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Causal Relation Between Functional Muscular Dysbalance and Osteoarthritis

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Abstract

Purpose: An atrophy of quadriceps muscle is generally supposed to be a consequence of knee osteoarthritis. Anyway, there are recent studies pointing reversely at quadriceps sarcopenia as one of factors causing it. We assume that chronic functional muscular dysbalance is the key pathophysiologic momentum in genesis of primary knee osteoarthritis.

Materials and Methods: A prospective study carried out from August 2022 to October 2023. 39 Patients (20 male and 19 female), divided into four cohorts (A,B,C,D). Five Patients were examined bilaterally, hence we examined 44 extremities. We measured by ultrasound transversal planar surfaces of ventral and dorsal muscle groups of the thigh and set them into mutual relation. In the first group A, there were young patients of age about 20 years, without any previous history or complaints to the examined limb. We chose patients of age 30 years or more, with the same criteria for the second group B. There were patients with chronic lesions to dorsal medial meniscus, which is generally known as pre-arthrosis in group C. The group D contained patients with manifest knee osteoarthritis, planed for a TKA. The exclusion criteria of the last both groups were any previous surgery or trauma to the extremity, or eventual neurovascular impairment. Ethical approval was done by the Ethics Committee of the Sächsiche Landesärztekammer. All the procedures being performed were part of routine care (EK-BR-89/23-1).

Results: In the first group A, there was a ratio between transversal planar surfaces of ventral and dorsal muscle mass of about 1.86 (SD 0.46). One patient of the group had a history of prolonged immobility due to trauma. Excluding this patient, the ratio was about 2.0 (SD 0.27) and this could be considered as a physiological value in our opinion. We found substantial decline of ventral muscle mass during the lifetime, beginning already in the early 30s, with the ratio of about 1.39 (SD 0.3) within the group B. Unsurprisingly, the patient groups C and D, with manifest pre- or arthrosis, were affected the most, with ratios of about 1.16 (SD 0.28) and 1.1 (SD 0.25) respectively. We found also quadriceps atrophy on otherwise healthy contralateral lower extremities in both C and D groups, with average ratio 1.23 (SD 0.49), suggesting the ventral muscular atrophy could be setting on first, causing further osteoarthritic changes of the joint, in these cases yet to come. The dorsal thigh muscle mass showed during the lifetime rather constant volumes, with average for group A about 189,3cm^2 (SD 44.9) and group B even 202cm^2 (SD 46.3). The quadriceps surface in group C was about 212.4cm^2 (SD 81.2) and 189.8cm^2 (SD 76.7) for posterior muscles, the average surface of group D was 193.8cm^2 (SD 102) for quadriceps and 183.6cm^2 (SD 100) for dorsal muscles. There seems to be some significance of the gastrocnemius muscle in relation to knee osteoarthritis also, as we noticed volume decline throughout lifetime, with 98cm^2 (SD 27.8) for A, and 75cm^2 (SD 27.8) for group B.

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Conclusion: The primary knee osteoarthritis could be a consequence of long-term dysbalance of adjacent muscle groups, developing slowly during the lifetime, with progressive quadriceps atrophy. The functionally dominant dorsal thigh muscles retain stable volumina during the whole life span and throughout all patient groups, regardless of the onset of osteoarthritis, with average surfaces of 191.2cm^2 (SD 7.7). In contrary, the antagonistic ventral muscle gradually decreases in mass during the time, from average 340cm^2 in the group A to just 224cm^2 (SD 96.2) within the subgroup B of age over 50 years. Physical inactivity or muscular atrophy due to knee pathology cannot explain this phenomenon, as we found it even in athletic individuals and the sarcopenia affects only one muscle group of both. We assume the spinal inhibitory reflex has a decisive role in pathophysiology of osteoarthritis generally. Functionally dominant, e.g. postural muscle groups, via spinal reflex inhibit their antagonists, with imbalanced joint strength equilibrium as a consequence. Moreover, in this case consecutive physical shortening of hamstrings shift femoral condyle due to tibial slope dorsally, leading to wrong joint kinematics, focal pressure peaks and amplified rollback with mechanical conflict between medial femoral condyle and dorsal part of medial meniscus. The anterior cruciate ligament elongation can be also viewed as a result of prolonged sagittal knee dysbalance. We believe systematic training ("up-tuning" via drill) of functionally recessive quadriceps muscle could pose a strategy to prevent farther development of osteoarthritis. Furthermore, proper muscular balance could be one of the key issues in long-term arthroplasty survival.

