Acta Scientific Orthopaedics (ISSN: 2581-8635)

Volume 6 Issue 5 May 2023

Research Article

Muscle Atrophy and Knee Osteoarthritis Joint Status: Highlights and their Implications [2017-2023]

Ray Marks*

Department of Health and Behavior Studies, Teachers College, Columbia University, New York, USA

***Corresponding Author:** Ray Marks, Department of Health and Behavior Studies, Teachers College, Columbia University, New York, USA.

DOI: 10.31080/ASOR.2023.06.0726

Received: March 27, 2023

Published: April 06, 2023

Abstract

Osteoarthritis, a disabling disease, commonly believed to originate in the cartilage lining of freely moving joints such as the knee, is increasingly shown to affect and/or be impacted by various muscle deficits surrounding the joint. This brief highlights the current research being published in this respect as far as evidence to support the importance of evaluating and treating any identified muscle atrophy in cases with or vulnerable to one or more manifestations of knee osteoarthritis. To this end, PUBMED, Google Scholar, and PubMed Central indices were selected to identify information specifically pertaining to the topic of muscle atrophy using the key words: Knee Osteoarthritis and Muscle/Muscle Fiber Atrophy. Results show, a reasonable body of current science based evidence supports the view that muscles at the knee joint are important to target in efforts to mitigate knee osteoarthritis in later life. While failing to provide in depth insights into muscle atrophy impacts, it appears treatments directed towards improving muscle structure and function at the knee joint hold promise for mitigating multiple knee osteoarthritis pathogenic disabling processes. Conversely, a failure to identify what components of the muscle system are specifically implicated in the osteoarthritis disease process at the knee joint may be expected to produce more negative or suboptimal clinical outcomes than not.

Keywords: Muscle Fiber Atrophy; Knee Osteoarthritis; Pathogenesis; Pain; Treatment

Introduction

As of January 2023, more than 100,000 reports pertaining to more than a century of discussions on the causes and remedies to counter the widespread joint disease known as osteoarthritis have generally failed to offer many older adults suffering from this disease any universal solution for reducing their disability, other than various medications and surgery. Moreover, even when these latter interventions are indicated or pursued, less than optimal results might ensue for various reasons, one being that the disease causes, that is, its upstream determinants, remain underappreciated as well as in dispute and hence not all disease determinants may commonly be evaluated or treated comprehensively and in a targeted manner.

This mini review sought to examine the most recent research pertaining to declines in muscle fiber numbers or composite muscle size or both in the context of efforts to better understand whether one or more muscle structural alterations might have a bearing on the ability of the older adult to protect the knee joint against injury and subsequent definitive knee osteoarthritis. This focus was specifically adopted given that the disability observed among many knee osteoarthritis sufferers, the joint most often affected by painful osteoarthritis may involve the presence of muscle atrophy consequent to muscle pain, fibrosis, muscle spasm, muscle inflammation, muscle fat infiltration, and possible muscle sensory receptor alterations that accompany the disease, that in turn, could serve to limit muscle usage and engender muscular weakness [1,2]. That is, although other factors may be involved in the complex nature of this progressive disease, the presence of any progressive state of muscle or muscle fiber atrophy could conceivably be expected to hasten or exacerbate knee joint attrition, especially in the older adult, including cartilage synthetic and degradation abnormalities. However, if this thesis is valid, it holds promise because this is a condition where multiple forms of muscle building interventions may effectively eliminate or reduce its adverse impact at all disease stages [3].

