Identification of a third belly of the opponens pollicis muscle

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SUMMARY

We have recently reported that fatty infiltration (FI) of the opponens pollicis (OPP) muscle is a common finding in patients with thumb carpometacarpal joint (CMC) osteoarthritis (OA). This FI is found in a reproducibly focal area of the deep proximal OPP, which we have provisionally called the "the third belly", to distinguish it from the previously described superficial and deep bellies of the OPP. The purpose of this study was to describe the anatomic features of the OPP third belly in our dissections of 14 human cadaver hands, and in the histology of an adult hand and a fetal hand.

The OPP third belly was found in all 14 dissected hands. It is the deepest and most proximal part of the OPP and completely covers the palmar surface of the trapezium and the palmar CMC capsule, with independent innervation directly from the motor branch of the median nerve.

The OPP third belly location and structure suggest a possible function to stabilize the CMC joint, which can be affected by underlying OA. It can be identified with accuracy on clinical imaging. Further studies should elucidate its specific biomechanical role in CMC pathology.

Key words: Anatomy – Osteoarthritis – Photogrammetry – Ultrasound imaging – Histology

INTRODUCTION

The thumb is the only digit capable of opposition, a unique characteristic of the human hand. The opponens muscle (OPP) is principally responsible for this function (Bowland et al., 2025, Karakostis et al., 2021), and in addition contributes to stabilizing the thumb carpometacarpal joint (CMC) by the screw home torque opposition mechanism that transforms the lax and incongruent joint at rest to a congruent stable joint in the final phase of opposition, which is essential for power pinch and grasp (Edmunds, 2006, Edmunds, 2011). The OPP muscle provides a dynamic stabilization of the CMC joint and the loss of this function can lead to joint instability, which can lead to OA (Norose et al., 2022).

We have recently identified fatty infiltration (FI) of the OPP muscle as a common finding in patients with CMC OA (El Hor et al., 2026). The FI distribu-

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Submitted: May 20, 2026 **Accepted:** May 26, 2026

https://doi.org/10.52083/FXFE7102

tion was limited to the deep part of the OPP muscle, and it could be organized in two specific locations: distal and medial to the first metacarpal diaphysis (Fig. 1a) or proximal and palmar to the CMC joint (Fig. 1b). The superficial part of the OPP muscle, also distal and medial to the metacarpal diaphysis, was always separate and distinct from the deep OPP, and without any FI.

To explain this OPP FI distribution, we hypothesized that the OPP muscle is organized in three distinct bellies: one superficial and two deeper bellies, with the third and deepest belly overlying the CMC capsule, distal trapezium and metacarpal base.

Despite the importance of the OPP muscle to human hand function, its detailed description in the literature is scant. An OPP two-bellied organization (superficial and deep) was previously described by Poirier and Charpy (1896) and Le Double (1897), a description reproduced in one recent article (Van Sint Jan and Rooze, 1994); but the OPP muscle is still described as a one-belly muscle in recent literature and in standard textbooks (Gupta and Michelsen-Jost, 2012; Standring et al., 2015; Hollinshead, 1976; Kaplan and Spinner, 1984; Tountas and Bergman, 1993).

The purpose of this study was: 1) to investigate the presence of an OPP third belly in cadaveric hands; 2) to describe accurately its attachments to the trapezium and first metacarpal; and 3) to investigate its independent character within the OPP.

MATERIAL AND METHODS

Cadaveric study

Fourteen frozen cadaveric hands (7 male, average age at death= 83 years) were obtained from the Willed Body Program of the Mayo Clinic Department of Clinical Anatomy. Each specimen was carefully dissected under 3.5X loupe magnification by a hand surgeon and a clinical anatomist. After specimen use was completed, each specimen was cremated, and the ashes returned to the donor's family. The abductor pollicis brevis (APB) and the flexor pollicis brevis (FPB) were reflected proximally to access to the OPP muscle. Each OPP muscle belly, its slip connection with the abductor pollicis longus (APL) and its innervation were photographed using a high-resolution digital camera (Canon EOS 5D and Nikon Z7) to characterize the gross anatomy. Then the bony insertion on the trapezium and on the first metacarpal were identified and described.

Histological Study

Adult hand histological analysis

In one additional hand, we performed a histological study using Hematoxylin and Eosin staining (H&E). The thumb with the thenar eminence was studied in 10 micrometers sections from the wrist to the tip of the thumb proximal phalanx. The specimen was selected after ultrasound scanning to ensure that the thenar eminence was not altered by any pathological process and specifically to confirm the absence of CMC OA and FI of the OPP muscle.

Fetal histological analysis

One hand from an 11-cm fetus (approximately 16 weeks gestational age) was studied. The specimen was part of a histological archive of human fetal and embryo anatomy collected by Prof. Johann Landsmeer and preserved at Leiden University, in the Netherlands. The hand was cut in 10-micron sections and sequential sections were stained with H&E and mounted on glass slides.

Visible Human Project (VHP)

In the VHP (Ackerman, 1999, 2025), the orientation of the hand was oblique to the axis of the VHP transverse sections, and this positioning of the hand, combined with the small proportion of the cross-section of the hand in the whole body VHP sectional image (the hands were positioned anterior to the abdomen), resulted in a limited number of pixels in the hand portion of the VHP images compared to the rest of the body. We extracted and processed the hand images from the original VHP photographic cross-sectional images. The hand images were stacked in a three-dimensional unit and rotated so that virtual transverse sections could be digitally created from the actual oblique sections available through the VHP.

