ASSESSMENT OF THIGH MUSCLES MECHANICAL CAPACITIES FOLLOWING ACL RECONSTRUCTION USING THE TWO-VELOCITY METHOD

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We evaluated the ability of recently proposed two-velocity method to discriminate between thigh muscle mechanical capacities of the involved and the uninvolved leg following ACL reconstruction (ACLR). 15 athletes were tested 4 and 6 months following ACLR. F-V linear relationship parameters (*F* intercept - F_0, *V* intercept - V_0, slope – *a*, and P_{max}) were obtained from line drawn through 60 and 180 °/s data (the 'two-velocity method'). In quadriceps, all parameters revealed between leg differences 4 and 6 months after ACLR. In addition F_0 and V_0 of the involved leg were higher at 6 than at 4 months after ACLR. In hamstrings, differences between legs were found only for F_0 at 4 months. In conclusion, parameter of the two-velocity method could be sensitive enough to detect between-leg differences in muscle *F*, *V*, and *P* producing capacities following ACLR.

KEY WORDS: muscle, testing, rehabilitation

INTRODUCTION: Isokinetic dynamometry has often been recognized as the gold standard method for monitoring muscle force (*F*) and power (*P*) recovery in individuals following ACL injury or reconstruction (Knezevic, Mirkov, Kadija, Milovanovic, & Jaric, 2014; Pua, Bryant, Steele, Newton, & Wrigley, 2008). Although various protocols have been suggested trough the literature, routine testing procedure often includes several angular velocities, where 60 °/s and 180 °/s could be considered as the standard ones. This has been based on the rationale that tests conducted at low joint angular velocities or even isometric conditions predominantly reveal muscle 'strength' (i.e., *F*), while high angular velocities predominantly reveal muscle *P* (Zemach, Almoznino, Barak, & Dvir, 2009). However, since the maximum *P* is typically recorded at high angular velocities that are beyond the standard testing ranges, with the maximum velocity (*V*) being even higher, the isokinetic tests conducted at standard angular velocities could neither discern between the muscle *F* and *P* producing capacities, nor allow for the assessment of maximum V. A solution of this problem could be based on the muscle F-V relationship. Namely, a number of approximately linear and exceptionally strong F-V relationships observed from various functional movement tasks tested at variable loading conditions have revealed reliable and valid parameters depicting the *F*, *V*, and *P* producing capacities of the tested muscles. Furthermore, findings from a recent study (Grbic et al., 2017) have not only proved the linearity of the isokinetic F-V relationship, but also shown that only two measurements at different velocities ('two-velocity' method) are sufficient to discern between the *F*, *V*, and *P* producing capacities of the tested muscles. Having that in mind, we conducted a study aimed to evaluate the ability of the two-velocity method to discriminate between the thigh muscles mechanical capacities of the involved and the uninvolved leg in athletes following ACLR. We hypothesized that the F-V relationship parameters would be able to distinguish both between the legs and between the sessions, particularly regarding maximum F and *P*. The findings would motivate further development of two-velocity method as an advanced isokinetic testing procedure that could discern among the muscle *F*, *V*, and *P* producing capacities in patients following ACLR.

METHODS: Fifteen athletes who had undergone ACLR were included in the study and tested 4 and 6 months following surgery. Their age was 21 ± 2 years, body mass 78 ± 6 kg, height 1.82 ± 12 m (data presented as mean ± SD). The ACLR procedure was performed by experienced surgeon, using the bone-patellar-bone tendon autograft. Postoperative rehabilitation protocol was same for the patients and it was commenced 3 days following surgery. Isokinetic strength of both legs and both muscle groups were tested first at a low speed of 1.05 rad/s (60 deg/s) and, after a 2-minute rest, at 3.14 rad/s (180 deg/s) using a Kin-Com AP125 isokinetic dynamometer (Chatex Corp., Chattanooga, Tennessee, USA). Each participant exerted 5 cycles of maximal voluntary repetitions of alternating concentric knee extensions and flexions. The range of motion during the knee was set to 80 deg. Two experimental trials were performed at each velocity and the trial with the highest peak force (*F*) was used for further analysis. Since *F* was directly recorded, in order to assess the F-V relationships the set angular velocity (in rad/s) was transformed into a linear velocity (m/s) by multiplying it with the length of the individual lever arms. F-V relationships were assessed by drawing a line through the *F* and *V* data obtained only from the 60 and 180 °/s angular velocities (the 'two-velocity' method). The F-V relationships were extrapolated to determine the maximum *F* (F_0; *F*-intercept) and maximum *V* (V_0; *V*-intercept), as well as the slope of the relationship ($a = F_0 / V_0$). Finally, the maximum power (P_{max}) was calculated from the product of F_0 and V_0 ($P_{max} = F_0 \times V_0 / 4$). Mixed model ANOVA [factors being 'leg' and 'test' (repeated factor)] was used to evaluate the differences within in parameters of the applied 'two-velocity' method (*a*, F_0, V_0 and P_{max}) both between the legs (involved vs. uninvolved), as well as between two sessions (4. months vs. 6 months post-ACLR). Where significant main effects and their interactions were found, the Bonferroni post-hoc test was applied.