The presence of focal areas or specific forms of muscle size declines at the knee such as reductions in one or more knee muscle cross sectional areas may also explain variations in knee osteoarthritis presentation and whether one or more knee compartments are found to be preferentially affected by osteoarthritis or not, such

as the medial, lateral, or patellofemoral components due to incongruent or abnormal joint loading and discordant joint protective reactions [4]. Skeletal muscle size abnormalities at the knee may also be likely to help explain the presence of differential inflammatory and catabolic gene expression between the contralateral and surgical limbs along with differences between the skeletal muscle surrounding the diseased hip versus knee joints [5]. However, despite some emergent consensus on the possible clinically significant role for muscles in the pathogenesis of disabling knee osteoarthritis, those discussing the topic of muscle size reductions, and/or muscle fiber atrophy of one or more of the knee muscles, which could explain some unique as well as general features of the disease that might be remediated, such as joint instability, as well as possible inefficient muscle shock absorption, and a high energy cost when walking any distance, have not been well studied or articulated to date, or even mentioned [6]. This seems hard to explain because muscle size features could well explain some aspects of the disease in both over as well as underweight older adults, prone to muscle mass losses, as well as where to place at least some prophylactic efforts specifically and are measureable in the lab or clinic with reasonable accuracy [7].

Drawn largely from the PUBMED database, the world's largest research repository, it was hoped the overview might provide the interested reader with a general perspective of current observations and trends in this regard, plus data and proposals worthy of further consideration and study. The possibility that the presence of any persistent muscle mass size declines at the knee joint may promote knee joint osteoarthritis, while conceptually plausible, is not widely accepted by all, although often the focus of therapeutic endeavors, but often not even mentioned as an option [8].

Materials and Methods

To obtain the most recent information on the above mentioned topic, the electronic data source PUBMED was carefully searched, and the selected articles were confirmed as those of key import after conducting a scan of PubMed Central, and GOOGLE Scholar data bases. The key time period of interest searched ranged from January 1, 2017- March 25, 2023. Applied were the key words, *Muscle atrophy or Muscle fiber atrophy, Quadriceps muscle and Knee osteoarthritis*. Results were largely limited to those that assessed some form of muscle quality or structural property as related to muscle size or cross-sectional areas in the context of knee osteoarthritis, regardless of cause. Excluded were other muscle correlates of knee osteoarthritis, exercise based studies, restricted muscle blood flow studies, and those focusing on other forms of osteoarthritis and younger populations under the age of 60 years. In light of the limited number of topical studies, only a narrative overview was deemed plausible. For earlier related reviews, and background issues, the reader can refer to Marks [9,10]

Results

As outlined in a recent related review of the link between an age associated muscle mass loss, and its relevance for function in older adults [11], very few articles that addressed the current topic of muscle size at the osteoarthritic knee of the older adult were found. When compared to other muscle attributes, such as muscle weakness, a key role for muscle atrophy and specifically for evidence of either a muscle fiber type 1 (slow twitch muscle fibers) or type 2 (fast twitch fiber) specific forms of atrophy in the context of knee osteoarthritis was challenging to assess. However, it seems some data point to the possible link between a diverse array of osteoarthritis symptoms and features of movement dysfunction that may implicate muscle associated adaptations such as loss of muscle mass, muscle fiber specific declines and degeneration, and muscle aging size alterations [12,13].

That is, while not necessarily a cause of knee osteoarthritis, but not ruling this possibility out [14,15], it does appear that the presence or various degrees of knee muscle atrophy can be observed to occur alongside an array of observable negative local muscle pathological features [16] including changes in muscle quality [17-19], muscle mass and echo density [20,21], muscle fat mass [22-25] and the presence of heightened functional disability and joint damage, early on in the disease process. Atrophic muscle attributes also appear associated with the degree of joint damage observed over time [21], although disputed by Misra., *et al*. [26] and to some degree by Kumar., *et al*. [23], Teoli., *et al*. [27] and Kawatake., *et al*. [28] although this group found vastus lateralis muscle atrophy in significantly more disabled knee osteoarthritis cases than controls. Mohajer., *et al*. [29] report that knee osteoarthritis have been shown to present with longitudinally MRI-derived decreases in quadriceps cross-sectional area and increased intramuscular adipose tissue that appear predictive of downstream symptom worsening and knee replacement.

