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Simultaneous measurement of intramuscular pressure and surface electromyography of the multifidus muscle

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Abstract The anatomic proof of a spinal compartment and the clinical symptoms of compartment syndrome in patients with chronic back pain are inconsistent with the rarely met measuring criteria of intramuscular pressure (IMP). Previous studies assume a dependence of the IMP on spinal alignment (degree of lumbar spine flexion) and the degree of muscle activation. The significance of these disturbance variables in the interpretation of IMP could explain the above discrepancy. This study therefore investigates the influence of both a 30% increase in trunk flexion and alterations in muscle contraction from 100% to 60%. Sixteen healthy subjects participated in the study. The IMP and mean rectified amplitude of the multifidus surface EMG signal were determined at rest and 0° and approximately 30° of lumbar spine flexion, and they were compared. Subsequently, both parameters were measured during both 100% and 60% maximal voluntary contraction (MVC) of the muscle and then correlated. During rest and 0° flexion, the median IMP was 9.3 mmHg (range 0.0–22.5) while the median mean rectified amplitude (MRA) of

the EMG signal was 1.98 μ V (range 1.32–7.38). In 30° flexion, the median IMP went up to 24.3 mmHg (range 1.4–97.3) with hardly any increase in the median MRA of 2.32 μ V (range 1.20–9.72). Under 60% MVC, the median IMP rose to 186.6 mmHg (range 15.4–375.4) and the median MRA to 21.02 μ V (range 4.63–43.63). During 100% MVC, the median MRA increased to 34.38 μ V (range 12.99–102.54) while the median IMP rose to 273.4 mmHg (range 90.4–395.1). Spearman's rank correlation coefficient for the IMP and MRA quotients of the 100/60% MVC values was $r=-0.21$. To sum up, it can be said that IMP was subject to great interindividual variation in all the experiments. This parameter is highly dependent on spinal alignment and muscular activity. Further studies are needed so that the IMP can be interpreted properly when diagnosing a chronic compartment of the erector spinae muscles.

Keywords Chronic compartment syndrome · Intramuscular pressure · Low back pain · Multifidus · Surface electromyography

Introduction

Due to the historic ties of orthopaedic surgery with radiologic diagnostics, structural causes – which can be detected with imaging techniques – are primarily blamed for chronic

lower back pain (LBP). However, even in MRI, only minor connections can be found between radiologic findings and LBP [6]. This leads to the assumption that functional impairments of the muscles, which elude the imaging diagnostics in many cases, play a role in the development of LBP.

The clinical symptoms of many LBP patients (pain related to physical tasks of daily life, improvement in symptoms at rest, and no neurologic defects in the lower extremities) are very suggestive of a chronic compartment syndrome. When making a diagnosis, the measurement of intramuscular pressure (IMP) is of great importance as an objective parameter [15, 16]. Various studies have shown the presence of paraspinal compartment anatomically [2, 14]. However, despite anatomic proof, further studies show only little correspondence of the clinical symptoms with IMP [7, 20]. It was thus concluded that chronic compartment syndrome of the erector spinae muscles constitutes only a very rare cause of chronic back pain.

The interpretation of IMP values has been subject to experience gained from studies of the tibialis anterior muscle [20]. It remains unsettled to what extent these experiments on the lower leg can be applied to the biomechanically much more complex spine. The comparison of a single-headed dynamic extremity muscle with a multi-headed static trunk muscle also appears questionable. Moreover, disturbance variables such as spinal alignment and degree of muscle activation have not been sufficiently taken into account. There is thus a possibility that patients were diagnosed false-positive or false-negative and that the parameter IMP is under- or overrated.

This study therefore investigates the significance of spinal alignment and muscle activity for IMP in healthy subjects. Simultaneous measurement of the mean rectified amplitude (MRA) of EMG activity was performed to differentiate between active and passive components of the IMP. The following questions were investigated in particular:

1. Does an alteration in the spinal alignment without muscle activity lead to a change in IMP and, if so, how is such a change directed?
2. Is there a correlation between the increase in force output and increased IMP or MRA?
3. Do increases in IMP and MRA correlate during a defined increase in force output?

