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The biomechanics of osteoarthritis in the hand: Implications and prospects for hand therapy

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ABSTRACT

Background: The unique anatomy of the human hand makes it possible to carefully manipulate tools, powerfully grasp objects, and even throw items with precision. These apparent contradictory functions of the hand, high mobility for manual dexterity vs high stability during forceful grasping, imply that daily activities impose a high strain on a relatively instable joint. This makes the hand susceptible to joint disorders such as osteoarthritis. Both systemic (eg, genetics, hormones) and mechanical factors (eg, joint loading) are important in the development of osteoarthritis, but the precise pathomechanism remains largely unknown. This paper focuses on the biomechanical factors in the disease process and how hand therapists can use this knowledge to improve treatment and research.

Conclusion: Multiple factors are involved in the onset and development of osteoarthritis in the hand. Comprehension of the biomechanics helps clinicians establish best practices for orthotics intervention, exercise, and joint protection programs even in de absence of clear evidence-based guidelines. The effect and reach of hand therapy for OA patients can be expanded substantially when intervention parameters are optimized and barriers to early referrals, access reimbursement, and adherence are addressed. Close and early collaboration between hand therapists and primary care, women's health, rheumatology, and hand surgery providers upon diagnosis, and with hand surgeons pre and postoperatively, combined with advances in the supporting science and strategies to enhance adherence, appear to be a promising way forward.

Introduction

The capacity to carry out everyday tasks such as writing, buttoning, grasping a cup of coffee, or throwing a baseball is mainly possible due to the mobility and strength of the hand. The versatile motion of the human thumb is unique and is considered one of the hallmarks of human evolution.

The functional paradox of the hand -high dexterity vs powerful grasp- implies that daily activities impose high demands on relatively unstable joints. The perpetual balancing of these conflicting properties makes the hand vulnerable to joint disorders.

The most prevalent joint disorder in the Western world is osteoarthritis (OA). OA is a joint disease in which progressive deterioration of cartilage is a common occurrence. In the United States, more than 50% of the population 65 years and older are estimated to suffer from this disabling and age-related disorder.[1,2] This number will expectedly rise with the growing life expectancy of the human population, along with the increase in prevalence with age.[3] The financial implications are tremendous: in the United States, hospitalizations related to OA lead to a yearly total cost of 14.9 billion USD, making it one of the most billable conditions both to private insurance and Medicare.[4]

OA of the wrist, thumb, and finger are common phenotypes of OA that severely impairs hand function and thus the quality of life.[5] A causal link between joint instability and the development of OA is often suggested.[6-9] However, the precise mechanisms that cause OA in the hand are largely unknown. Multiple factors contribute to thumb base OA, including systemic (ie, genetics and obesity)[10-14] and mechanical factors.[15] These mechanical factors relate to the forces exerted around or inside the joint and are affected by underlying elements which also affect each other, such as muscle activation, bone motion, and joint stabil-

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ity. The hand therapist can use biomechanics to better understand what drives OA in the hand and help establish evidence-based best practices that will expand the effectiveness and reach of hand therapy.

Biomechanics of the native and diseased hand

Mobility vs stability

The carpal bones in the hand are relatively unstable during a resting posture,[16-18] yet the joints are subjected to high compressive forces during hand usage. Cooney and colleagues estimated joint forces at the CMC joint of 88-127 Newton during lateral key pinch and of 834-1608 Newton during power grasp.[19] These high forces acting upon a small joint (~130 mm^2 [20]) imply, at least theoretically, a high force-to-total articular area ratio compared to a large joint such as the knee. Indeed, an average articular area of a male femur is ± 640 mm^2.[21] During walking or stair climbing the knee is loaded with 3-6 times the person's body weight.[22] For a male of 70 kg this means a theoretical distribution of 0.3 N / mm^2 when walking or 6.4 N / mm^2 when climbing stairs vs 0.9 N / mm^2 during lateral key pinch and 12.4 N / mm^2 during power grasp, suggesting at least two-three times greater force per unit area seen in the hand compared to the leg. To withstand such forces, the hand requires a protective soft tissue to provide adequate stability. The envelope of soft tissue that surrounds the joints consists of active stabilizers (muscles) and passive stabilizers (ligaments).