Unsurprisingly Ghazwan., *et al*. [30] show pre-knee replacement surgery patients do appear to adopt a specific gait pattern that is disease specific and dose responsive as shown by the observation of greater muscle co activation indicators in knee joint osteoarthritis involving more than one knee joint compartment when compared to the disease of a single compartment. Their data further suggest but do not confirm a muscle specific force impact on knee joint that is not the same as that in hip osteoarthritis. Roelker., *et al*. [31] suggest findings that imply aging alone may not significantly alter modular control; however, the combined effects of knee osteoarthritis and aging may together impair the modular control of gait. Osteoarthritis significantly altered biomechanics and neuromuscular control during the squat, with males-who may exhibit significant morphological neuromuscular impairments [18] employing a hip-dominant strategy, allowing them to achieve a greater lower limb range of motion [32]. Muscle wasting may also be related to impaired muscle regeneration [33].

In addition, the finding that the culminating remedy for helping an older adult cope with knee osteoarthritis pain, and its impact on wellbeing, namely surgery, may indeed yield profound adverse effects on muscle fiber size and intrinsic contractility in its own right if not addressed may contribute to-rather than resolve-functional disability [34]. In addition, a failure to acknowledge the intrinsic pathological changes that may be prevalent in the knee muscles of osteoarthritis cases, for example those sent for tibial osteotomy due to leg malalignment problems [35], that may be quite profound [17], may likewise be expected to limit rather than foster strength capacity and function even when applying seemingly efficacious exercise or other muscle associated interventions [36].

At the same time, it can be predicted that exercising in the face of pain or joint swelling, or failing to exercise entirely, can be expected to set the stage for muscle atrophy [37,38], as well as a decline in muscle strength and volume loss [39,40] and multiple functional aberrations that worsen over time.

In the meantime, even though the available data examined may not be representative of all knee osteoarthritis cases, the chief knee stabilizer or quadriceps muscle if atrophied can clearly influence the degree of joint protection regardless of cause or whether muscle is a reactive rather than a direct cause of knee osteoarthritis. A role for atrophy in other knee muscles is generally not alluded to or studied but may be valuable to examine at some point. As well, examining the presence of muscle atrophy and its possible causes may help to establish more evidence-based target therapies that can counter detrimental muscle correlates more strategically and successfully or help in slowing the disease or reversing it [7,15].

Discussion

A wealth of data have revealed that osteoarthritis, a complex joint disease which frequently affects the knee joint, induces inordinate degrees of intractable disability and immense societal and human costs among older populations wherever they reside. As a result, many reports speak to the immense pain and disease associated disability and need to reduce or eliminate this condition, while others suggest sufferers adopt the idea that this is a chronic irreversible condition, even if in examining remedial correlates of the disease, muscle related factors have been increasingly discussed and may be amenable to various forms of muscle building therapies.

Even though often omitted in current discussions, there is also a visible trend and move away from the idea that osteoarthritis is principally a disease of the cartilage tissue lining one or freely moving joints, such as the knee, the most commonly affected joint, to a more inclusive view that osteoarthritis is a disease of the whole joint, including the muscles. The rationale for this is that muscles not only help protect joints, but may enable or foster mobility that in turn impacts muscle quality and its structural properties, but its structure and function are susceptible to various forms of degeneration or biomechanical influences consequent to abnormal stress exposures, as well as fatty tissue infiltration [41]. As such, when the knee has been examined carefully over time, the knee extensors in particular are often found to have diminished force producing capacity and cross sectional area, especially in cases with severe knee osteoarthritis requiring surgery who may exhibit associated stability decrements as well as mobility impairments, and knee extensor strength deficits that are greater in those with bilateral disease as well as healthy controls [42]. Other data show some knee osteoarthritis cases may exhibit significant neuromuscular disease along with features of neuropathy or myopathy that do not appear age related [43]. Aily., *et al*. [44] show the presence of knee osteoarthritis is associated with early thigh muscle changes that seem to intensify and that appear similar to the effects of the aging process.