Subjects, material, and methods

Subjects

Sixteen subjects (ten males, six females) with healthy backs and between 25 and 50 years old participated in the study. The subjects'

body mass index (BMI) had to be between 20 kg/m² and 28 kg/m². Back pain had to be described as <2 on a visual analogue scale (VAS) of 0 to 10. Table 1 gives a description of the subject group with regard to gender, age, height, weight, and BMI. Having given their written consent, the patients were enrolled in the study, for which a favourable decision had been obtained from the ethics committee (University of Ulm no. 45/97, 13 January 1998).

Measurement of intramuscular pressure

The subjects were positioned prone on an examination table. After thorough cleansing, degreasing, and disinfection of the skin, 1 ml of local anaesthetic was injected up to the fascia at the level of the 3rd lumbar vertebral body 1 cm laterally to the median line. Using an indwelling venous cannula, an Argus 4F piezoelectric pressure probe [24] (MIPM, Mannendorf, Germany) was then inserted into the MF caudally, at an angle of 45°, to a depth of 4 cm. To minimise differences between sides in terms of different static loads on the multifidus muscle (MF), the side expected to be subject to greater static load was measured, i.e. the left side in 14 right-handed individuals and the right side in the two left-handed study participants. The probes were secured with adhesive film so that no dislocation was possible. The analogue signals of the probe were digitised with 10 Hz and stored for evaluation at a later date.

Electromyography

Below the probe insertion points, surface electrodes were attached along the course of the fibres over the muscle belly of the MF. Bipolar recordings were made with a reference electrode over the vertebra prominens. Self-adhesive silver/silver chloride surface electrodes with a gel pad of 1.2-cm diameter were used for recording. The distance between the electrodes was 2 cm. The raw EMG signal was recorded with a band width of 5 Hz to 1000 Hz, digitised with 2000 Hz, and stored for evaluation at a later date. The MRA served as a parameter.

Experiment

Simultaneous recordings of IMP and the EMG signal were performed in four separate tests (Table 2). The first measurement was carried out with the subject at rest and prone. In this test, the lumbar spine flexion corresponded to the neutral zero position and thus to 0°. The subject was then seated in a back extensor (device 140, David, Neu-Ulm, Germany) that had been adjusted to a position corresponding to 30° lumbar spine flexion. With the aid of a lordosis cushion and a special hip-lock mechanism, this machine allows relatively precise adjustment of the lumbar flexion in sitting position. The lordosis cushion has an opening in the middle to prevent irritation from the electrodes and probes. Good intraindividual and interindividual comparability of the test position is thus ensured. By propping the arms up on the thighs, the subject can hold this position without any muscular strain. In this position, measurement was performed without application of force, followed by

Table 1 Demographic data of subjects by sex

	Males (n=10)			Females (n=6)		
	Median	Min/max	Qu1/Qu3	Median	Min/max	Qu1/Qu3
Age (years)	30	25/47	26.5/32	25	25/29	25.3/28.8
Height (cm)	182	1.7/1.89	1.76/1.84	1.63	1.63/1.86	1.65/1.8
Weight (kg)	78.5	68/90	70.8/83.5	60	60/77	63.0/74.3
BMI (kg/m ²)	23.9	21.8/27.8	23.0/24.9	22.3	22.3/24.1	22.4/23.2

Table 2 Test position, load, and duration of load for the four tests

Test	Position	Load	Duration
1	0° (prone)	0% MVC	5 s
2	30° flexion	0% MVC	5 s
3	30° flexion	100% MVC	5 s
4	30° flexion	60% MVC	5 s

measurements at maximal voluntary contraction (100% MVC) and 60% MVC.

Analysis of data

Descriptive and test statistical analyses were performed for both parameters. This involves calculation of the median, 1st and 3rd quartiles, minimum, and maximum. Box plots were used for graphic representation. The statistical tests performed (Wilcoxon's test for independent samples) were interpreted purely orientationally. To describe relationships between force output and IMP/MRA, the difference and quotient of the 100% and 60% MVC values were calculated for both parameters. The comparison was based on the medians and the 95% confidence interval. In addition, Spearman's rank correlation coefficient (ρ) was determined for the 100% and 60% MVC values of the two parameters. For both the IMP-100% vs MRA-100% pair and the IMP-60% vs MRA-60% pair, partial Spearman's correlation was calculated taking into account the BMI.