The metacarpals and phalanges create a substantial lever arm between the load acting at the tip of the fingers and the carpal bones. Hereby, multiplying the force at the fingertips up to 12 times at the base of the metacarpal.[19] Especially the thumb base endures substantial forces during grasping, as the thumb functions as the anti-finger. Thus, when an object is grasped with the entire hand, the load on the fingers is distributed over four digits, while only one digit, namely the thumb, opposes the force of the four fingers. The above-mentioned high compressive forces, combined with the small articular surface of the CMC joint lead to elevated contact pressures. High mechanical loading at a joint is associated with the development of OA.[23–25] Furthermore, repetitive precision gripping (eg, by dentists or lab workers) and forceful gripping (eg, by occupational cotton pickers and rock climbers) are associated with hand OA.[23]

Neuromuscular control

In contrast to weight-bearing joints, such as the knee joint, the mechanical loading of the hand is largely generated by the contraction of intrinsic and extrinsic muscles. It is, therefore, of high clinical relevance to understand muscle activations during functional tasks. At a clinical level, it has been established that patients with hand OA have decreased submaximal force control, unrelated to pain levels.[26] However, little is known about intrinsic hand muscle activity during function tasks, partly due to the incompatibility of the intrinsic muscles with surface electromyography (EMG).[27,28] The existing studies that used fine-wire EMG mainly focused on the differences between changes in grip position or balancing precision grip tasks[29,30] and found activation patterns in healthy women to be highly subject-specific.[31]

The complex hand musculature also plays an important role in the stabilization of the joints in the hand. Compared to ligamentous structures, the musculature can generate substantially higher stabilizing forces. Besides grip strength and upper limb coordination, a distinct third domain of hand function is dexterity (Fig. 1).[29,32] This measure of neuromuscular control is the interaction between force generation at the fingertip level and directional control of the finger. Dexterity has been shown to decrease with age and is sensitive enough to discriminate between healthy controls and OA patients.[32]

Bony motion

To understand hand function and dysfunction, information about native hand motion is necessary. Defining carpal motion has proven to be difficult due to the small and superimposed arrangement of the bones. Bone kinematics have mostly been investigated using surface-based three-dimensional (3D) motion capture techniques such as high-speed video, optoelectronic, electromagnetic, or computed tomography (CT)-based systems.[33-36] None of these methods allows direct evaluation of 3D (meta)carpal bone movement as this would rely on a rigid connection between the markers and the bones. Direct tracking of bony motion is possible using biplane fluoroscopy. However, this requires highly specialized equipment and application to the hand is difficult due to the superimposed arrangement of the carpal bones.[37-40] Dynamic or 4D CT makes bone motion quantification possible in vivo, yet, the data flow management can be cumbersome and the temporal resolution is too limited to quantify dynamic instabilities like scaphoid snapping.[41,42] Thus, a profound understanding of the entire kinematic chain remains lacking.[43] Another challenge in quantifying in vivo carpal relationships is the change in articular contact and articular joint space with motion. Changes in articular contact size and pattern are valuable surrogates for joint loading since in vivo force measurements of the cartilage and subchondral bone is currently not technically possible.

In a clinical setting, joint stiffness and decreased range of motion are often reported symptoms in hand OA patients. An important wrist motion for activities of daily life is the dart thrower's motion.[44,45] This oblique wrist motion from radial deviation in extension towards ulnar deviation in flexion does not involve motion in the radiocarpal joint, thus making clinical measurement using a goniometer difficult.[45,46]

