The Lumbricals Are Not the Workhorse of Digital Extension and Do Not Relax Their Own Antagonist

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That the lumbrical muscles are the workhorse of digital extension and that they can relax their own antagonist have been time-honored principles. However, we believe this dogma is incorrect and an oversimplification. We base our assertion on anatomy, innervation, and the notion that muscle architecture is the most important determinant of muscle function. Wang and colleagues proposed the lumbrical to be a sophisticated tension monitoring device. We elaborate on their well-supported thesis, further proposing that the lumbricals also function as a constant tension spring within the closed loop composed of the digital flexors and the extensor mechanism. *(J Hand Surg Am. 2021;46(3):232−235. Copyright © 2021 by the American Society for Surgery of the Hand. All rights reserved.)*

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The lumbrical muscles (from the Latin word *lumbricus*, meaning "earthworm") originate and insert in the hand and are consequently considered intrinsic hand muscles. It has long been dogma that the lumbrical muscles are the workhorse of digital extension and that they can relax their own antagonist.[1] We believe this dogma to be incorrect and an oversimplification. Our argument is based on anatomy, innervation, and the notion that muscle architecture is the most noteworthy determinant of muscle function.[2−7] Because reported combined physiological cross-sectional area (PCSA) of the lumbricals is only 0.33 cm^2 and thus could generate only about 7 N of force, it is almost inconceivable the lumbricals could overpower or relax their antagonists, the much more robust flexor digitorum profundus (FDP), which have a combined PCSA that is almost 25 times the lumbricals (7.92 cm^2).[6,8,9] In addition, given their relatively small extensor moment arms, these muscles cannot provide sufficient proximal interphalangeal (PIP) and distal interphalangeal (DIP) extension torque needed to be considered the workhorse of finger extension.

Wang and colleagues[2] proposed that the lumbrical is a sophisticated tension monitoring device. We would like to elaborate on their well-supported thesis and further propose that the lumbricals also function as a constant tension spring within the closed loop composed of the digital flexors and the extensor mechanism (Fig. 1).

ANATOMY, FUNCTION, AND INNERVATION

The lumbricals originate from the FDP of their respective fingers in the midpalm, pass volar to the transverse intermetacarpal ligaments, volar to the metacarpophalangeal (MCP) joints, and insert into the radial lateral bands of the extensor apparatus, which, in turn pass dorsal to the PIP joint axis.

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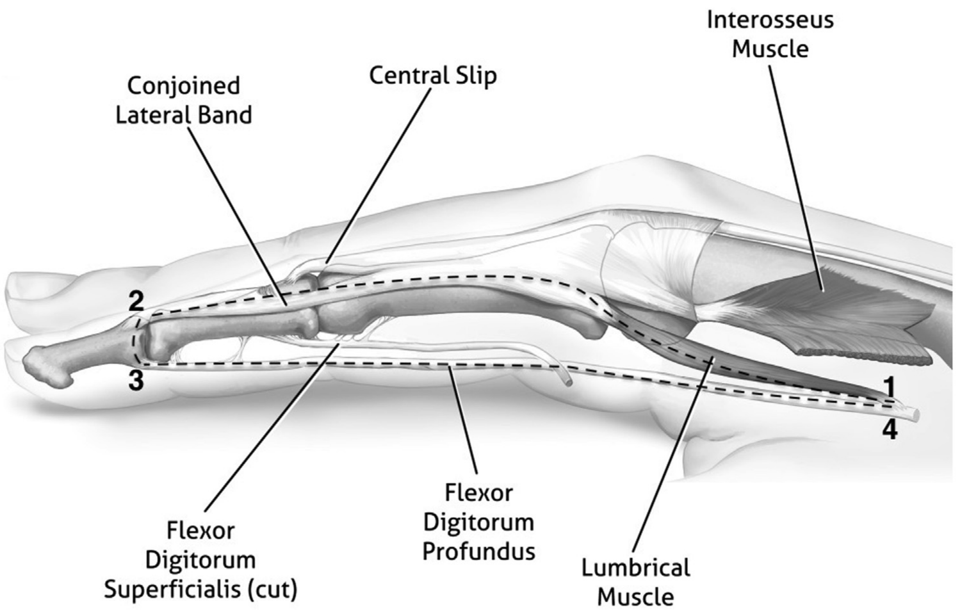