Results

Intramuscular pressure and mean rectified amplitude at rest during 0° and 30° flexion

To settle question 1, the IMP and the MRA were measured in 0° and 30° lumbar spine flexion, without muscle con-

traction, and then compared. A wide range was obtained for both parameters (Table 3). The median IMP value in 30° flexion was 24.3 mmHg (range 1.4–97.3). Thus, higher values ($P < 0.001$) were measured than in 0° flexion in all subjects except one, with a median of 9.3 mmHg (range 0.0–22.5).

The median change from 0° to 30° lumbar spine flexion was 10.5 mmHg (range -0.9–88.4). In terms of percentage, this corresponds to a median increase of 190.5% and thus almost a tripling of the IMP. At the same time, the MRA decreased slightly in five individuals. In another nine, the increase in MRA was less than 1 μ V. Active muscle contraction could thus be ruled out as the cause of the IMP increase in 14 of 16 subjects. Two subjects were found to have greater increases (2.6 μ V, 2.1 μ V). In comparison with the MRA values at 100% MVC (40.9 μ V, 83.1 μ V), however, these increases were small in terms of percentage (2.5%, 6.4%), so that the increase caused by muscle contraction in these two cases should at least be rated as very small (Fig. 1).

Intramuscular pressure and mean rectified amplitude during extension with 100% and 60% MVC

To answer questions 2 and 3, the IMP and MRA were measured at 100% and 60% MVC and then correlated. Compared to the values at rest, the IMP and MRA rose greatly under contraction of the muscles. The median IMP increase at 100% MVC was 235.8 mmHg (95% confidence interval 88.7–377.7), while at 60% MVC it was 147.0 mmHg (95% confidence interval 5.3–309.7). For the MRA increase at 100% MVC, a median of 30.0 μ V

Table 3 IMP and MRA of the multifidus for each subject without load in lying and sitting positions. Absolute and percentage differences are shown

Subject no.	Sex	IMP		IMP Difference		MRA			
		0° flexion (mmHg)	30° flexion (mmHg)	30–0° (mmHg)	30–0° (%)	0° Flexion (μ V)	30° Flexion (μ V)	Difference 30–0° (μ V)	Difference 30–0° (%)
3	M	0.2	1.4	1.2	619.7	1.5	1.8	0.2	14.9
11	M	5.3	22.5	17.2	327.5	1.5	1.2	-0.3	-22.1
15	F	6.0	6.8	0.8	13.7	2.2	2.3	0.1	4.5
1	F	6.4	13.3	6.9	108.4	2.3	1.5	-0.8	-34.6
13	M	7.3	28.9	21.7	298.8	7.4	7.1	-0.3	-4.5
8	M	8.0	28.1	20.1	251.1	1.5	1.8	0.3	16.4
14	M	8.4	20.2	11.8	140.7	2.0	2.2	0.3	12.7
4	M	8.9	97.3	88.4	998.7	1.7	2.7	1.0	60.5
7	F	9.7	71.4	61.7	634.7	2.2	2.1	-0.1	-3.2
10	F	11.1	37.9	26.8	240.3	3.4	4.1	0.7	19.5
5	M	11.2	70.2	59.0	527.1	3.6	1.9	-1.7	-46.3
16	M	12.5	19.8	7.2	57.6	1.8	3.8	2.1	117.1
9	M	13.8	21.5	7.7	56.1	2.5	3.5	0.9	37.3
12	F	17.0	26.1	9.1	53.9	2.0	4.6	2.6	132.2
2	M	19.9	28.4	8.5	42.9	1.9	2.0	0.1	2.6
6	F	22.5	21.6	-0.9	-3.9	1.3	2.1	0.8	59.1

Fig. 1 Intramuscular pressure and MRA of the MF without load in 0° flexion (prone) and 30° flexion (sitting)

Fig. 2 Graph of the IMP-60% and MRA-60% pairs for each subject. The partial Spearman's correlation taking the BMI into account is $r=-0.117$

was obtained (95% confidence interval 10.7–87.3). The median MRA increase at 60% MVC was $19.5 \mu\text{V}$ (95% confidence interval 4.2–37.1). The partial correlation was $r=-0.117$ for the IMP-60% and MRA-60% values (Fig. 2) and $r=-0.214$ for the IMP-100% and MRA-100% values (Fig. 3).

Pressure values over 350 mmHg were measured in six individuals during the 100% MVC load, two of them even at 60% MVC (Table 4). As the upper limit of the measuring probe was 350 mmHg, the actual IMP value can not be determined for this group.