Keywords: Arthrosis; Osteoarthritis; Quadriceps muscle; Atrophy; Ratio

Introduction

Progressive atrophy of adjacent muscles is generally considered to be a consequence of ongoing osteoarthritis. In the nearer spotlight, there are meanwhile reports [1-3] about a possibly reversed relationship of the two, pointing at quadriceps muscle atrophy as a risk factor of knee osteoarthritis. However, none of the studies shed light on the pathogenesis of the process so far, nor explained why particularly the quadriceps muscle should be so important. We suppose chronic functional muscular dysbalance to be the key pathogenetic factor for primary osteoarthritis. A sedentary lifestyle, long standing, sitting and walking, at work, at home or during transportation, is via neuronal regulation leading to gradual functional dominance of the hamstring group against its antagonistic quadriceps muscle. The consecutive atrophy of the later one and shortening of the first are after certain time leading to wrong knee kinematics and pathological pressure-peaks, thus causing osteoarthritis.

Materials and Methods

A prospective study was carried out from August 2022 to October 2023. 39 Patients (20 male and 19 female), divided into four cohorts (A,B,C,D). Five Patients were examined bilaterally; hence we examined 44 extremities. The patients were routinely treated in our clinic with symptoms varying from acute trauma to chronic skeletal disease. We measured transversal plane surfaces of ventral and both dorsal femoral muscle groups by ultrasound and set them into mutual relation. On the medial side, the sartorius muscle and adductors were included, because subtle differentiation among multiple muscle bellies in the depth of thigh could pose a difficulty. We measured this dorsal-medial muscle mass as one unit. We examined the gastrocnemius muscle as well, both parts, immediately underneath the joint line.

We used a sonography head of 9MHz (Siemens, Acuson X150). The examination was performed in laid-back position, with about 45° hip flection and 90° flection in knee and possibly relaxed muscles. The muscle heads were identified and measured in two dimensions, with the longest radius first and a second one perpendicular to it. Since the muscles in their transection planes in vivo and in vitro always resemble an ellipse, we used a simple form a × b × pi to count the planar surface. This parameter reflects the particular muscle belly volume quite precisely for sake of comparison.

There were young patients of age about 20 years (18.8 in average, SD 3.67), without any previous history or complaints to examined limb in the group A. We chose patients with age of above 30 years (50.35 in average, SD 15) for group B with the same exclusion criteria. Within the group C (average age of 54.43, SD13.9) there were patients indicated for arthroscopy with chronic lesion to dorsal medial meniscus, which is generally known as pre-arthrosis. The group D (average age 69 years, SD 9.4) contained patients with manifest knee osteoarthritis, planned for TKA. Exclusion criteria of the last both groups were any previous surgery or trauma to examined extremity, or eventual neurovascular impairment.

For immediate data collection we used our own pre-designed paper charts (Figure 1). The examination was performed after a documented informed consent. Statistical analysis was made with program BiAS, version 11.05, license number W64-310105. We used descriptive statistics, two-sample t-test and simple Pearson correlation.

Ethical approval was done by the Ethics Committee of the Sächsiche Landesärztekammer. All the procedures being performed were part of routine care (EK-BR-89/23-1) and according to rules of Helsinki declaration.

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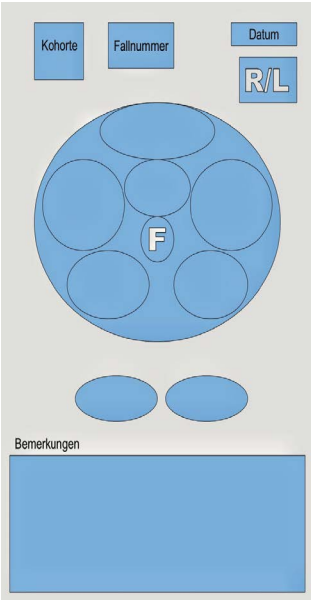

Figure 1: Pre-designed paper charts.

Results

In the first group A, there was a ratio between transversal planar surfaces of ventral and dorsal muscle mass of about 1.86 (SD 0.46). One patient of this group had a history of over a year prolonged immobility due to trauma of the contralateral lower limb. Without this patient, there was the ratio of about 2.0 (SD 0.27) and this could be considered as a physiological value in our opinion (Figure 2A).

