Introduction

In 2017, Chen, et al. [1] affirmed the importance of all synovial joint structures, rather than simply the articular cartilage lining when discussing the pathogenesis of the painful disabling joint disease known as osteoarthritis. Another body of research shows acceptance of muscle strength as a factor in the osteoarthritic disease process [2,3], and that muscle dysfunction may be a causative or pre-existing, rather than a reactive disease factor [4]. This brief expands this topic by examining recently published findings concerning quantitative and qualitative muscular changes observed in the context of the pathogenesis of osteoarthritic joint damage, given that a better understanding of the role of muscle in this condition may be extremely helpful clinically. Second, it stresses what researchers might focus on in the future, as well as what clinicians might do to ameliorate their client’s osteoarthritis symptoms. This information was sought in a continuing effort to improve upon prevailing preventive options for countering osteoarthritis, the most prevalent joint disorder, and the leading cause of chronic joint pain and functional disability throughout the world.

In addition, it was specifically sought because the possibility that pathology of the neuromotor system, as well as excess or abnormal muscle forces may promote or exacerbate joint dysfunction may enable more targeted treatments for patients to emerge than are presently available. Moreover, the available literature housing multitudes of osteoarthritis related studies on articular tissue biology, pharmacologic and surgical options for osteoarthritis, stem cell research and tissue bioengineering, shows none have proven viable to date as either a treatment approach or conceptual framework for guiding clinical practice.

To examine the extent to which muscle appears to be implicated in the disabling and prevalent pathology of osteoarthritis, recent publications on this topic area were sought and carefully examined and analyzed.

Methods and Procedures

To examine the degree to which current research focuses specifically on muscle in the context of osteoarthritis, data embedded in peer reviewed English language publications containing the key words, osteoarthritis and muscle, and others, based on prior work in this realm were sought. The time periods covered were largely limited to those publications reported between June 2015 and April 2017, given available prior comprehensive analyses on this topic [eg. 5-8]. Data bases employed were: PUBMED and Web of Science. Results were limited to clinical non-experimental studies that assessed some form of muscle quality or structural property in the context of osteoarthritis. Excluded were animal models, as an appropriate replicable animal model of osteoarthritis and relevant muscle...
Other topics housed in the current literature focused on the impact of skeletal muscle vitamin D levels on osteoarthritic muscle [29, 30], the role of muscle imbalances in osteoarthritis [31], and the role of atrophy of distant muscles as a significant correlate of osteoarthritis [32]. The role of muscle composition changes, muscle fat infiltration [33], and negative contractile changes and its impact on osteoarthritis was also discussed [34].

To add to the diversity of this information, almost all studies employed different assessment approaches, even if a similar variable or idea was examined. In addition, some reported associations between reduced rates of torque development and intrinsic contractile deficits [14], while others noted an association between having a proportionately lower lean body (muscle) mass and osteoarthritis [35-36]. Another body of current literature focused on the role of muscle thickness, the role of altered moving distance of the muscle insertion, and the role of mental health in mediating or moderating osteoarthritis strength and disability [37,38].

While many studies of osteoarthritis have examined muscle strength capacity and its outcome at various joints, most conclusions are based on the role of concentric strength measures, rather than eccentric strength measures. However, consistent with Serrao, et al. [39]. Petrella, et al. concluded a reduced ability to generate eccentric muscle forces in a timely manner [40] is a more significant factor in terms of explaining cartilage damage than concentric strength values. Yet, others have stressed the importance of abnormal dynamic muscular force adaptations [41-43], afferent sensory dysfunction [44,45], dysfunction of the tendon-aponeurosis entity of muscle [46], along with diminished strength capacity [47], co-ordination impairments, co-activation ratios and sums [17] in explaining the osteoarthritic pain and disability cycle. Alternately, others imply it is reduced muscle endurance, rather than muscle strength that influences joint force abnormalities associated with the disease process [48].

In this regard, Astephen-Wilson, et al. [49] found cases with knee osteoarthrosis do experience abnormal loads of their major weight bearing joints bilaterally, and these abnormalities persist despite treatment of the affected limb. However, whether these findings are attributable to the presence of either pre existing muscle pathology and/or an alteration in afferent input to the central nervous system and long term adaptations that may prove detrimental to articular cartilage in vulnerable joints such as the knee is impossible to establish. Although Ferrari, et al. [50] found concomitantly worsening of the muscular deficit and atrophy of hamstrings led to persistent and disabling knee pain associated with osteoarthritic joint damage, in a patient with progressive amyotrophy, whether this occurs in osteoarthritis cases more generally over time is also not known.