As a consequence, in light of the observed link between knee strength declines in osteoarthritis cases, and their multiple weight-bearing functional challenges and possible progressive declines in muscle protein synthesis, or muscle area losses due to increases in muscle fat mass infiltration [42,45,46], it seems reasonable to advocate extending the largely medically oriented treatment focus that prevails for knee osteoarthritis to include exercise and muscle building interventions as well as weight optimization and joint protection approaches. This appears consistent with what we have learned over the past few years, and the immense ongoing challenges to alleviate the burden of disability at the knee among aging populations. As with earlier studies in this realm [45,46] the prevailing data appear to be in general agreement that there is a risk of prolonged knee joint damage or progressive functional disturbances if one or more of the knee muscles surrounding an osteoarthritic joint are atrophic [21], although this may hard to detect or isolated to a single muscle group [47]. Accordingly, recommendations concerning exercise as a panacea to counter knee osteoarthritis disability prevail widely, but most studies that assess this idea do not account for the nature of any underlying muscle pathology or specific muscle fiber size abnormalities that may have a treatable origin. Hence, this non specific or generic approach may explain in part why very few tangible advances in this area of suffering are apparent to date, and does not explain who is most likely to suffer, or recover, why pain is often unrelieved, or who is likely to sustain severe functional limitations or a spread of the disease to other joints or show no quadriceps or joint biomechanical changes when walking post quadriceps strength training exercises [48].

Areas of promise do exist, and include, but are not limited to concentrated efforts directed towards uncovering any distinctions between fiber type atrophy in the context of any observable muscle mass size declines, in both the knee extensors and flexors, as well as their differing sub components, and its association where present with objectively verifiable disease progression markers and knee compartmental lesion site. Obesity and its possible impact on increasing the muscle fat mass and decreasing the muscle mass fraction as well as its impact on joint loading plus possible muscle force changes at the patella femoral or tibial joints should be carefully examined in the future and from varying vantage points including biomechanical as well as histological and clinical ramifications. Vitamin D, muscle and nerve injury, and nutrient correlates that may impact or explain prevailing variations and extent of muscle mass deficits in the older adult population with knee osteoarthritis also warrants attention. Examining beneficial as well as any harmful impacts of various exercises or doses of these on muscle biomechanics and why strength exercises alone may fail to improve biomechanical function would be extremely helpful as well in all likelihood.

In the meantime, based on available representative data [17, 24, 48-53], it appears safe to suggest that regardless of cause, muscle atrophy or altered muscle size manifestations at the aging knee joint in any form is likely to explain or induce one or more of the understudied attributes listed below

- Knee joint shock absorption and stability deficits
- Possible muscular imbalances and joint alignment alterations
- Decreases in knee joint range of motion
- Poor overall function, fatigue, muscle efficiency and pain
- Proprioception and reflexive response time deficits
- Persistent joint inflammation, stiffness, and swelling
- Pain, increased joint stresses, and cartilage derangement
- Subnormal cartilage and bone compression and shear forces
- A heightened rate of disease progression and handicap perceptions
- Overall de-conditioning and risk of weight gain
- Diminished emotional and social wellbeing
- Selected functional challenges post knee arthroplasty surgery.

Consequently and in consideration of the above structural and functional knee osteoarthritis disease manifestations and their possible muscle size correlates, the idea that osteoarthritis is attributable to cartilage destruction alone and not to any muscle associated factors, a view that remains quite pervasive, must surely be re-examined more comprehensively in the future to rule out or clarify its role in the osteoarthritic disease process as implied by Yagi., *et al*. [54] and explained by de Ceurnik., *et al.* [55]. Moreover, even if muscle is not considered a key osteoarthritis pathogenic factor, and the idea that the disease is 'incurable' or 'inevitable' persists, numerous publications continue to advocate for the knee osteoarthritis sufferer to undertake exercises of varying types even though this recommendation is hard to validate as is its structural significance and its diverse determinants are rarely examined or categorized and may remain unaffected as a result. Indeed, many exercise approaches even though widely advocated, may not be appropriate in the face of unexamined or appreciated neuropathic or central nervous system sensori-motor dysfunction, joint effusion, abnormalities or increases in muscle protein degradation and suboptimal contractile response rates or both that can all predictably mediate muscle composition and integrity, as well as muscle tone and joint stiffness and stability correlates. as well as any age associated cardiovascular or bone fragility conditions adversely, rather than successfully.