We found a substantial decline of ventral muscle mass during lifetime, beginning already in the 30s, with the ratio of about 1.39 (SD 0.3) within group B. The atrophy of ventral muscle mass was more manifest in the subgroup B of patients older than 50 years, with the ratio of 1.18 (SD 0.35), resembling at the first glance strongly the group C, with 1.16 (SD 0.28). We found no significant difference between the two last groups (p= 0.0531). Anyway, there was a difference between the groups B and C (Cohen 2.856, p= 0.01) in the t-test, and even between the subgroup B of 50 years older and C, there was a Cohen effect size of more than 2.4. The explanation of the leap could be the onset of arthrosis itself (Figure 3).

Unsurprisingly, the patient groups C and D, with manifest pre- or arthrosis were affected most, with ratios of about 1.16 (SD 0.28) and 1.1 (SD 0.25) respectively (Figure 2B). However, the difference between the two groups was just marginal (Cohen 0.063, p=0.0655). We can assume there´s no further progress of muscular atrophy between the last two groups and no difference from pathophysiological point of view between these two stages of osteoarthritis (Figure 4).

Sonography pictures comparing the quadriceps of a healthy individual (left) vs. atrophy (right) Note the difference in echogenicity and volume.

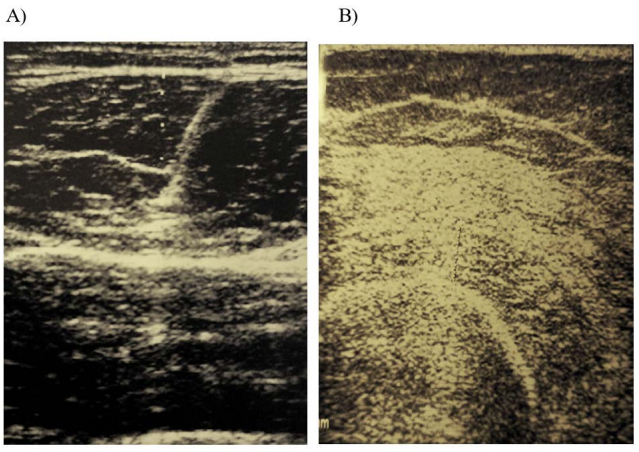

Figure 2: A) First group A batio between transversal planar surfaces of ventral and dorsal muscle mass of about 1.86 (SD 0.46) **B)** The patient groups C and D, with manifest pre- or arthrosis were affected most, with ratios of about 1.16 (SD 0.28) and 1.1 (SD 0.25) respectively.

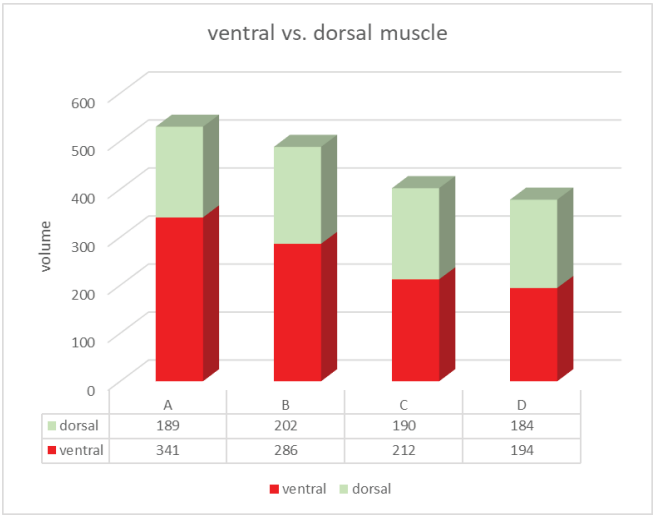

Figure 3: Depicting muscle volume in in their mutual relation, the dorsal muscle with blue bars and quadriceps with red.

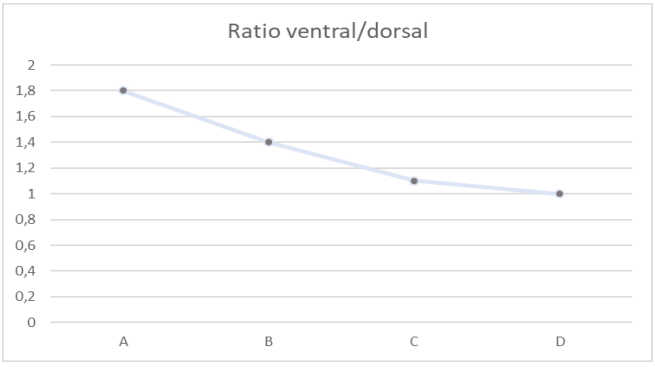

Figure 4: Depicting numeric ratio of ventral vs. dorsal muscle mass throughout the groups. Note almost no difference between the groups C and D.