Nonetheless, Tuna, et al. [51], and Macias-Hernandez, et al. [52] reported finding early changes in femoral, tibial, and patellar cartilage that were significantly correlated with muscle strength, and suggested these early changes might play an important role in the pre-clinical phases of osteoarthritis. Others state muscle associated changes observed in osteoarthritis are compensatory rather than causative [22,53], and that muscle power of the agonists as well as the antagonists on both the affected osteoarthritic limb as well as the contralateral limb affect temporal aspects of day to day function [27].

Colgan, et al. [54] who studied patients prospectively, noted that despite clinical score improvements for pain and functional ability

### Key Findings

Despite a sizeable number of possible thematic related publications identified at PUBMED and Web of Science data bases over the past two years, only a limited number were found to specifically focus on the present topic of interest [see Table 1 for various key words used and their yield].

Among these publications, most were derived from cross-sectional studies, studies based on mathematical modeling, or prospective studies of post surgical patients. Rather than any coherent body of information, these publications included a very broad array of thematic topics, rather than any uniform body of content. These topics included observations of how various forms of muscle dysfunction interact with various forms of osteoarthritis pathology, various measures of osteoarthritis pain, and various aspects of osteoarthritis function [9-11]. Others described the relationship between muscle contraction durations [12], or the rates at which selected muscles contract [13] and their association with the extent of the prevailing osteoarthritis pathology [eg. 14,15].

Yet others focused on examining the association between the impact of muscle co-activation processes on joint moments [16,17], sarcopenia and its relationship with osteoarthritis [18], muscle activation imbalances [19], the role of abnormal muscle loading forces [20], and muscle weakness and movement patterns [21] in the context of osteoarthritis.

Additional themes focused on possible the relationship of osteoarthritis to muscle structural abnormalities, muscle mass alterations [22], motor control abnormalities, altered muscle co-activation patterns [23], and muscle thickness abnormalities [24]. Other themes focused on muscle strength and inflammation [25-26], and aspects of muscle power and function [27,28] in the context of various forms and degrees of osteoarthritis.

| Data Source | Key Words and Number of Citations |
|-------------|----------------------------------|
| **PubMed Jan 2015-April 15, 2017** | Muscles and osteoarthritis-535, Knee osteoarthritis and muscle-404, Hip osteoarthritis and muscle-153, Hand osteoarthritis and muscle-40, Muscle abnormalities in osteoarthritis-39, Muscle atrophy and osteoarthritis-41, Osteoarthritis and muscle pathology-86, Motor control and osteoarthritis-46, Sarcopenia and osteoarthritis-27, Muscles and their role in osteoarthritis -20 |
| **Web Science Jan 2015-April 15, 2017** | Muscles and osteoarthritis-1001, Knee osteoarthritis and muscle-925, Hip osteoarthritis and muscle-372, Hand osteoarthritis and muscle-86, Muscle abnormalities in osteoarthritis-37, Muscle atrophy and osteoarthritis-31, Osteoarthritis and muscle pathology-679, Motor control and osteoarthritis-116, Sarcopenia and osteoarthritis-31, Muscles and their role in osteoarthritis -14 |

**Table 1: Extent of possible current sources of information on muscle and osteoarthritis.**
post surgery, this did not translate to the expected degree of dynamic gait improvement. They indicated that post-operative rehabilitation programs should include extensor muscle exercises to increase power and to retain the operative gain in passive range of motion, which might help improve gait patterns. This idea was supported by findings that lower limb muscle activation patterns do appear to be significantly altered for four of the lower limb muscles of the affected limb of the osteoarthritis limb during stair climbing. These adaptations were said to be indicative of co-contraction strategies in the total knee arthroplasty patient [55], but could have been related to changes in muscle composition of multiple muscles, rather than function alone [33].

Table 2: Random sample of diverse topics focused on in current literature concerning muscle and osteoarthritis over time periods Jan 2015-April 2017.