RESULTS: Figure 1 shows the lines that represent the studied F-V relationships assessed from the averaged across the participants' data within each group.

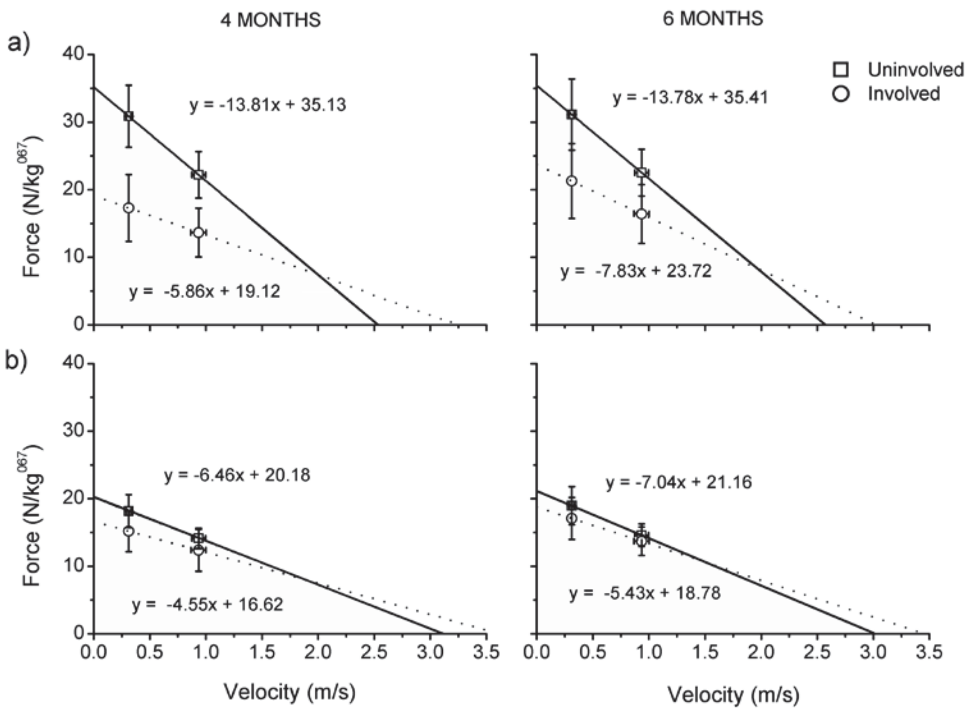

Figure 1: F–V relationships observed from 'two-velocity' method for quadriceps (upper panels) and hamstrings (lower panels) of the uninvolved (full line) and the involved leg (dotted line) obtained 4 and 6 months after ACLR. Data were averaged across the subjects.

The parameters (i.e., F_0, V_0, a, and P_{max}) obtained from 'two-velocity' method (data averaged across the subjects within each leg) are presented in Table 1. Regarding quadriceps, the *F*-intercept (F_0) revealed significant effects of both 'leg' ($F[1,26]= 40.5$, $\eta^2=0.61$, $p<0.01$) and 'test' ($F[1,26]= 12.07$, η2=0.32, $p<0.01$) as well as their interaction ($F[1,26]= 5.78$, $\eta^2=0.18$, $p<0.05$). F_0 was lower in the involved than in the uninvolved leg, and it was lower at 4 months post-ACLR than at 6 months post-ACLR. In terms of the *V*-intercept (V_0), regression slopes (*a*) and maximum power output (P_{max}), main effect was significant only for 'leg' (F[1,26]= range 5.29 to 26.26, $p<0.01$), due to between leg differences in all parameters both at 4 and 6 months after ACLR. In addition, V_0 was lower at 4 months post-ACLR than at 6 months post-ACLR (‘test’ $F[1,26] = 5.41$, $\eta2 = 0.17$, $p < 0.05$). Regarding hamstrings, main effect of factor test was significant only for F_0. No other main effects or their interactions were found (all $p > 0.05$).

Table 1. Parameters obtained from ‘two-velocity’ method applied on isokinetic data

		Quadriceps		Hamstrings	
		Uninvolved	Involved	Uninvolved	Involved
F_0	4 months	35.7 ± 6.0	20.4 ± 5.4‡	20.5 ± 3.1	17.7 ± 3.1‡
	6 months	36.6 ± 6.3	25.1 ± 6.1‡#	21.5 ± 3.6	20.0 ± 3.3
V_0	4 months	2.6 ± 0.8	3.4 ± 1.2‡	3.2 ± 0.9	3.4 ± 0.9
	6 months	2.4 ± 0.5	2.7 ± 0.4#	3.0 ± 0.8	3.1 ± 0.5
a	4 months	15.1 ± 5.5	6.8 ± 3.0‡	7.1 ± 2.8	5.6 ± 2.0
	6 months	15.4 ± 4.6	9.6 ± 2.9‡	7.8 ± 3.1	6.7 ± 1.7
P_{max}	4 months	22.8 ± 6.0	16.5 ± 4.7‡	15.9 ± 3.2	14.9 ± 4.6
	6 months	21.9 ± 4.3	16.8 ± 4.4‡	15.8 ± 2.3	15.3 ± 3.6