The median IMP quotient of 100/60% MVC was 1.55 (95% confidence interval 1.14–2.33). A median of 1.85 was obtained for the MRA quotient, with a 95% confidence interval of 1.24–2.53. Spearman's rank correlation for the two quotients was -0.21 (Fig. 4).

Fig. 3 Graph of the IMP-100% and MRA-100% pairs for each subject. The partial Spearman correlation taking into account the BMI is $r=-0.214$

Discussion

Spinal alignment and intramuscular pressure

There are several studies [7, 14, 18, 19] which describe the IMP of paravertebral muscles in healthy subjects. The values are comparable to a limited extent only, as different positions and loads were investigated with different measuring methods. The probe implant sites also differ by several centimetres, so that some studies measured the multifidus muscle while others measured the iliocostalis or longissimus muscles. Two studies [7, 18] measured IMP values between 0 mmHg and 16 mmHg lying and between 2 mmHg and 21 mmHg in sitting position. Our study's values at rest were similar and thus underline the parameter's high interindividual variation.

The change from lying to sitting position with 30° lumbar flexion results in a great increase in IMP values. This increase can be explained by the alteration in spinal alignment. In the literature, two studies report higher IMP values in kyphotic posture as opposed to upright [7, 11]. Müller et al. measured values in healthy subjects that were five to ten times higher in kyphosis. Konno suspects a connection between increased IMP values and disease-related kyphosis, which occurs for instance in cases of degeneration or compression fractures. However, neither study included EMG measurement of the muscles, so that it remains unclear to what extent changes in IMP were attributable to changes in muscle contraction.

Only minimal changes in the electrical activity were found in response to the change in posture in all patients of our study. Increased IMP as a result of active muscle contraction can thus be ruled out. There must be passive factors underlying the IMP increase. Tightening of the muscle fascia with increasing flexion would be a possible cause.

Table 4 IMP and MRA for each subject at 100% and 60% MVC and the relation of 100% to 60% MVC

Subject no.	Sex	IMP			MRA		
		100% MVC (mmHg)	60% MVC (mmHg)	Relation 100/60	100% MVC (μ V)	60% MVC (μ V)	Relation 100/60
15	F	90.4	15.4	5.9	29.5	14.6	2.2
6	F	118.8	81.9	1.4	39.3	31.8	1.3
1	M	202.1	120.9	1.7	34.8	18.6	2.0
14	M	222.9	144.8	1.5	44.0	17.4	2.8
10	F	243.2	104.3	2.3	18.8	17.0	1.1
2	M	270.9	176.8	1.5	64.7	17.5	3.7
13	M	272.3	142.4	1.9	71.8	29.8	2.8
8	M	288.7	204.5	1.4	102.5	34.2	3.1
11	M	307.2	196.4	1.6	13.0	4.6	3.4
12	F	334.6	265.5	1.3	14.7	10.1	1.8
16	M	>350	23.1	>15.5	46.8	43.6	1.1
9	M	>350	222.7	>1.6	33.9	25.2	1.4
4	M	>350	242.9	>1.4	29.6	32.8	0.9
3	M	>350	313.9	>1.1	23.2	13.3	1.9
5	M	>350	>350	–	35.2	25.0	0.8
7	F	>350	>350	–	34.4	25.3	1.8

Fig. 4 Graph of the quotient of MRA 100/60% and IMP 100/60% for each subject. The two lines show the value 1.67, which would correspond to the force output ratio 60% to 100%

The posture during the measurement can also play a role due to the orthostatic pressure. Experiments involving the tibialis anterior muscle [23] showed that IMP increases 1.5- to 3-fold as a result of a change from lying to standing position in healthy subjects and patients both with and without chronic compartment syndrome.

Due to the alteration in spinal alignment, IMP values of >30 mmHg were measured in four individuals in sitting position. Thus, purely because of a change in position, one in four subjects reached IMP values at which sufficient nutritive perfusion of the muscles can no longer be

expected. Two studies [3, 13] showed that the critical capillary pressure of the muscles is approximately 30 mmHg and that a muscle is supplied with blood during relaxation only. For this reason, various studies [10, 15, 21] set this limit for the indication of a fasciotomy.