Ligaments

Previous research has suggested that ligament laxity may cause OA in the hand through a lack of stabilization of the joint.[6-9] Hormone-induced ligament laxity possibly explains the higher incidence of thumb base OA in women compared to men (12% for men vs 21% for women > 55 years old).[47] The reported sex-based differences between the mechanical properties of ligaments may not, however, be linked to differences in stability of the CMC joint.[48] On the other hand, research in other joints points towards the involvement of ligament dysfunction in the progression of OA. For example, in a study group of 20 patients who were clinically diagnosed with interphalangeal joint OA (chronic joint pain lasting >1 year), high-resolution magnetic resonance imaging scanning revealed structural changes of the interphalangeal collateral ligaments despite the absence of radiographic cartilage deformation.[31] A subsequent cadaver study underlined these findings. Magnetic resonance imaging scans as well as histological staining of the interphalangeal joints showed structural ligament changes without radiographic OA.[49,50]

In the knee, damage to the collateral ligaments, hypermobility of the knee, and varus or valgus malalignment due to ligament dysfunction are considered risk factors for knee OA.[51–53] Likewise, wrist dart thrower's motion exercises have been reported to stress the scapholunate (SL) ligament and create an SL gap in patients with SL dissociation.[54] Considering the above, a correlation between thumb ligament dysfunction and CMC joint disorders seems

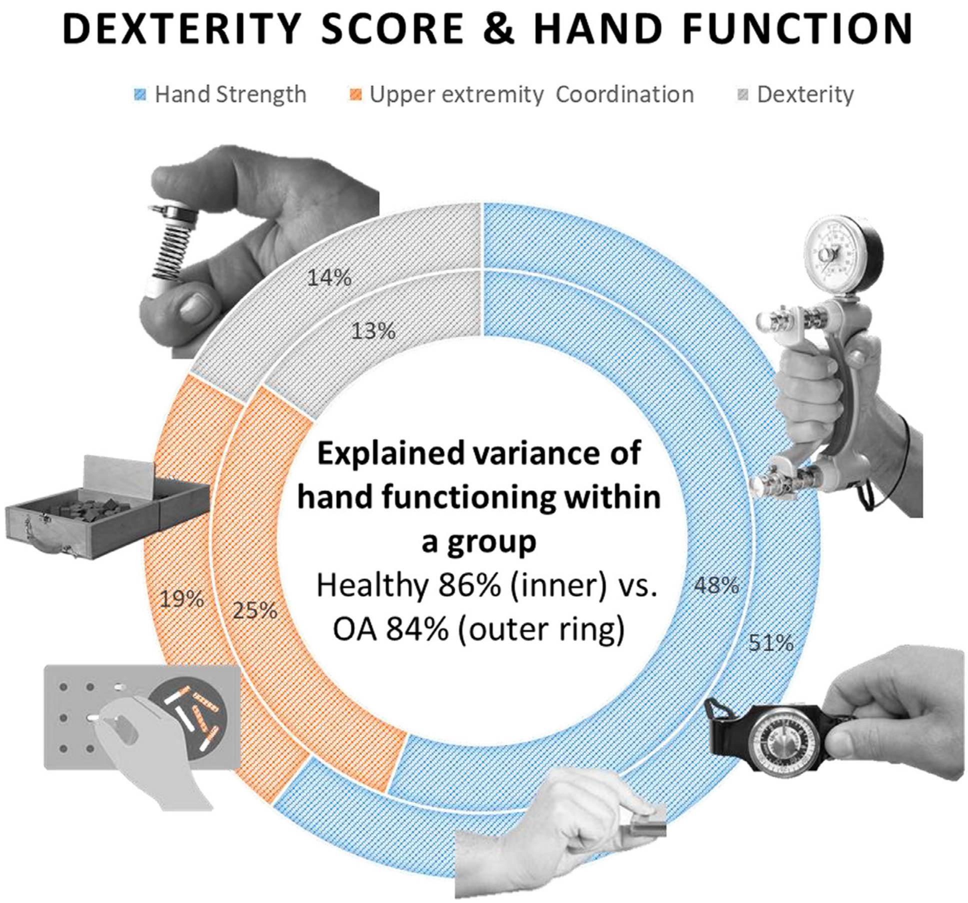

Fig. 1. Reducing the multidimensional nature of hand function to three domains. Dexterity differs from upper limb coordination (pegboard, block & box). The inner ring depicts the distribution over the different domains for healthy people. The outer ring depicts the distribution of thumb osteoarthritis patients. For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.