Given that factors that control muscle activity and reactivity and that may influence muscle structure are rarely discussed as possible disease mediators, or are not even alluded to [56] new evidence in this regard appears indicated so that clinicians can direct their clients optimally and safely. The possibility that joint damage can be attenuated in response to carefully construed efforts to enhance muscle properties, synaptic efficacy, provide greater functional reserve, limit fat infiltration, and foster optimal muscle fiber recruitment rates, while improving the capacity to attenuate harmful joint forces in a timely, as well as inadvertent suffering should be studied accordingly, and may reduce the need for intensive post operative interventions to counter the onset or magnitude of muscle atrophy complications at that point [57].

Moreover, even though muscle strength training is the most common remedy espoused for knee osteoarthritis and may be warranted if related to muscle size [58-60], a failure to appreciate the need for endurance exercises to minimize muscle fatigue, or any imbalances in type 1 muscle fiber presence may induce or perpetuate joint dysfunction. Low impact approaches rather than high impact approaches are also generally indicated because muscle fatigue may not only undermine joint protection in its own right plus cartilage integrity, but exercise overload could evoke muscle degeneration, inhibit muscle neo formation, or exacerbate muscle fiber inflammation or splitting in its own right thus inducing varying degrees of immobilizing muscle spasm and swelling as well as joint pain. At the same time a failure to examine and appreciate that osteoarthritis may involve deficits in the surrounding muscles, not only joint cartilage tissues, and that these alone may stem from diverse sources and not be comparable, may fail to counter the pres-

ence of any remediable feature of muscle atrophy or its risk as well as fostering abnormal joint biomechanics and excess pain. As well, a failure to target the muscle sources of any joint destruction may be expected to limit the ability to 'repair' the joint lesion through cartilage specific or gene therapy measures. Older adults in severe pain, those who are obese or underweight or sedentary, those who are vitamin D deficient and in the higher ages who are likely to be most vulnerable should be specifically targeted, along with efforts to educate them about the importance of their role in maximizing their muscular strength, flexibility, endurance and optimal weight status.

Concluding Remarks

The results of this exploration pertaining to muscle atrophy at the knee joint in the context of osteoarthritis, while limited, clearly tends to show:

- Muscles at the knee joint may play a mediating, moderating or causative role in fostering progressive knee joint attrition if atrophic.
- The key causes of this and the lack of objectively defined biomechanical and histological features of the affected joint as well as unaffected joints remain unclear and understudied.
- Failures of exercises as well as some drugs and surgical regimens may have occurred because the inherent muscle correlates of osteoarthritis remained unexamined or are not specifically targeted in a desired dosage and in a timely mode, even if modifiable.
- To better understand the nature of muscle atrophy at the osteoarthritic knee and its clinical and surgical implications further careful and comprehensive robust studies of less and more severe knee osteoarthritis cases of different ages ranges and with differing health profiles are highly indicated.
- Case studies that depict the full extent of the prevailing and ensuing joint pathology and its functional correlates using multiple evaluation approaches may greatly advance this line of inquiry and enable more consequential personalized and specific therapies to be applied and with favorable results and are strongly advocated.

Acknowledgements

None.

Conflicts of Interest

None.

Funding

None.

Bibliography

1. Fink Bernd., *et al.* "Morphologic changes in the vastus medialis muscle in patients with osteoarthritis of the knee". *Arthritis and Rheumatism* 56.11 (2007): 3626-3633.

2. Rice David A., *et al.* "Mechanisms of quadriceps muscle weakness in knee joint osteoarthritis: the effects of prolonged vibration on torque and muscle activation in osteoarthritic and healthy control subjects". *Arthritis Research and Therapy* 13.5 (2011): R151.

3. Wang Yuanyuan., *et al.* "Increase in vastus medialis cross-sectional area is associated with reduced pain, cartilage loss, and joint replacement risk in knee osteoarthritis". *Arthritis and Rheumatism* 64.12 (2012): 3917-3925.