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We found also quadriceps atrophy on otherwise healthy contralateral lower extremities in patients of both C and D groups, with average ratio of 1.23 (SD 0.49), suggesting the ventral muscular atrophy could be setting on first, causing further osteoarthritic changes of the joint, in these cases to be expected the next.

Similar results came up in t-test from direct comparison of muscle volumes. We leave them out to keep the message short, especially as the ratios reflect the situation better. Dorsal femoral muscle mass showed during the lifetime rather constant values (Figure 5). For group A with average about 189,3cm^2 (SD 44.9) and group B even 202cm^2 (SD 46.3). Comparing both groups A and B in t-test we found no significant difference between them (Cohen 0.1893, p= 0.634).

Groups C and D were then intrinsically quite variable, though in relation to each other rather stable muscle mass. The quadriceps surface in group C was about 212.4cm^2 (SD 81.2) with 189.8cm^2 (SD 76.7) for posterior muscles. The average of group D was 193.8cm^2 (SD 102) for quadriceps and 183.6cm^2 (SD 100) for dorsal muscles. Set into comparison, the dorsal mass in both groups showed no significant difference in t-test (Cohen 0.0767, p=0.846), the same can be said about quadriceps (Cohen 0.008, p= 0.984), as mentioned above (Figure 4).

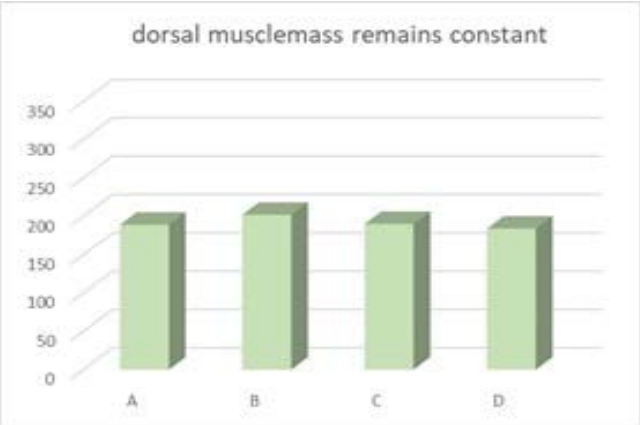

Figure 5: Showing constant dorsal muscle volumina through the groups.

In contrary to quadriceps muscle, after onset of osteoarthritis, there was no leap- phenomenon found in dorsal muscle mass between the patient groups B and C (Cohen 0.1117, p= 0.777).

There seems to be some significance of gastrocnemius muscle to knee osteoarthritis also, as we noticed volume decline throughout the lifetime, with 98cm2 (SD 27.8) for the group A, and 75.3cm^2 (SD 27.8) for B. This trend was also noted in groups C, with 75.cm^2 (SD 44), and D with 49.8cm^2 (SD 19.4). Hereto we found no significant difference between groups B and C (Cohen 0.0364, p=0.926). Afterwards, however, we noticed a mild difference between groups C and D (Cohen effect size 0.399, p=0.331). The muscle volume of gastrocnemius showed a strong correlation to quadriceps muscle throughout the lifetime and groups (Pearson 0.7076, SD 0.0641).

Discussion

Meanwhile, knee extensor weakness is in numerous studies named as a risk factor for developing knee osteoarthritis [1-3]. However, the studies explained neither the exact pathogenesis of the process, nor explained the importance of the knee extensor. We suppose chronic functional muscular dysbalance to be the key pathogenetic factor for primary osteoarthritis.

The knee extensor atrophy affects firstly and mostly the rectus and intermedius muscles. Their anteroposterior dimension under 1cm each seems to be strongly pathognomonic for knee osteoarthritis and could be used as a diagnostic tool.