FIGURE 1: Pertinent features of the radial aspect of digital extensor and flexor mechanism. We propose that one function of the lumbrical is to act as a tensioning spring within a closed loop of the flexor and extensor mechanism, outlined by the dotted line.

Cadaver and electromyographic studies show that lumbrical muscles contribute both to MCP joint flexion and PIP and DIP joint extension.[10–12]

The lumbrical muscles are unique for 3 reasons. First, they are the only human muscles that arise and insert onto a tendon, rather than bone. Thus, their length is influenced by the concurrent actions and position of the FDP and the extensor mechanism. The index and middle finger lumbricals are unipennate and originate from the radial side of the FDP tendon, whereas the ring and little finger lumbrical muscles are bipennate and originate on the adjacent surfaces of the FDP tendons. Classic teaching is that the index and long finger lumbricals are innervated by the median nerve via common digital nerve branches and the ring and little finger lumbricals by the deep branch of the ulnar nerve. However, there are other common variations in which the median nerve innervates only the first lumbrical or the first 3 lumbricals, and in these cases, the remaining are innervated by the ulnar nerve. The first lumbrical is virtually always median and the fourth is always ulnar innervated. One study found that in 64% of cases, the third lumbrical was dually innervated.[13–15] A second unique property of the lumbrical muscles is their high muscle spindle density, the highest of all upper-extremity muscles, a characteristic of muscles involved in precise motor function, such as the tongue, extraocular muscles, and jaw muscles.[2,4] Muscle spindles provide critical afferent information required for refined proprioception.[2,4] Finally, in terms of architectural design, the lumbricals have relatively long fibers, which means that their fiber length-to-muscle ratio ranges from 0.85 to 0.90, the highest values reported for any human muscle.[16]

MUSCLE PROPERTIES

Skeletal muscle architecture is defined as the arrangement of muscle fibers relative to the long axis of force generation, and best predicts muscle function.[6,7,16] Among the 5 major parameters that define a muscle's architecture (fiber length, PCSA, pennation angle, mass, and muscle length), muscle functional properties are most influenced by PCSA and fiber length.[6] The PCSA is directly proportional to isometric force generation whereas muscle fiber length is directly proportional to excursion and contraction velocity.[6,7] Muscles with long fibers (such as the lumbricals) have broad length–tension curves. Because many sarcomeres are arranged in series, optimal sarcomere length for force generation for individual sarcomeres is maintained over a broader range of muscle length compared with muscles with short fibers (such as the interossei), which have narrow length tension curves (Fig. 2). Thus, from a muscle design perspective, the lumbricals are muscles designed to produce a relatively low constant force over a wide range whereas interossei produce relatively high force over a narrow range.

The lumbrical and interosseous muscles both function to flex the MCP joints and extend the interphalangeal joints. However, it has been determined that the lumbricals are only weak MCP joint flexors and PIP and DIP joint extensors compared with the interosseous muscles, which is predicted