likely. If and how ligament dysfunction influences the onset or development of CMC OA, however, remains unknown.[55,56]

Biomechanics vs biology

Multiple factors contribute to the onset and development of OA, including systemic (ie genetics and obesity) and mechanical factors. Most research focuses on either one or the other. This strict delineation of the two factors hinders OA research. That OA is more than a simple wear and tear disease is not a novel concept[15]; nonetheless, the interest in how mechanical stress and strain influence the physiological processes has only recently been growing. To date, the interaction between biomechanical and biological factors in cartilage diseases has been primarily studied in the larger and more accessible knee and hip joints, while combined datasets of the thumb are virtually non-existent.

Articular cartilage consists of chondrocyte cells with an extracellular matrix filled with fluid. When the cartilage is compressed by mechanical loading, the cartilage deforms and water gets slowly exuded from the tissue.[57] Due to this biphasic nature, it takes time for the tissue to re-absorb the water and recover from the compression. Repeated loading of the cartilage creates an accumulation of strain. This physiological strain is expressed as the proportional decrease in cartilage thickness. It has been demonstrated that static loading or no loading of the cartilage has detrimental effects on protein synthesis and up-regulates gene expression of catabolic pathways.[58] Normal dynamic physiologic loading (a physiological strain of 5%-15%) can be anabolic and anti-inflammatory by an increased matrix synthesis and up-regulated gene expression of anticatabolic pathways.[59–61] High strains (50%-70%) can lead to necrosis and apoptosis.[62–65] The mechanical loading of chondrocyte cells triggers a myriad of direct (mechanotransduction[24]) and indirect (ie, hydrostatic pressure,[66] osmotic changes,[61] fluid flow,[24] biophysical signals that up or down-regulate gene expression of (anti) catabolic and inflammatory pathways. To understand how the complex interplay between biomechanics and mechanobiology is linked to the pathophysiology of hand OA, a more advanced integration of datasets is necessary.

Biomechanical underpinnings of hand therapy interventions

Our understanding of the role that muscles, ligaments, and connective tissue play in hand function continues to evolve. Nonoperative hand therapy modalities for OA are primarily aimed at maintaining a pain-free range of motion, functional strength, and joint stability, as well as avoiding fixed deformities and thumb web space contractures – all in an effort to maintain function. The goals of hand therapy in early hand OA disease are to lessen abnormal stressors on finger joints and ligaments to prevent deformities while maintaining functional strength. There are multiple ways to achieve this goal: for example, splinting, joint protection (JP), and exercise.

Orthotic interventions

Orthoses are the most used nonoperative treatment of persons with thumb and wrist OA. They provide rest and immobilization to reduce joint inflammation and pain.[67] A good-fitting orthosis design can lessen high forces on the joints during high-load activities to avoid or correct subluxation or deformity of the finger or thumb.[68,69]

In a recent biomechanical analysis of 4 types of thumb orthosis,[68] two-hand-based and two-hand wrist, CT images were used to measure in vivo kinematics of the radioscaphoid, scaphotrapeziotrapezoid (STT) and CMC joints during thumb movement. While all orthoses decreased the joint kinematics compared to free motion it was observed that it was not necessary to limit thumb movement to limit STT joint rotation. Using these findings, a clinician might consider only limiting wrist motion and not include the thumb in patients with isolated STT OA, suggesting enhanced patient comfort and therapy adherence.

Orthoses for boutonniere deformity have been given a biomechanical underpinning by Merritt and Jarrell in 2020.[70] Using cadavers, a relative motion flexion orthotic was designed to correct for chronic boutonniere deformity, a condition often seen in hand OA.[71] Positioning the injured digit in 15°-20° greater MP flexion relative to its adjacent digits alters the forces on the central slip of the extensor digitorum communis by relaxing the profundus and its lumbrical, while simultaneously increasing the extrinsic extensor and interphalangeal forces via the lateral slips. In cadaveric models, it has been shown that the RMF boutonniere orthosis design safely permits finger and wrist active motion without increased tension on the repaired or ruptured tendon. A better understanding of the dynamic biomechanical relationship between the fingers' extrinsic and intrinsic extensor mechanism was crucial to the design of an orthosis that would allow for early motion while allowing the extensor digitorum communis to heal.