| Research group             | Joint      | Muscle Attribute                      | Observation                                                                 |
|----------------------------|------------|----------------------------------------|-----------------------------------------------------------------------------|
| Bammam et al. [25]         | Hip        | Muscle inflammation, protein syn.      | Muscle inflammation and suppressed muscle protein synthesis was evident in non-traumatic total hip arthroplasty patients affected limb |
| Culvenor et al. [14]       | Knee       | Knee flexor + extensor strength        | Thigh strength predicts risk for knee replacement in women                  |
| Harding et al. [58]        | Knee       | Knee + ankle muscle forces             | Obesity increased posterior muscle forces and joint forces during gait, which may exceed joint ability of OA cases to accommodate load readily |
| Hodges et al [12]         | Knee       | Co-contraction duration knee           | Augmented knee muscle co-contraction speeds up medial compartment knee OA progression |
| Jeong et al. [59]         | Knee       | Surface electromyography               | Flexion-relaxation rates of erector spinea was not the same in older osteoarthritis cases as in younger cases |
| Lee et al. [48]           | Knee       | Ratio leg muscles/fat mass             | Leg muscle mass correlates with pain                                       |
| Omori et al. [60]         | Knee       | Quadriceps strength                    | Dynamic quadriceps strength is likely to be more strongly associated with radiographic grade of knee OA than static measures |
| Petrella et al. [40]      | Knee       | Muscle strength                        | Lower knee extensor torque is associated with pain, stiffness, and function |
| Takacs et al. [61]        | Knee       | Concentric/eccentric knee strength     | Decreased muscle strength and frontal plane stability during external perturbation and reduced proprioception appeared related |
| Tsuchagoshi et al. [62]   | Hip        | Peak hip extension angle + muscle      | Peak hip extension angle correlated with hip and knee muscle strength, and peak hip extension angle during gait |
| Wakabayashi [63]          | Hip        | Muscle mass                            | Preoperative psoas muscle mass on non-operative side was associated with postoperative gait speed mass |
| Zacharias et al. [34]     | Hip        | Hip abductor muscle volume             | Gluteal muscle atrophy and fat deposits were related to disease severity   |

Discussion

Evidence that muscle is involved in the osteoarthritic process is increasing steadily, along with the possibility that muscle weakness, muscle balance [31], muscle power deficits [64,65], low skeletal muscle mass [66], and disturbances residing in the neuromotor system may be a causative, rather than a reactive disease factor [44,51,67,68]. Supporting this idea are findings that those with stronger muscles may function more ably than those with weaker muscles [43,69], while those with symptomatic osteoarthritis show different muscle activation patterns than those generated by asymptomatic individuals with the same radiographic grade [49], which could influence skeletal cell behavior [70]. They may also experience less pain as well as better function [15,66,71] and better joint stability over time [44].

However, even when muscle is observed to be implicated in the pathogenic process, it is not possible at present to establish which muscles are of most import in mediating or moderating various forms of osteoarthritis. Support for any causative role for muscle in the osteoarthritic disease process is especially challenging given that most studies exploring this topic remain cross-sectional without any consistent conceptual model or set of consistent hypotheses. Unsurprisingly, whether muscle power rather than strength is potentially highly important in mediating the disease [64,65,72], or whether muscle timing, muscle mass, muscle co-ordination, muscle co-contraction, muscle fatigue, or imbalances are paramount in this...
disease process, is impossible to discern with any clarity. Gender, weight status, nutritional status, general health status, trauma and aging factors and their influence on either muscle or joint status or both are also extremely difficult to tease out with so few well designed and adequately powered predictive studies.

Hence, despite a reasonable volume of research directed towards assisting practitioners and researchers to better understand this topic, no apparent conclusions about a definitive role for any aspect of muscle structure or function or both in the osteoarthritis pathogenic process can be forged. As a result the clinical implications of this body of knowledge are unclear at best.

That is, despite a reasonably vast array of related studies on this present topic, related current studies seem to have few commonalities or guiding principles to rationalize their objectives and approaches. Not only are different disease stages studied, with different tools, and with dissimilar premises and aims, but the challenges in synthesizing data from morphological studies, [39,46], alongside electromyographic studies [eg. 19,53,59], muscle volume studies [36], plus studies examining the role of elevated skeletal muscle FoxO1 protein and reduced IL-15 protein expression and strength in people predominantly with knee osteoarthritis [26], remains immense.

In addition, even though the impact of muscle weakness on pain or radiographic changes [56], appears to be a consistent finding across several studies, the relative importance of muscle strength versus other muscle attributes, and their possible temporal order of development, is unclear in the absence of comparative and prospective evaluations of other muscle attributes. These include muscle endurance, muscle fatigue, muscle imbalance, muscle inflammation and abnormal muscle fat content [74].

Similarly, not all authors agree on the relevance of muscle impairments in the context of osteoarthritis, even when examining similar issues. Farrokhi, et al. [73] for example, found contact mechanics in cases with knee osteoarthritis to be unrelated with muscle strength mechanics, while others have implied there is a relationship between knee flexor moments and pain at the osteoarthritic knee [75]. As well, Skou, et al. [57] found muscle strength was not a predictor of an increased risk for knee replacement, even though others found that changes in neuromuscular function can conceivably predate the disease onset [44,71] and can strongly predict pain and extent of disease [22,60].

In another report, Lim, et al. [76] found no trend to exist between measures of quadriceps electromyography and knee alignment in people with knee osteoarthritis, even though subjects who were less impaired had similar muscle patterns to those who were severely impaired, and the presence of imbalanced vastus medialis, lateralis ratio was not equitable from within subjects. However, the sample size was small, ages studied were younger than 60 years of age, and body mass on average was in the normal range, while the torque measures were examined during seated contractions, not weight bearing positions.