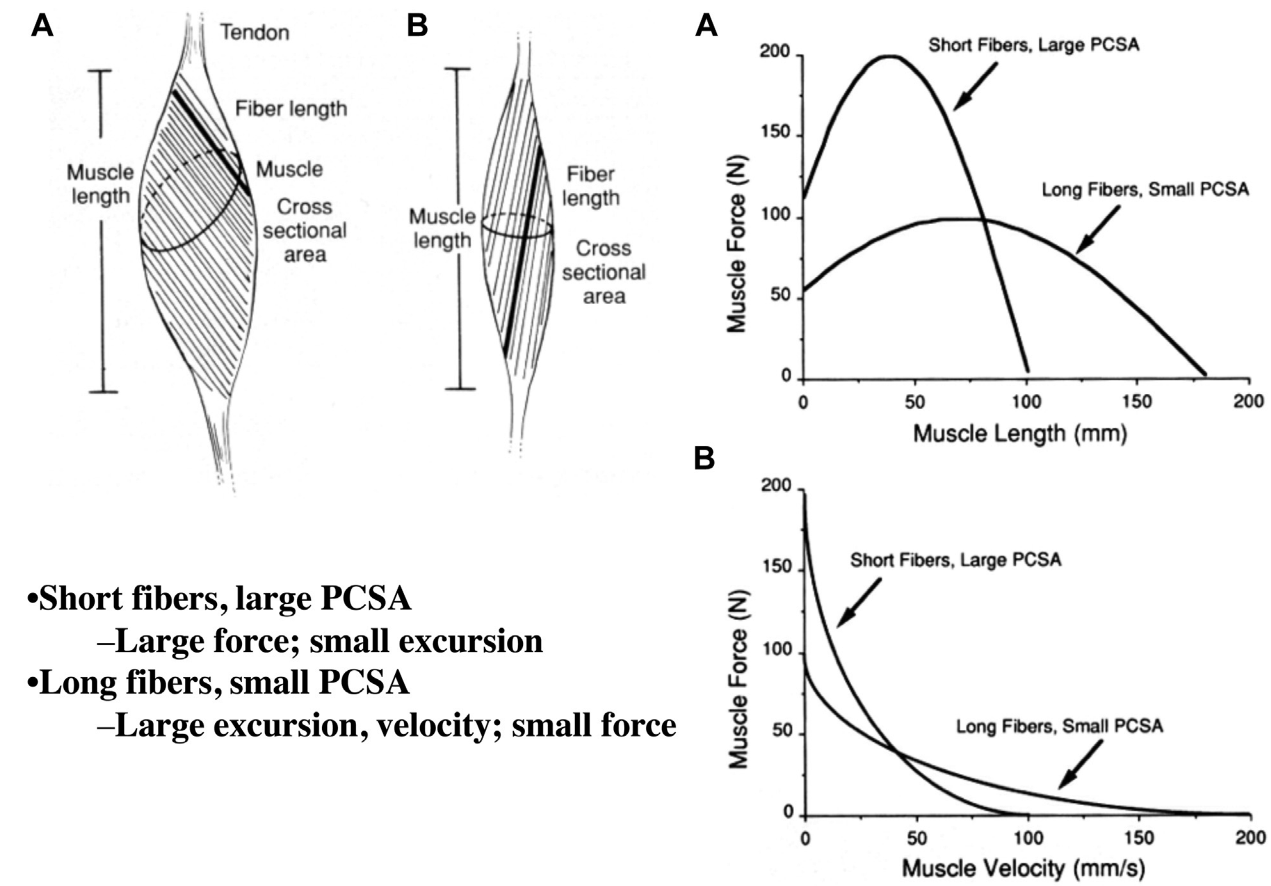

FIGURE 2: Schematics of muscles with different architecture. Muscle "A" has short fibers and a large PCSA. Muscle "B" has long fibers and a small PCSA. Graph "A" indicates that muscles with short fibers and large PCSA can generate high force but have short excursion and muscles with long fibers with small PCSA generate lower forces but have longer excursion. Graph "B" similarly compares these muscles highlighting that long fibered muscles have a higher contraction velocity compared to short fibered muscles.

based on our understanding of their respective muscle architectures.[8,17] The combined interossei have about 15 times the PCSA, and the digital extensors 10 times the PCSA of the lumbricals.[6,18] Furthermore, the FDP muscles combined have almost 25 times the PCSA of the lumbricals combined.[6,18] These data argue that the lumbricals have neither the force-generating capacity to be the workhorse of digital extension nor the ability to relax their antagonists.

