ELECTROMECHANICAL DELAY OF THE KNEE EXTENSOR MUSCLES AND RELATION TO THE INITIAL MUSCLE LENGTH

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The purpose of the present study was to elucidate the relation between initial muscle length (IML) and electromechanical delay (EMD) of the knee extensor muscles. The results showed distinctly shorter EMDs (18-20 ms) in an optimal muscle length (OML) than reported before. Furthermore beginning in an OML an increment of EMD was to be seen in direction of both stretched (21-26 ms) and unstretched (31-36 ms) IML. EMD-length-curve in course rather seems to correspond with the inverse force-length-curve. It must be concluded that EMD is not directly dependent on IML, but rather on the maximum force and the rate of force development. From these results it must be concluded that EMD is misinterpreted because EMD cannot mainly be determined by the time it takes to stretch the SE by the CE.

KEYWORDS: electromechanical delay, knee extensor muscles, muscle length, explosive force

INTRODUCTION: Comparing the EMG of a muscle with the corresponding force-time-course, a distinct phase-shift can be detected between the electrical activity (EMG onset) and the mechanical response (force onset). This time shift is called motor time [13] or electromechanical delay (EMD) [1,10]. EMD has been found to be correlated to the maximal voluntary contraction (MVC) force, the rate of force development and the muscle fibre type composition [14]. An exact knowledge of the EMD can suggest important conclusions for the motion-analysis concerning the mechanical effectiveness of a particular muscle - e.g., the knee-extensor- and flexor-muscles in sprint running [12] - which becomes evident via the corresponding EMG. However, the exact value of EMD remains a factor of uncertainty. Recent results show an EMD of about 25 ms [5,7,8] for explosive MVCs of the HS in an optimal muscle length (OML). Therefore these values are distinctly under those previously determined for the hip flexor and knee extensor muscles, ranging between at least 32 ms [11] and 118 ms [6]. However, athletic movement normally starts in an initial muscle length (IML) which is not necessarily identical with OML. Previous publications comparing two or at the most three IML show both positive and negative relations to EMD. While [10,14] found a shorter EMD in a stretched muscle, [3] by contrast found a shorter EMD in an unstretched muscle. By way of contrast recent results comparing six IML of the HS [8] show an EMD-length-curve with neither a constant positive nor a negative relation to the IML. EMD-length-curves in course rather seem to correspond with the inverse force-length-curve.
To verify these surprising results and considering that previous results are not very satisfactory, it was the aim of the present study to elucidate the relation between IML and EMD of the knee extensor muscles (KEM).

METHODS: For purposes of this study, 14 male subjects performed four explosive maximal isometric voluntary contractions with their KE in eight different length positions (Fig. 1) from unstretched (UP, pos. 1) to stretched (SP, pos. 8) by varying the knee angle (KA: 5°, 15°, 30°, 45°, 60°, 75°, 90°, 100"). The EMG-time-curves of m.vastus medialis (VM) and m.vastus lateralis (VL) and the relevant force-time-curves were digitally recorded with a sampling rate of 1 kHz. EMD was estimated visually which has been shown to be the most exact method [9] by help of a specially designed computer program that considers influencing effects as experimental artefacts [2]. Supplementary the true-EMD (TEMD) [4] was defined as the EMD of the earlier onset of EMG of either VM or VL in each trial.

RESULTS: The results (Table 1, Figure 2) showed the shortest EMD (18-20 ms) in pos. 5 or pos. 6, while an increment of EMD was to be seen in direction of both stretched (21-26 ms) and unstretched (31-36 ms) IML. The results in OML (pos.5 and 6) were distinctly shorter than the shortest values reported before [11]. TEMD as well as EMD of VL and VM showed a similar course of EMD-length-curve. Attributable to the small differences between the EMDs of the other positions there were in the main only significant differences between UPs (pos. 1 and 2) and the remaining positions.