4. Drummer Devin J., *et al.* "Perioperative assessment of muscle inflammation susceptibility in patients with end-stage osteoarthritis". *Journal of Applied Physiology (Bethesda, Md.: 1985)* 132.4 (2022): 984-994.

5. Goldman LH., *et al.* "Role of thigh muscle cross-sectional area and strength in progression of knee cartilage degeneration over 48 months - data from the Osteoarthritis Initiative". *Osteoarthritis and Cartilage* 24.12 (2016): 2082-2091.

6. Lespasio Michelle J., *et al.* "Knee osteoarthritis: a Primer". *The Permanente Journal* 21 (2017): 16-183.

7. Mahmoudian Armaghan., *et al.* "Early-stage symptomatic osteoarthritis of the knee - time for action". *Nature Reviews. Rheumatology* 17.10 (2021): 621-632.

8. Hussain SM., *et al.* "Knee osteoarthritis: a review of management options". *Scottish Medical Journal* 61.1 (2016): 7-16.

9. Marks R. "Muscles as a pathogenic factor in osteoarthritis". *Physiotherapy Canada* 45 (1993): 251-251.

10. Marks R. "Muscles-a potent treatable pathogenic factor in the pain of osteoarthritis". *EC Orthopaedics* 1 (2016): S1.

11. Lunt Eleanor., *et al.* "The clinical usefulness of muscle mass and strength measures in older people: a systematic review". *Age and Ageing* 50.1 (2021): 88-95.

12. Fu Shengxing., *et al.* "Postural balance in individuals with knee osteoarthritis during stand-to-sit task". *Frontiers in Human Neuroscience* 15 (2021): 760960.

13. Shorter Emily., *et al.* "Skeletal muscle wasting and its relationship with osteoarthritis: a mini-review of mechanisms and current interventions". *Current Rheumatology Reports* 21.8 (2019): 40.

14. Herzog Walter and David Longino. "The role of muscles in joint degeneration and osteoarthritis". *Journal of Biomechanics* 40.1 (2007): S54-63.

15. Mahmoudian Armaghan., *et al.* "Towards secondary prevention of early knee osteoarthritis". *RMD Open* 4.2 (2018): e000468.

16. Cunha Jonathan Emanuel., *et al.* "Knee osteoarthritis induces atrophy and neuromuscular junction remodeling in the quadriceps and tibialis anterior muscles of rats". *Scientific Reports* 9.1 (2019): 6366.

17. Noehren B., *et al.* "Alterations in quadriceps muscle cellular and molecular properties in adults with moderate knee osteoarthritis". *Osteoarthritis and Cartilage* 26.10 (2018): 1359-1368.

18. Serrão Paula Regina MS., *et al.* "Men with early degrees of knee osteoarthritis present functional and morphological impairments of the quadriceps femoris muscle". *American Journal of Physical Medicine & Rehabilitation* 94.1 (2015): 70-81.

19. Taniguchi Masashi., *et al.* "Quantity and quality of the lower extremity muscles in women with knee osteoarthritis". *Ultrasound in Medicine and Biology* 41.10 (2015): 2567-2574.

20. Zhang Xini., *et al.* "Relationship between knee muscle strength and fat/muscle mass in elderly women with knee osteoarthritis based on dual-energy x-ray absorptiometry". *International Journal of Environmental Research and Public Health* 17.2 (2020): 573.

21. Taniguchi Masashi., *et al.* "Enhanced echo intensity in vastus medialis is associated with worsening of functional disabilities and symptoms in patients with knee osteoarthritis: a 3-year longitudinal study". *Rheumatology International* (2022): 1-8.

22. Godziuk Kristine., *et al.* "The impact of sarcopenic obesity on knee and hip osteoarthritis: a scoping review". *BMC Musculoskeletal Disorders* 19.1 (2018): 271.

23. Chopp-Hurley Jaclyn N., *et al.* "Evaluating the relationship between quadriceps muscle quality captured using ultrasound with clinical severity in women with knee osteoarthritis". *Clinical Biomechanics (Bristol, Avon)* 80 (2020): 105165.