As mentioned, the lumbrical muscles have the highest fiber length—muscle length ratios in the human body, with muscle fibers extending 85% to 90% of their muscle length compared with the interosseous muscles, which have muscle fibers that span only 41% to 52% of muscle length.[6] Lumbrical muscles are built for long excursion and high contraction velocity whereas interosseous muscles are built for high force generation and low excursion. Why do we have muscles that are architecturally so different and that have the same effects on the digital joints? We believe it is because they have differing purposes.

Fundamentally, fingers are made of 3 phalanges balanced atop each other, with the proximal phalanx functioning as an intercalated segment between the metacarpals and the other phalanges. The proximal phalanx has no tendon attachments; its position is influenced by muscle—tendon forces imposed on adjacent bones, transmitted to the proximal phalanx indirectly via ligament attachments and joint surface stress. Ideally, the phalanges work in concert, positioning the finger in space with accurate, stable, and balanced movements capable of varying degrees of force and counterforce. To position a finger precisely in space in the sagittal plane, finger flexor and extensor forces must be balanced. We propose that one function of the lumbrical is to act as a tensioning spring within a closed loop of the flexor and extensor mechanism (Fig. 1). Specifically, as outlined by the dashed line in the figure, the loop starts proximally at the origin of the lumbrical on the FDP (Fig. 1, point 1). The dorsal part of the loop consists of the lumbrical and its distal extension as a part of the radial lateral band, the conjoined lateral band, and terminal tendon insertion into the distal phalanx (Fig. 1, point 2). The loop continues volarly as the insertion of the FDP on the distal phalanx (Fig. 1, point 3), and then proximally as the FDP joins the lumbrical origin (Fig. 1, point 4). We propose that the lumbrical functions as an active tensioning or length-setting system for the extensor mechanism, stabilizing digital position similar to a guy line on a tall tower. The lumbrical guy line balances tension in the extensor mechanism despite varying amounts of digital flexion. The design of the lumbrical allows it to function with high contraction velocity, near its optimal sarcomere length for maximal force generation at variable muscle lengths owing to its long fibers (and thus, its broad length−tension curve). Wang et al[2] posed an elegant evidence-based theory in which, with its high spindle innervation density, the lumbrical's purpose was to serve as a highly specialized tension monitoring device. We further theorize that the lumbricals serve as a spring in a closed loop, facilitating collaboration of the intrinsic and extrinsic digital flexors and extensors, balancing and stabilizing the intercalary segments made of the 3 digital phalanges. This spring role of the lumbrical, along with the features of sophisticated proprioception, facilitates fine selectively and variably forceful digital motor control.[2,4] The theory of the proprioceptive and tensioning role of the lumbricals could be tested by having subjects perform fine motor tasks before and after selective blocks to the lumbricals. Willing subjects would be required to perform isolated lumbrical blocks accurately, selectively, and reversibly.

Some clinical conditions provide examples of the consequences of breaking this well-designed closed loop. Detachment of the FDP from its insertion from tendon injury or DIP amputation can result in paradoxical extension. In these scenarios, because the FDP no longer is attached to its insertion in the terminal phalanx, instead of digital flexion, when the FDP contracts, force is transmitted through the lumbrical origin to the radial lateral band effecting PIP extension. If the FDP is reconstructed with a tendon graft that is too loose, paradoxical extension can also occur. Theoretically, loose grafts could be compensated to some degree by the lumbrical, owing to its long fiber length, but at some point, the muscle will not have enough active range and paradoxical extension will result. It is known that lumbrical origin release can correct this problem and allow better digital flexion.[19] Furthermore, the lumbrical has been used as a muscle flap for median nerve coverage without incurring a major deficit.[20] These points dispute the importance of the lumbricals. We would argue that for routine or gross manual tasks, it is possible to function without lumbricals, but perhaps not play a violin or perform other precise digital tasks. Further work on lumbrical function is needed.

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