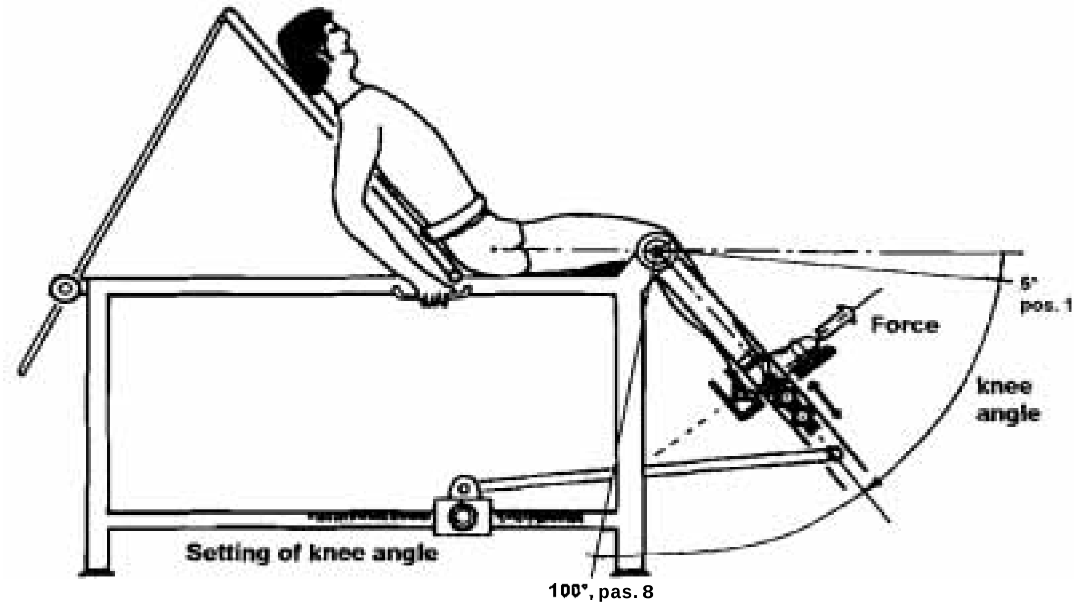

Figure 1 - Experimental station to pick up the EMG- and force-time-curves of the KEM for determination of EMD

Table 1 EMD- and Force-Values, Significant Differences in EMD-Positions

	KA	F [%]		VM		VL		TEMD	
	[°]	[N]	Stdev	[ms]	Stdev	[ms]	Stdev	[ms]	Stdev
Pos. 1	5	214	48	34,0	14,7	31,0	13,4	35,5	14,1
Pos. 2	15	293	59	29,3	10,9	30,1	11,2	32,3	11,4
Pos. 3	30	386	63	23,8	9,5	23,5	9,3	27,6	9,2
Pos. 4	45	462	86	22,9	7,3	19,9	6,9	24,5	7,0
Pos. 5	60	508	97	22,1	6,8	17,8	6,7	23,4	6,8
Pos. 6	75	447	94	19,6	7,4	18,9	7,7	23,1	6,3
Pos. 7	90	388	61	21,0	7,6	20.4	7,9	24,4	6,9
Pos. 8	100	407	63	22,5	10.3	21,3	13,4	25.6	12,7
p<=.01				Pos: 1-3..8, 2-4..7		Pos: 1-3..8, 2-3..8, 3-5		Pos: 1-3..8, 2-4..7	
p<=.05				Pos: 2-3, 2-8, 3-6		Pos: 3-6		Pos: 2-3, 2-8, 3-5..7	
p<=.10				Pos: 3-6		Pos: 3-4, 3-6		Pos: 3-4	