Understanding the biomechanics of the joints and tissue being splinted can help the therapist find a balance between comfort, movement limitations, and the ability to safely perform activities when using orthotic devices to treat their patients' hand and thumb OA.

JP

JP is a self-management intervention designed to assist people with hand arthritis to improve activities of daily living . JP programs (JPP) include education in altering work habits, use of proper joint and body mechanics, use of assistive devices and orthotics, and modifying functional performance. This intervention was originally developed for patients with rheumatoid arthritis[72,73] and later adopted in people with hand OA.[74] In many studies, the JP program is integrated with hand flexibility and strength exercises, so the effect of JP alone is difficult to evaluate. In general studies of JP interventions and programs have been limited with most reporting low-to-moderate quality evidence related to pain and function with few evaluating biomechanical outcomes.[75–78]

A few key biomechanical principles utilized by most JPP are worth noting. To provide a pain-free range of motion and avoid deforming forces, tasks using key pinch are typically adapted to use a different type of grip thus avoiding the strong force of the ADD muscle.[79] This can be accomplished by using larger joints to complete the task, adaptation of the task, or the use of adaptive equipment. Adaptive equipment also allows for the completion of occupational activities that otherwise would be difficult to perform given the decreased ROM, dexterity and strength, and significant pain common in later hand OA.[76] One key concept is the use of large grips or handles on work and self-care implements to decrease the force exerted to perform a task. While research on ergonomics and optimal tool handle size using biomechanical principles exists,[80] most studies are performed within healthy populations and may be of limited utility when evaluating proper grip size in a patient population with painful joints, and decreased strength and ROM. Too large of a diameter object might load the osteoarthritic thumb joint abnormally in a similar way to a web space abduction contracture.[81] The lack of muscular stability combined with a completely slack dorsal radial ligament might not be able to prevent the palmar tilting of MC1 during cylindrical grasping.[82,83] By contrast, pinching or opening a jar does not require the same degree of thumb abduction. While there is limited mechanistic research in this area, Tanashi et al. have recently demonstrated that the use of adaptive equipment (e.g., button aids, built-up keys, lever-style knobs) and modified approaches (e.g., using larger proximal surfaces and joints) reduce the kinematic demands (i.e., flexion and extension) of arthritic hand joints.[84]

Another principle of JP is to reduce the effort and force needed to complete the task. Nunes and colleagues demonstrated that patients with hand OA patients apply more excessive grip forces than control subjects when gripping and lifting an object.[85] As the weight of an object goes up, so too does the amount of force required to grasp and lift that object. Using biomechanical principles specific to hand and thumb OA when making adaptations to activities of daily living tasks a therapist might make sure that the adaptation of the task allows the thumb to stay in 30° of metacarpophalangeal (MP) flexion, that the adaptive materials are lightweight and use a material with a sufficient coefficient of friction to lessen the grip forces needed. The principle of enhancing the coefficient is friction is supported by the work of McGee and Mathiowetz who report that use of nonskid materials, when combined with the use of the left hand, reduces the hand forces required to open a sealed jar while also improving the hand's torque generating capacity in women with hand OA.[77,86] While JP programs are based on and supported by biomechanical principles and evidence, additional scientific proof as to their efficacy in preventing further joint degradation in hand and thumb OA is needed.