The cause of arthrosis should be sought within the neuronal network steering of muscular interplay, with hereditary, non-hereditary and epigenetic factors as its modulators. The muscles represent solely an executive element, with cartilage and bone affected as a consequence. For the forward human locomotion and standing, the isometric contraction of dorsal thigh muscles is essential, especially in the late swing phase [4]. For propulsion, there is a strong involvement of gluteal and calf muscles [5] necessary. Due to hamstring isometric contraction, the fixed pelvis offers stability to gluteus maximus muscle. Permanently strained spindles of the dorsal thigh muscles suppress via spinal reflex the antagonist muscle. In the long term, such imbalance must have some effects on knee joint.

This could explain why overweight worsens the course of osteoarthritis but is not the single factor leading to it. Just 30% of patients with osteoarthritis are truly obese [6], hence high body weight can be viewed as a cofactor of osteoarthritis, but not its cause. Similarly, the familiar occurrence of primary osteoarthritis might not be related to some poor cartilage-bone quality, but rather to neuromuscular and behavioral traits, which are hereditary as well [7-9]. The ventral muscular atrophy seems to be a general phenomenon [4,10], since we found it even in young individuals after prolonged physical inactivity. Due to different function and strain, the inactivity atrophy affects preferably the extensor knee muscles. Whether this mechanism set forth could lead to arthrosis, remains unclear.

There is a known causality between muscular dysfunction and osteoarthritis in spasticity [11] and altered EMG-patterns

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were seen in osteoarthritic patients [12]. Also shoulder rotator cuff tears are linked to arthrosis [13,14] due to unbalanced muscle traction. Hence the role of muscles in the pathogenesis of osteoarthritis can be seen as undisputable. The equilibrium of muscle strength on the joint could be for each joint specific, in principle 1:1, in order to maintain the proper joint kinematics in physiological means. Even slightly different basal tonus could lead to higher injury rates at sports [15].

The strength ratios between the quadriceps muscle and flexors were measured already previously. The absolute knee extensor muscle force should exceed the flexors in relation to 3:2 [16,17]. Interestingly the median ratio within our group B was 1.52 and the average ratio of groups A and B together was 1.5346 (SD 0.4765, median 1.575), which is completely consistent with the above-mentioned works and could be defined as a physiologic minimum for maintenance of regular knee kinematics. We do not fully agree with Kapandji et al. [18], who postupated the ratio of 3:1. There is some variability in muscle strength of different muscle groups, depending on their function and daily use [19]. That must be taken into consideration, since lifestyle and specific sports are associated with particular musculoskeletal pathologies and even osteoarthritis. However, microtrauma does not have to explain this phenomenon entirely [20] and we may be simply dealing with an issue of imbalanced muscle groups.

Conclusion

We suppose chronic functional muscular dysbalance to be the key pathogenetic factor for primary osteoarthritis. Sedentary lifestyle, long standing, sitting and walking, at work, at home or during transportation, is leading via neuronal regulation, to gradual functional dominance of the hamstring group against antagonistic quadriceps muscle. After time, the consecutive atrophy of the later one and shortening of the first are leading to wrong knee kinematics and pathological pressure-peaks, thus causing osteoarthritis.

Since permanently in use for walking and standing, strained even in flection, the posterior femoral musculature retains its mass during the lifetime, whereas the quadriceps muscle tends to decline. This phenomenon should not be attributed to physical inactivity, since it can be found even in athletic individuals. The posterior femoral muscle groups are also far more important for upright postural balancing than knee extensor, making them functionally dominant. These muscles seem to retain their stable volumes during the whole life span and throughout the patient groups regardless the arthrosis, with average surfaces of 191.2cm^2 (SD 7.7), whereas antagonistic ventral group volume gradually decreases during the lifetime, from average 340cm^2 in the group A to 224cm^2 (SD 96.2) within the subgroup B of age over 50 years.

Functionally dominant muscle groups inhibit via spinal reflex their antagonists, with imbalanced joint strength equilibrium as a consequence. Moreover, shortening of hamstrings shift femoral condyle due to tibial slope dorsally, leading to wrong joint kinematics, excessive focal pressure peaks and amplified rollback with mechanical conflict between medial femoral condyle and dorsal part of medial meniscus. The anterior cruciate ligament elongation can be also viewed as a result of prolonged sagittal knee dysbalance. We believe systematic training ("up-tuning" via drill) of functionally recessive quadriceps muscle, could pose a strategy to prevent further development of osteoarthritis [21]. Furthermore, proper muscular balance could be one of the key issues in long-term arthroplasty survival [22,23].

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