24. Kumar Deepak., *et al.* "Quadriceps intramuscular fat fraction rather than muscle size is associated with knee osteoarthritis". *Osteoarthritis and Cartilage* 22.2 (2014): 226-234.

25. Veronese Nicola., *et al.* "Lower limb muscle strength and muscle mass are associated with incident symptomatic knee osteoarthritis: a longitudinal cohort study". *Frontiers in Endocrinology* 12 (2021): 804560.

26. Misra Devyani., *et al.* "Risk of knee osteoarthritis with obesity, sarcopenic obesity, and sarcopenia". *Arthritis and Rheumatology (Hoboken, N.J.)* 71.2 (2019): 232-237.

27. Teoli Anthony., *et al.* "Vastus medialis intramuscular fat is associated with reduced quadriceps strength, but not knee osteoarthritis severity". *Clinical Biomechanics* 96 (2022): 105669.

28. Kawatake Ednei Haruo., *et al.* "Immunohistochemical analysis of the quadriceps femoris muscle before and after total knee arthroplasty". *The Knee* 40 (2023): 42-51.

29. Mohajer Bahram., *et al.* "Role of thigh muscle changes in knee osteoarthritis outcomes: osteoarthritis initiative data". *Radiology* 305.1 (2022): 169-178.

30. Ghazwan Aseel., *et al.* "Knee osteoarthritis alters peri-articular knee muscle strategies during gait". *PloS One* 17.1 (2022): e0262798.

31. Roelker Sarah A., *et al.* "Effects of age and knee osteoarthritis on the modular control of walking: A pilot study". *PloS One* 16.12 (2021): e0261862.

32. Bayliss Zajdman Olivia R., *et al.* "Females with knee osteoarthritis use a detrimental knee loading strategy when squatting". *The Knee* 38 (2022): 9-18.

33. Silva Jordana Miranda de Souza., *et al.* "Muscle wasting in osteoarthritis model induced by anterior cruciate ligament transection". *PloS One* 13.4 (2011): e0196682.

34. Toth Michael J., *et al.* "Effects of total knee arthroplasty on skeletal muscle structure and function at the cellular, organellar, and molecular levels". *Journal of Applied Physiology (Bethesda, Md.: 1985)* 133.3 (2022): 647-660.

35. Ma Xin-Long., *et al.* "Chinese clinical practice guidelines in treating knee osteoarthritis by periarticular knee osteotomy". *Orthopaedic Surgery* 14.5 (2022): 789-806.

36. Assis Livia., *et al.* "Musculoskeletal atrophy in an experimental model of knee osteoarthritis: the effects of exercise training and low-level laser therapy". *American Journal of Physical Medicine and Rehabilitation* 94.8 (2015): 609-616.

37. Chiba Daisuke., *et al.* "Knee effusion evaluated by ultrasonography warns knee osteoarthritis patients to develop their muscle atrophy: a three-year cohort study". *Scientific Reports* 10.1 (2021): 8444.

38. Kus Gamze and Ipek Yeldan. "Strengthening the quadriceps femoris muscle versus other knee training programs for the treatment of knee osteoarthritis". *Rheumatology International* 39.2 (2019): 203-218.

39. Tsukada Ayumi., *et al.* "Unilateral-dominant reduction in muscle volume in female knee osteoarthritis patients: computed tomography-based analysis of bilateral sides". *Journal of Orthopaedic Surgery and Research* 15.1 (2020): 543.

40. Xu Jichun., *et al.* "Knee muscle atrophy is a risk factor for development of knee osteoarthritis in a rat model". *Journal of Orthopaedic Translation* 22 (2019): 67-72.

41. Ho Kevin Ki-Wai., *et al.* "End-stage knee osteoarthritis with and without sarcopenia and the effect of knee arthroplasty - a prospective cohort study". *BMC Geriatrics* 21.1 (2012): 2.

42. Lankhorst GJ., *et al.* "The relationships of functional capacity, pain, and isometric and isokinetic torque in osteoarthrosis of the knee". *Scandinavian Journal of Rehabilitation Medicine* 17.4 (1985): 167-172.