Exercise

Biomechanical changes have been long implicated in the pathogenesis of OA.[87] The goal of exercise within hand OA is to maintain functional strength, decrease pain, increase function, and potentially decrease pathologic forces and misalignment of the joints.[74,88,89] While the European Alliance of Associations for Rheumatology and the American College of Rheumatology recommend exercise as an important therapeutic intervention in hand and thumb OA, there is little known about the most effective dosage of exercise and robust studies on its efficacy are limited.[90]

There is moderate evidence that strength and upper limb coordination training improve pain, grip, and pinch strength, and self-reported disability.[91,92] However most studies on this subject suffer from low statistical power, a lack of a control group, do not report baseline values, use outcome measures with a strong floor effect, or do not report within-group changes postintervention.[93] Recent studies demonstrated more robust study designs and seem to yield useful, yet nuanced results. The prospective study from Tsehaie et al shows that at least a third of the 809 thumbs OA patients involved benefited from a combined orthotic intervention + strength + range of motion treatment.[94] Research by Wouters et al, Tveter and colleagues, and a lower-quality evidence retrospective study by Johnson et al. also report favorable outcomes on pain, grip strength, and hand function using a combined treatment for thumb base OA.[88,94,95] Exercise with the goal to change the biomechanics of a joint is not novel but has regained traction.[96,97] Using biomechanical principles to create a training program that increases dynamic thumb stability, such as done by McVeigh and team, breaks new ground in a promising way that warrants further research driven by hand therapists.[91]

