion sequences. Overall, the results show evidential support for the use of qualitative isokinetic assessment in differentiating between IMC patterns of injured and intact knees.

The second finding of the current study was the possible link between qualitative IMC patterns and specific knee pathologies. The IMC shape analysis revealed that MM injuries were associated with a single pattern irregularity displayed only at the knee extension, while concurrent and combined dysfunctional patterns were likely to target knee injuries involving deficient ACLs. Specifically, the main difference reported between injured knees with ACL involvement and injured knees without ACL involvement, that merits interest for a correct differential diagnosis, was the absence of "Shaking" patterns for injured but preserved ACL knees in the IMCs of both extensor and flexor muscles (Table 2). From a mechanical perspective, such differences in the IMC irregularities may have been caused by excessive laxity of the ACL deficient knee [26,27], as well as by the anterior subluxation of the tibia at midrange during maximum knee extensions [8,12]. It is well known that open kinetic chain (OKC) knee extension is produced by isolated contraction of the quadriceps, which results in anterior translation of the tibia. Palmitier et al. [28] developed a biomechanical model demonstrating the forces produced at the tibio-femoral joint during OKC extension, deducing that the resultant force on the knee can be resolved into a compressive component and a shear component. When the resistance is applied perpendicular to the distal aspect of the leg, as occurring during OKC exercises, a posterior shear of the femur is produced. In this scenario, the ACL provides 85% of the restraining force to this anterior tibial shear [29], especially during the last 45° of knee extension. Thus, exercises performed in this range could stretch secondary restraints in an ACL-deficient knee, resulting in dysfunctional extensor muscles' IMC outputs. As for the flexor muscles' IMC analysis, the concomitant presence of "Shaking" patterns and torque variability (Table 3) may have occurred due to the increased activity of the extensor antagonist muscles. Bryant et al. [30] previously reported that the electromyographic (EMG) activity level of knee extensor muscles, acting as antagonists during the flexor muscle contractions, is inversely associated with knee flexor torque variability. The greater the knee extensors' antagonistic EMG activity, the greater is the knee flexors' variability. The authors suggested as targeted mechanisms, potentially leading to the increased extensor muscle antagonist EMG activity, the maladaptive phenomenon defined as "quadriceps dyskinesia" and the altered mechanoreceptor-mediated feedback from connective tissues. Although the aforementioned explanations and associated consequences are plausible, it is purely speculative to back up the results of our study on them considering the limitations of our study. In fact, in our study direct EMG recordings were not collected from the involved population; thus we cannot draw clear conclusion on the neurophysiological potential mechanism underlying the observed findings. Another explanation of the dysfunctional IMC patterns in ACL injured knees may be the mechanical modifications following an ACL injury event which causes neuromuscular impairment in various functions of the entire injured limb. A direct neuromuscular link exists in humans between the sensory nerves of the ACL and all the muscles around the knee [31]. Briefly, receptors of the Golgi, Pacinian, Ruffini, and bare ending types of the knee ligaments mediate their afferent signals, and it is evident that these nerves exhibit vigorous discharge activity upon loading of the ligaments, thus provoking subsequent muscular activity responses [31,32]. This neuromuscular reflex has been proven to be directly protective for the ACLs during excessive stress in all conditions, and may primarily be of importance for the functional stability of the knee. It is clear that preservation of joint stability is an important function of muscular co-activation, which provides the joint with some measure of stability in addition to the role of the ligaments. As consequence, it is reasonable that the failure to elicit the reflex creates an unfavourable background where the agonist muscle activation results are significantly inhibited or in latency [26,33], while antagonist muscle co-activation [30,34] seems to increase in amplitude and duration [35,36]. Even with the same joint configuration, the net mechanical effect of different loading conditions requires that the central nervous system adjust the strategy accordingly [37]. These neuromuscular adaptations, in combination with the aforementioned alterations to the biomechanics of the joint, induce changes to the sensory feedback originating from the mechanoreceptors in and around the knee [15,36]. This in turn may compromise the coordination of muscles crossing the knee, and may present a possible reason for decreased smoothness of the torque-time curve pattern during maximal knee extension-flexion [16].

Finally, a possible explanation for the absence of pattern irregularities in the flexor muscles' IMCs of MM knees may be attributable to the specific biomechanical demands upon the medial meniscus during knee flexion tasks. It is known that one of the major meniscal functions is to distribute stress across the knee, thus providing shock absorption and serving as secondary joint stabilizers [38]. Different authors have used numerical techniques to analyse the distribution of contact pressures and compression stress on meniscal tissues. Both simulation and experimental studies [39-41] have obtained similar results showing that, during knee sagittal motion, the total tibial-femoral contact forces overloading the meniscal structures seem to follow a common trend, resulting in a decrease from their maximum at nearly full extension to their minimum at 90° of flexion. Furthermore, given that the knee isokinetic assessment is performed through a mono-axial movement without any involvement of rotational kinematics, it is plausible to consider that the lack of torsional and pivoting loads and stress allows the joint motion to produce a normal and smooth IMC.

CONCLUSIONS

In conclusion, consistent knee isokinetic abnormalities are identified in young adults with MM and ACL injuries. These abnormalities include specific IMC shape abnormalities and asymmetrical isokinetic measures which can differentiate MM tears from ACL tears and from normal knees. These findings suggest that different knee pathologies may be associated with different qualitative IMCs, which could be used as an additional presentation tool in clinical settings.

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Conflict of interests

The authors declare no conflict of interests regarding the publication of this manuscript.

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