‡ Significantly different from the uninvolved leg (p<0.01)
# significantly different from measurement at 4 months post-ACLR (p<0.01)

DISCUSSION: This study evaluated the ability of the recently proposed ‘two-velocity’ method to discriminate between thigh muscle mechanical capacities of the involved and the uninvolved leg in athletes following ACL reconstruction. The main finding could be that the F-V relationship obtained from ‘two-velocity’ method was sensitive enough to detect the hypothesized between-leg differences tested 4 and 6 months after ACLR, as well as to detect time related changes in muscle capacity of the involved leg. Novel and particularly important finding could be that the observed differences in P_{max} between the involved and the uninvolved leg predominantly originate from the differences in F_0, rather than in V_0 (Figure 1). As expected, the largest between-leg differences in F-V relationship parameters were recorded 4 months after ACLR. Less steep slope and therefore lower maximum power observed in the involved leg predominantly originated from a deficit in maximum force rather than in maximum speed. Similar results were obtained 6 months after ACLR suggesting to large deficits in dynamic power output of the involved leg. Although time-related changes were present in maximum strength of the involved leg they were not large enough to increase maximum power. The importance of quadriceps and hamstrings strength measures particularly those obtained from isokinetic dynamometry in patients recovering from ACL injury or reconstruction are well documented in the literature (Knezevic et al., 2014; Pua et al., 2008; Zemach et al., 2009). However, the main limitation of standard isokinetic dynamometry protocols is that they are based on measurements performed under mainly one or two angular velocities, and therefore do not allow for discerning between different muscle capacities. As a result, the outcomes of routine testing procedures have been of limited informational value, leading to arbitrarily interpretation of the recorded forces and torques, particularly regarding the outcomes of the applied rehabilitation interventions. The potential solution of this problem could be the two-velocity method proposed by Grbic and co-workers (2017) that was further evaluated in the present study. The obtained findings support the premise that F-V relationship extrapolated from only 2 trials performed at distinctive angular velocities could be applied for the assessment of the mechanical capacities of knee extensors and flexors in athletes following ACLR. A potential limitation of the presented study could be that the outcome of the ‘two-velocity’ method has been based on relatively narrow range of angular velocities and, therefore, F_0 and V_0 were the outcomes of distant extrapolation. Furthermore, it remains underexplored how different types of contraction (e.g., eccentric contraction) affect both the F-V relationship in general and the concurrent validity of the ‘two-velocity’ method. Further research is needed to standardize the testing procedures regarding the angular velocities applied, contraction type, and to additionally explore the reliability, validity and sensitivity of the observed parameters. In addition, future studies should include the analysis of EMG data at lower and higher velocities in the involved leg to investigate the potential presence of neural suppression at lower velocities. Nevertheless, compared with the standard testing protocols routinely applied in the research and clinical settings, the ‘two-velocity’ method could provide a deeper insight into the properties and function of tested muscles, as well as contribute to further refinement of the methods applied to monitoring the rehabilitation process and recovery following an ACLR.

CONCLUSION: Force-velocity relationship parameters obtained from the ‘two-velocity’ method could be sensitive enough to discern between the uninvolved and the involved leg in athletes following ACLR. Between-leg differences in maximum power observed both at 4 and 6 months after ACLR appear to mainly originate from differences in maximum strength (F_0), but not the velocity (V_0). In addition, time-related differences (4 and 6 months after ACLR) observed in the involved leg are mainly based on the improvement in maximum strength and partly in maximum speed (i.e., V_0), but surprisingly not in maximum power. The proposed 'two-velocity' method should be further evaluated since it could both advance our knowledge of muscle mechanics following ACLR and contribute to further refinement of the methods applied to monitoring the rehabilitation process and recovery following an ACLR.

REFERENCES:

Grbic, V., Djuric, S., Knezevic, O. M., Mirkov, D. M., Nedeljkovic, A., & Jaric, S. (2017). A Novel Two-Velocity Method for Elaborate Isokinetic Testing of Knee Extensors. *International Journal of Sports Medicine*, Submited

Knezevic, O. M., Mirkov, D. M., Kadija, M., Milovanovic, D., & Jaric, S. (2014). Evaluation of isokinetic and isometric strength measures for monitoring muscle function recovery after anterior cruciate ligament reconstruction. *The Journal of Strength & Conditioning Research, 28*(6), 1722-1731

Pua, Y.-H., Bryant, A. L., Steele, J. R., Newton, R. U., & Wrigley, T. V. (2008). Isokinetic dynamometry in anterior cruciate ligament injury and reconstruction. *Annals Academy of Medicine Singapore, 37*(4), 330

Zemach, L., Almoznino, S., Barak, Y., & Dvir, Z. (2009). Quadriceps insufficiency in patients with knee compromise: How many velocities should an isokinetic test protocol consist of? *Isokinetics and exercise science, 17*(3), 129-133

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