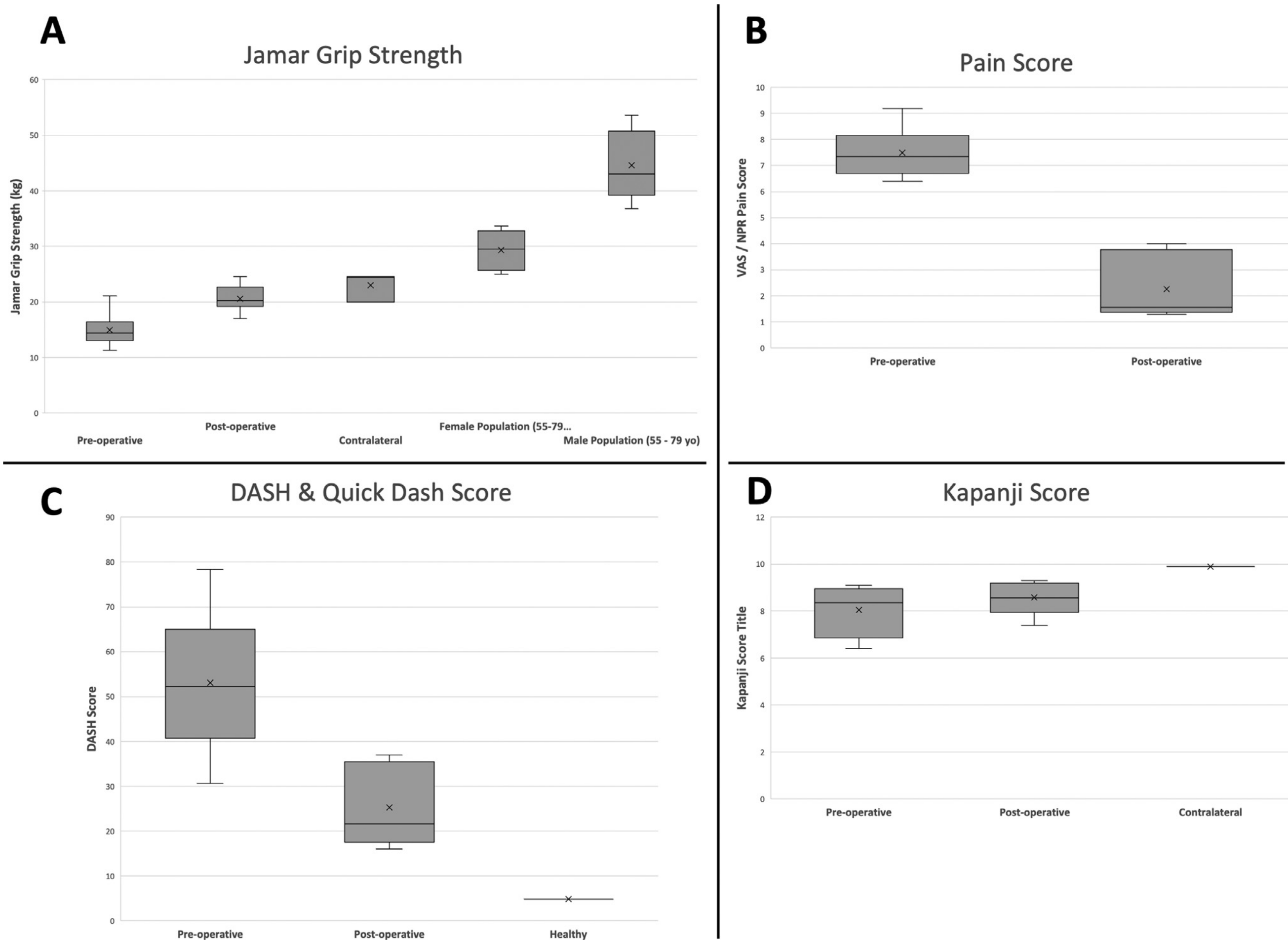

Fig. 2. Pooled data comparing pretrapeziectomy, > 12 months post-trapeziectomy, contralateral, and age-matched population data ($N = 350$) for Jamar grip strength: $N = 467$ (A), Visual Analogue Pain score: $N = 213$ (B), DASH/Quick DASH upper extremity functioning questionnaire: $N = 464$ (C), and Kapandji Score: $N =$. 116 (D), DASH score for healthy controls was set at the lowest score (0) + 1 minimal important clinical difference level.

Treating joint laxity in CMC OA patients has been a focus of early therapeutic exercise intervention. Joint laxity decreases joint congruency with subsequent high point-loading and cartilaginous degradation.[98] Significant changes in proprioception and neuromuscular control of the thumb occur early in the disease process adding to the instability of the joint.[32,99-101,26 102-104] The weakening of ligaments and muscles allows the stronger adductor pollicis (ADD) as well as the abductor pollicis longus to destabilize the CMC joint and increases the amount of dorsal radial translation of the metacarpal base.[82,105] This would add additional stress to the surrounding tissue and can lead to a stretching of the extensor pollicis brevis and a volar displacement of the EPL tendon forcing the MP joint into flexion, secondarily causing the interphalangeal (IP) joint to hyperextend and the thumb to collapse. In vivo and cadaveric studies have shown that simulated activation of the first dorsal interosseous (FDI) and OP act to decrease radiologic CMC subluxation.[106,107] Morbagha et al also noted that isometric loading of the FDI produced the least amount of dorsoradial translation of the thumb metacarpal base and abductor pollicis longus was found to be a prime destabilizer.[105] Moulton and colleagues noted in their cadaveric study that 30° of MP flexion moves the contact force more dorsally and unloads the area of greatest cartilage degradation on the volar articular surface.[108] These findings would support using a neurodynamic mobilization approach to thumb exercises in the direction of CMC abduction and opposition as well as FDI strengthening. A similar cadaveric study by Esplugas and colleagues suggest that proprioceptive training of the mid-carpal pronator muscles might stabilize the ulnar side of the wrist, thereby preventing scaphoid collapse.[16] A good example of one of these types of exercises would be isometric strengthening in the C-position. This allows for the flexion of the MP and the strengthening of the abductor pollicis brevis and OPP. There is some emerging evidence to support proprioceptive training as an adjunct to thumb CMC stability exercises where pain and joint position sense outcomes are enhanced by the addition of conscious proprioception training.[109]

There are many approaches to using exercise with patients with hand and thumb OA that a therapist can choose from. Until more comprehensive scientific data supports the use of one approach over another, the hand therapist can use biomechanics to better understand what forces drive deformity to design safe exercise programs to maintain strength and muscular balance, especially in early-stage OA.