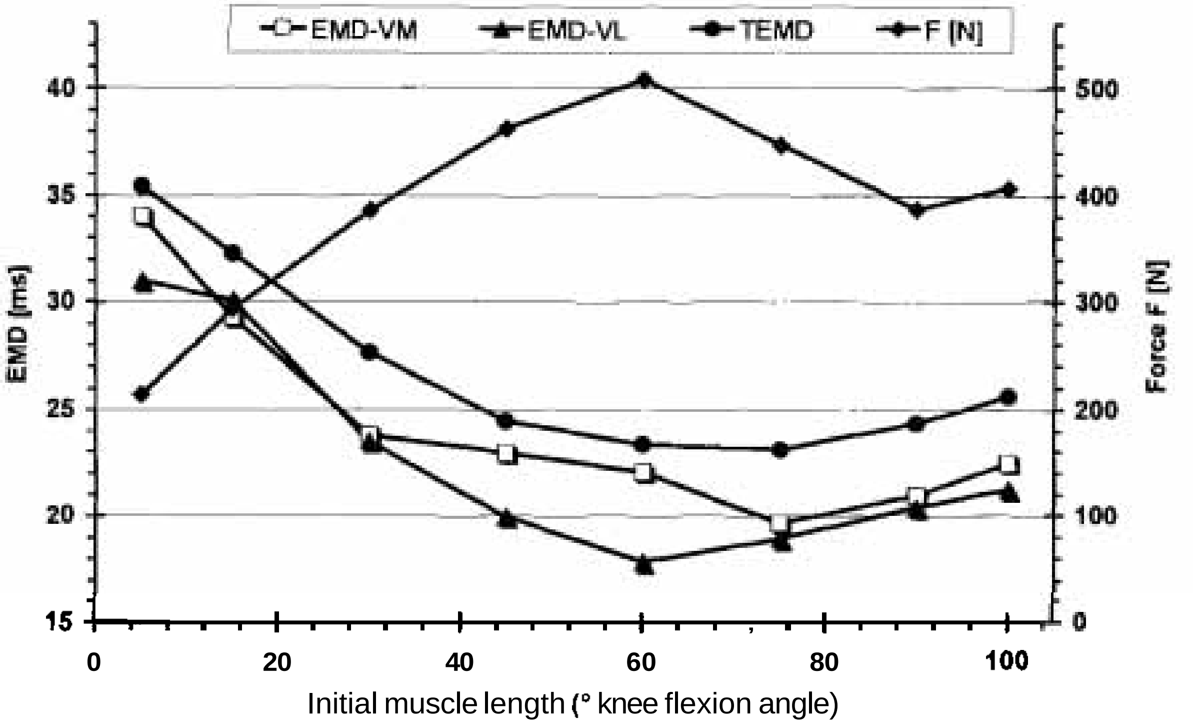

Figure 2 - EMD and force in different IML-positions

CONCLUSIONS: In an OML the results show EMDs of the KEM which are distinctly shorter (9-15 ms) than the shortest previously determined EMDs (32 ms [11]) for the same muscle group. Furthermore maximum differences of about 13 ms or 55-75% of EMD in different IML especially concerning UPs are not negligible in exact motion analysis. Therefore IML must be considered in order that knowledge of the EMD can provide exact conclusions concerning the mechanical effectiveness of a particular muscle. In contrast to previous results of the KEM the EMD-length-curve shows neither a positive nor a negative relation to the IML. EMD-length-curves in course rather seem to correspond with the inverse force-length-curve. As mentioned in recent studies this discrepancy may be due to the fact that in earlier publications at the most only two positions of IML were compared. Thus a line as a hypothetical direct connection between an unstretched (pos. 1, Figure 2) and every more stretched position shows a negative relation between EMD and IML whereas a line between an optimal (pos. 4 and 5) and a stretched position (pos. 8) shows a positive relation. So the surprising recent results for the HS (4,6,7) are impressively confirmed by the present results.
It must be concluded that EMD is not directly dependent on IML, but rather on the maximum force and the rate of force development (RFD), which depends on the degree of overlapping of the sarcomeres in different length positions. However, it may be the case that the relation between maximum force and EMD is caused by the time for the contractile elements (CE) to develop a continuous tension at the series elastic elements (SE). Dependent on the degree of overlapping, single sarcomeres produce lower forces by time in both directions from OML. This should result in different times intervals to reach the same continuous tension in the sarcomere-chain between both ends of the fiber.
Furthermore according to the related publications, EMD contains several components, which are linked to the force generation: the conduction of action potential along the T-tubuli system, the release of Ca^{2+} by the sarcoplasmatic reticulum, the cross-bridge formation between actin and myosin, the tension development in the contractile element (CE) and the time it takes to stretch the series elastic elements (SE) by the CE [1,10]. In all publications on this subject the major portion of EMD, with direct or indirect references to [1,10], is referred to the last component, the stretching of the SE. Therefore it is concluded that all factors shortening (lengthening) the time for the stretching of the SE also shorten (lengthen) the

EMD [11]. But in contrast to this present definition, proceeding from pos. 5 or 6 (Figure 2) both EMD and muscle tension increase continuously in more stretched IML. However, it is not considered that in physiological positions a permanent tension exists in SE comparable with a stretched rubber band, and they do not slacken. Therefore a force generated by the CE at one end of the SE can only have a stretching effect if the other end of the SE is held back by the same amount of counter-force. It is of decisive importance that this happens at the same time without any delay. Therefore and in contrast to previous results [1,10] EMD cannot be determined mainly by the time it takes to stretch the SE by the CE.
From the present and in view of the confirmed recent results it must be concluded that EMD is misinterpreted and a redefinition seems to be essential. However, these results impressively underline the importance of further investigation of EMD and suggest that we have to redefine the EMD in different IML for all muscles involved in athletic motions.

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