43. Glasberg MR., *et al.* "Muscle pathology in total knee replacement for severe osteoarthritis: a histochemical and morphometric study". *Henry Ford Hospital Medical Journal* 34.1 (1986): 37-40.

44. Aily Jéssica Bianca., *et al.* "Evaluation of vastus lateralis architecture and strength of knee extensors in middle-aged and older individuals with knee osteoarthritis". *Clinical Rheumatology* 38.9 (2019): 2603-2611.

45. Gibson JNA., *et al.* "Effects of therapeutic percutaneous electrical stimulation of atrophic human quadriceps on muscle composition, protein synthesis and contractile properties." *European Journal of Clinical Investigation* 19.2 (1989): 206-212.

46. Pegreffi Francesco., *et al.* "Prevalence of sarcopenia in knee osteoarthritis: a systematic review and meta-analysis". *Journal of Clinical Medicine* 12.4 (2023): 1532.

47. Tayfur Beyza., *et al.* "Neuromuscular joint function in knee osteoarthritis: A systematic review and meta-analysis". *Annals of Physical and Rehabilitation Medicine* 66.2 (2023): 101662.

48. DeVita Paul., *et al.* "Quadriceps-strengthening exercise and quadriceps and knee biomechanics during walking in knee osteoarthritis: a two-centre randomized controlled trial". *Clinical Biomechanics (Bristol, Avon)* 59 (2018): 199-206.

49. Moutzouri Maria., *et al.* "Early initiation of home-based sensori-motor training improves muscle strength, activation and size in patients after knee replacement: a secondary analysis of a controlled clinical trial". *BMC Musculoskeletal Disorders* 20.1 (2019): 231.

50. Lohnes Jessica., *et al.* "Do individuals with knee osteoarthritis walk with distinct knee biomechanics and muscle activation characteristics? An investigation of knee osteoarthritis, hip osteoarthritis, and asymptomatic groups". *Gait and Posture* 99 (2023): 14-19.

51. Yasuda Tadashi., *et al.* "Association of preoperative muscle composition of the lower extremity with gait function after total knee arthroplasty". *Journal of Orthopaedic Science* 28.1 (2023): 188-194.

52. Suzuki Yusuke., *et al.* "Rate of force development in the quadriceps of individuals with severe knee osteoarthritis: A preliminary cross-sectional study". *PloS One* 17.1 (2022): e0262508.

53. Wada Osamu., *et al.* "Influence of the severity of knee osteoarthritis on the association between leg muscle mass and quadriceps strength: the SPSS-OK study". *Clinical Rheumatology* 38.3 (2019): 719-725.

54. Yagi Masahide., *et al.* "Relationship between individual forces of each quadriceps head during low-load knee extension and cartilage thickness and knee pain in women with knee osteoarthritis". *Clinical Biomechanics* 91 (2022): 105546.

55. De Ceuninck Frédéric., *et al.* "Bearing arms against osteoarthritis and sarcopenia: when cartilage and skeletal muscle find common interest in talking together". *Drug Discovery Today* 19.3 (2014): 305-311.

56. Primorac Dragan., *et al.* "Knee osteoarthritis: a review of pathogenesis and state-of-the-art non-operative therapeutic considerations". *Genes* 11.8 (2020): 854.

57. Singla Ravi., *et al.* "The course of knee extensor strength after total knee arthroplasty: a systematic review with meta-analysis and -regression". *Archives of Orthopaedic and Trauma Surgery* (2023): 10.

58. Young A., *et al.* "The size and strength of the quadriceps muscles of old and young men". *Clinical Physiology (Oxford, England)* 5.2 (1985): 145-54.

59. Yamauchi Koun., *et al.* "Atrophy of individual thigh muscles measured by MRI in older adults with knee osteoarthritis: a cross-sectional study". *Annals of Physical and Rehabilitation Medicine* 63.1 (2020): 38-45.

60. Li Yuanyuan., *et al.* "Gastrocnemius muscle injury is the condition to induce cartilage degeneration of the rabbit tibiofemoral joint: a new perspective". *BioMed Research International* (2022): 7532434.