Challenges and future opportunities in hand therapy

Accessibility and reimbursement

The concepts of hand therapy for hand OA patients are well established. However, widespread adoption is hindered by multiple barriers. In addition to the non-pharmacological treatment gap,[110] we believe there are two main factors that compound the problem:

1) limited understanding of the physiological underpinning of hand exercise, and 2) limited access to supervised therapy (including the availability of services and limited reimbursement)[111] These limitations contribute to the additional challenge of poor adherence to home exercise programs.[112]

Future hand therapy research should aim to address these barriers by establishing and quantifying the physiological changes created with targeted hand exercise. This will provide biological evidence of efficacy and a rationale for implementation and reimbursement. Additionally, identifying a change in clinical and physiologic measurements in symptomatic subjects will lay the groundwork for early diagnosis, early intervention, and personalized treatment. Secondly, improving home exercise adherence by remote patient monitoring in an incentivized environment with feedback and interactivity will increase therapy adherence, enable progress tracking, and its documented efficacy will simultaneously increase reimbursement, drive down the overall cost of hand therapy, and might incentivizes earlier referrals to hand therapy rather than a late referral to orthopedics after the disease has progressed to later stages and conservative treatment can be less effective.[95]

Prehab for surgical hand OA patients

While not all patients with CMC OA will need it, surgery may be required. When this decision has been reached, "prehab" might enhance surgical outcomes. Increased access to effective hand therapy across the spectrum of OA disease will expand clinical applications. Compared to physical therapy for large joints, hand therapy as a prehab tool is underutilized. Joint proprioception, strengthening, and functional training prior to surgery is a well-established practices for a plethora of surgeries.[113-115] Yet, such an approach appears to be limited to, non-existent in the hand therapy space.

CMC OA and the common surgical treatment, trapeziectomy is a prime example of a paucity of hand therapy prehab treatment options. The primary driver of the clinical decision to proceed to surgery is self-reported pain. Nonoperative treatment is often used to alleviate pain and postpone surgery. These patients demonstrate under usage of their painful hand, thereby triggering a downward spiral of further weakening and under usage. Unsurprisingly, post-trapeziectomy patients are mostly pain-free but report loss of grip strength. When pooling data from studies that compared pre- and postsurgery functioning and compare this to age-matched reference groups, a similar picture arises (details in Tables 1-5 in the Supplementary Materials). Grip strength is substantially lower postoperatively compared to their healthy cohorts (Fig. 2A), while physical functioning as reported by QuickDASH (Fig. 2C), pain (Fig. 2B), or Kapandij score (Fig. 2D) shows a clear ceiling effect of the trapeziectomy surgery.[116-134] Naturally, this only speaks of patients who opted for surgery.

Despite not being a meta-analysis, improving upon trapeziectomy seems not measurable with either pain, Kapandji, or DASH scores. A focus on improving grip strength and the creation of more refined outcome measurements seems warranted. These data raise the question if a prehab course of muscular strengthening and neuromuscular reeducation might improve surgery outcomes for OA patients who had previously received and not responded to other conservative treatments. Trapeziectomy is a relatively safe and highly successful procedure. Postponing surgery as long as possible for surgical patients invariably means operating on a severely weakened hand, which might gain more from access to early, consistent, at-home hand therapy in the run-up to earlier surgery.[135]

Conclusion

Multiple factors are involved in the onset and development of OA in the hand. Comprehension of the biomechanics helps clinicians establish evidence-based best practices for orthotic interventions, exercise, and JPP. The effect and reach of hand therapy for OA patients can be expanded substantially when optimal intervention parameters are better understood and barriers to early referral, access, reimbursement, and adherence are addressed. Close and early collaboration between hand therapists and primary care, women's health, rheumatology, and hand surgery providers upon diagnosis and with hand surgeons pre and postoperatively, combined with the advancement of the science of hand therapy interventions appear to be a promising way forward**.** Through high-quality research, quantifying the physiological and clinical changes of targeted hand therapy will be possible. Thereby, laying the foundation for improved access and implementation and for demonstrating the professional worth of hand therapy to legislators and insurance companies.

Conflicts of interest

None.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jht.2022.11.007.

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  b case series
  c retrospective cohort
  d prospective cohort
2 The reoperation rate was approximately
  a 10%
  b 5%
  c 15%
  d 50%
3 The authors investigated
  a costs
  b reoperation rates
  c therapy utilization
  d all of the above
4 The most common reoperation procedure was
  a delayed secondary repair
  b re-repair
  c tenolysis
  d Hunter rod and tendon graft
5 Higher rates of reoperation were associated with higher number of therapy sessions
  a false
  b true

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