However, IMP values over 30 mmHg were not connected with pain symptoms in any of the subjects in this study. It thus has to be doubted that a universally valid pressure limit can be defined. It is extremely likely that individual condition, capillary density, heart rate, and blood pressure at the time of the IMP measurement exert an influence. Therefore, IMP as a single deciding parameter is surely insufficient for correctly diagnosing chronic functional compartment syndrome of the MF muscles. Spinal alignment and the position of the subject during measuring (lying, standing, sitting) must be taken into account in the interpretation of IMP, as the measured value can be changed many times over by these factors.

Muscle activity and intramuscular pressure

Aside from passive factors, IMP is also dependent on the force output of the muscles [17]. Great increases in EMG amplitudes and IMP values have been observed during muscle contraction. The values reported in the literature are between 81 mmHg [11] during squats with a load of 10 kg and 340 mmHg [5] during maximal contraction in a dynamometer. All studies describe tremendous interindividual variation at the same absolute loads [11, 19] and at the same MVC-related relative loads [2, 5, 14]. Despite these irregularities, IMP and EMG amplitude were described as a good measure of force output in two papers

[5, 11]. However, neither paper revealed to what extent the increases in EMG amplitude and IMP correlated with force output in the individual cases nor discussed any parameter that exerts an influence on IMP or MRA. We were able to show in our study that IMP and MRA are greater at 100% MVC than during a load of 60% MVC. However, the percentage increase varies markedly from one subject to the next. For each subject, the trunk extension torque increased 1.67-fold from 60% to 100%. Although the medians of the IMP quotient (1.55) and MRA quotient (1.85) were close to the expected ideal value of 1.67, it was still possible that in one subject (no. 2), the MRA increased by a factor of 3.7 while the IMP increased only 1.5-fold. In subject 15, on the other hand, the IMP increased 5.9-fold, while there was only a 2.2-fold increase in MRA. The low partial Spearman's correlation of IMP and MRA at both load levels further shows that the changes in IMP depend not only on muscle activity but must also be influenced by other factors.

As spinal alignment includes many of the passive components, it is feasible that lumbar lordosis increases under load in some patients while decreasing in others. The change in lumbar lordosis during exercise was not measured in our study, as its significance was only recognised after compiling the study results. Other problems related to measuring technique can also explain these differences. Different pressures were measured in different locations within the same compartment [23]. The reliability of surface EMG is also dependent on the location of the electrodes [1, 8]. In addition, EMG amplitude is highly dependent on the filtering properties of the skin and subcutaneous fatty tissue. All these parameters complicate inter- and intraindividual comparison.

Both the comparison between IMP and MRA and that of force output are also very difficult. Trunk extension torque was measured in all experiments, including this study. It remains unknown whether the multifidus part changes in the same proportion. It is also unknown whether there are individually different levels of activity in the multifidus at 60% MVC. It is possible that this muscle is already activated to the maximum in some individuals but only partly in others.

Moreover, additional mechanisms support the erection of the lumbar spine, but measuring their contributions would require tremendous effort. Intra-abdominal pressure, for instance, supports extension of the lumbar spine [4, 12, 22]. Together with a contraction of the mm. obliques abdomini, the fibre structure of the fascia thoracodorsalis also contributes to extension [22]. Under load, the subject may change the lordosis of the lumbar spine, which not only affects IMP but also changes the EMG amplitude [9].

It thus becomes clear how complex the study design must be for the measurement and interpretation of a functional parameter. However, it remains unclear how many single parameters are additionally hidden in the system. On balance, the combination of all disturbance variables can probably mean negative and positive influences on IMP and MRA. In view of this, the deduction of connections or even diagnoses based on measurement of a single parameter appears questionable. Most functions of the human body are subject to multifactorial influences. Consequently, the function of the locomotor system must not be simplified and reduced to a purely mechanical character.

The IMP and EMG amplitude are highly dependent on muscle activity and, as far as we can interpret them to date, imprecise indicators of trunk extension torque. However, many details concerning the connections between increases in IMP and MRA and the resulting force output are not yet understood.

Summary

It becomes apparent that IMP is highly dependent on both active and passive factors. Without simultaneous EMG measurement which shows an active component, clear interpretation of an increase in IMP is not possible. For this reason and due to its extreme interindividual variation in all tests and the existence of unknown disturbance variables, the parameter must be interpreted with great care when used in clinical routine (compartment diagnosis).

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