In addition, concentric strength may be less important than eccentric strength in men [39], muscle strength may predict disease progression for women, but not men [14], endurance may be highly important, not strength [48], and muscle fat content may be more important than not [74]. As well, as shown in Table 2, data representing this topic stem largely from studies of knee or hip osteoarthritis, but are poorly articulated for joints other than the hip or knee, even though osteoarthritis of the hand, neck, back, ankle, elbow, and shoulder are all sites that produce severe disability. Surprisingly, very few studies have examined osteoarthritis cases with multiple joint involvement even though this is more common than not and could be very telling.

As well, the use of data from intervention studies, where control subjects could still sustain an ‘intervention’ effect [12], differences in self-reported function [77,78] versus actual function [79], differences in the nature of the functional activities assessed, plus differences in muscle measurement tools, joints, muscles and muscle attributes examined, along with disease status differences, severely limit the ability to extract any conclusive trends of import from this data. Moreover, though discrepancies between muscle power versus strength prevail, the actual impact of muscle power on joint physiology and structure is not well described, when compared to the correlate of strength [51].

In short, despite more than 40 years of efforts to examine muscle status in the context of osteoarthritis pathology, no firm conclusion about its etiological role, nor what aspect of muscle status or impairment is most salient - if indeed a temporal association, prevails. While it is recognized some relevant research may not have been located, or has been published in former years, or in a foreign language, the role of muscle as a protective factor in minimizing joint forces and impact as indicated by Bouchouars, et al. [53], along with the possibility that rather than muscle being a compensatory or reactionary joint component, excessive muscle co-contraction found in osteoarthritis may be a maladaptive response [86], has also not received wide examination when compared to other aspects of osteoarthritis pathology. However, regardless of these limitations, and the fact negative studies may not be published, it seems possible that by drawing on the prevailing data base, those in the field can be encouraged to work together to develop a more universal conceptual model of how muscle adaptations and joint status may be interrelated in the osteoarthritic disease process [see Figure 1 for a tentative set of ideas]. In particular, exploring whether different clinical profiles exist and whether tailoring interventions accordingly may foster the ability to deliver more personalized healthcare to this population warrants careful consideration [47].

Implications and Conclusion

While harnessing the entire data base to systematize more definitive trends than is evident in the present snapshot of current research may be valuable, it is the author's belief that more efforts towards developing carefully construed biomechanical, radiological, molecular, biochemical, and neuromuscular oriented prospective studies of adequate duration are indicated to advance this line of inquiry, despite the increasing volume of reports. To verify or dispute hypothetical evidence based associations depicted in Figure 1 and expand upon trends depicted in Table 2, more prospective studies focusing on muscle co-activation effects [17], the role of eccentric as well as concentric forces on the emergence and progression of osteoarthritic joint disease [40], as well as the role of distant muscles [42,69], and the tendon-aponeurosis complex [46] are indicated [46,59]. In addition, delineating the role of muscle fat infiltration [33,81], muscle inflammation [25], and vitamin D [30] and its impact on muscle structure and function in the context of osteoarthritis may
prove exceptionally insightful [80], as may efforts to conduct well designed case control studies using validated instruments.

However, without a strong coordinated national or international task force to guide this line of research, it is probable that many laudable studies conducted to date in isolation may still prevent the emergence of any universal understanding or directive for advancing care. As well, without an agreement upon a standardized test battery for measuring the most important muscle attributes deemed salient in osteoarthritis on a routine basis, clinicians may fail to appreciate the important role played by muscle in osteoarthritis disease process, and how to use this information to directly foster optimal osteoarthritis outcomes.

Until more research is forthcoming though, the literature indicates clinicians should be encouraged to routinely examine the muscular as well as the joint status of their osteoarthritis clients, and to tailor their treatment recommendations appropriately. Indeed, regardless of joint status, employing this approach sooner, rather than later, and following up their initial findings with carefully construed targeted solutions known to impact neuromuscular function favorably, patients seeking to improve their joint status can expect to reap more benefit than not from such therapy, at all stages of the disease process.

Recommendations must clearly be applicable and commensurate however with the nature of the resultant and presiding interactions between the patients’ muscles and joints, and what is considered beneficial in the individual situation, as well as harmful. Current literature is important to employ in this regard, given the fact that it houses general observations, as well as some unique findings that could help to reduce the disease burden, while modifying the disease process favorably. However, more research directed towards revealing the extent to which deficiencies in the motor system contribute to articular cartilage degeneration, and in what way, will most assuredly improve the prognosis for those at risk as well as for those with different degrees of osteoarthritis disability significantly, as well as profoundly.

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