The organization of the OPP muscle and its insertions were further analyzed in these images.

Digitizing OPP insertions and 3D model

In two additional cadaveric hands, a high-resolution CT photon-counting scan was performed, and two different techniques were used to create a 3D model of the OPP bony insertions:

1. Photogrammetry: the CT scan was performed prior to the dissection, after which the bony insertions of each OPP belly was outlined using a different colored dye, and then the insertions were digitized by a 5-camera Med Creator® scanner (Med Reality, Chicago, IL) using photogrammetry technology to create a 3D model (Fig. 7). 360 photos were taken simultaneously by 5 Canon cameras (EOS 2000D®). The detailed photogrammetry technique used has been described in a previous study (Oliveira et al., 2024).

2. Navigation system: after dissecting the hand, 13 beads, each 2mm in diameter, were glued around the first metacarpal bone. These fixation points were placed so as not to interfere with the insertions of the OPP muscle and to ensure continuous exposure of each OPP muscle belly. The bony insertions of each OPP belly were then digitized. Care was taken to maintain the hand's position throughout this process. To secure the hand and fingers, clay was applied to the dorsal side of each hand, attaching them to an acrylic platform. At this point, the cadaveric hands were scanned (CT) and the images were sent to our institution's Biomedical Imaging Resource (BIR) to load into the navigation system. The cadaver hands, still fixed to the acrylic plate, were brought to the BIR and positioned on an operating table. A Medtronic Stealth Station TREON plus was used with a passive planar blunt probe to register the 13 beads in digital space. These physical beads were utilized to align the hand's scan, allowing the probe's location to be accurately reproduced on the digital model. Once calibrated, the probe's position was accurate to within 1 mm. After calibration, the OPP insertions and anatomical landmarks were recorded as digital coordinates. These points were then transferred to the digital scan of the hand, serving as visual markers on the 3D model.

RESULTS

Cadaveric study

A separate third belly muscle was found in all 14 cadaveric hands, in each with the same characteristics: it is a thin belly, deep to the superficial OPP belly and situated in the same plane as the deep second belly but proximal to it. The third belly originates from the flexor retinaculum, the trapezium ridge, the palmar trapezium facet and the CMC capsule and inserts on the base of the thumb metacarpal just distal to the anterior oblique ligament insertion (Fig. 2).

The third belly receives a dedicated proper nerve from the motor branch of the median nerve (Fig. 3) and receives on its radial border of its deep surface a constant slip from the APL tendon.

The second or deep belly originates from the flexor retinaculum and inserts on the lateral shaft of the first metacarpal, deep to the first belly. Importantly, the fiber orientation of the third belly differs from that of the second belly, being more transversely oriented, and the fibers are much shorter, bridging the CMC but not extending further distally.

The first or superficial belly is superficial to the second and third bellies and its distal insertion is on the lateral ridge of the first metacarpal.

We have found the first metacarpal head to be free from any OPP insertion.

Histological study

An independent third belly was identified on the axial slides of the adult hand (Fig. 4) and on the fetal hand (Fig. 5). The results were similar to those of the dissected specimens: a third OPP belly insertion on the flexor retinaculum, trapezium ridge, a large insertion on the palmar trapezium surface lateral to its ridge, a capsular insertion and a connection with the APL tendon.

Visible Human Project

On the sagittal sections, we identified the third OPP belly with its short fibers running from the palmar trapezium facet and CMC capsule to the proximal first metacarpal (Fig. 6).

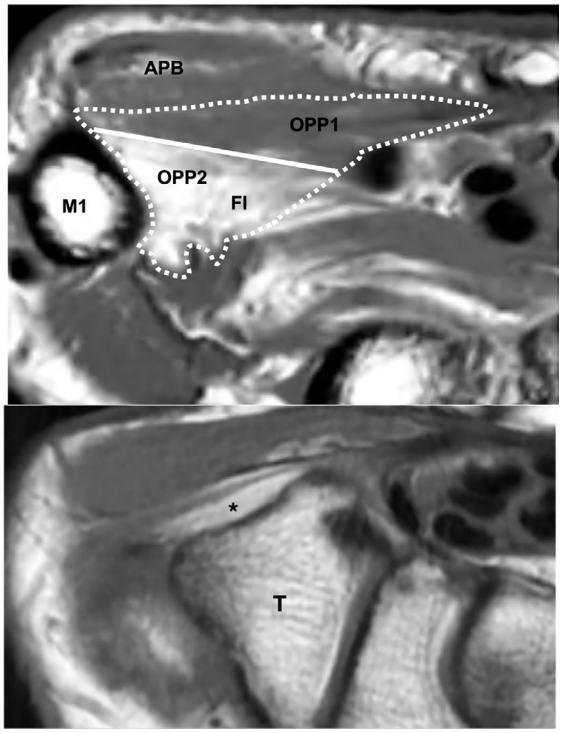

Fig. 1.- Axial T1 images at the level of the proximal first metacarpal diaphysis (M1) of the right-hand MRI in patient with T.CMC osteoarthritis. 1A(above): This demonstrates fatty infiltration (FI) to the deep part of the opponens muscle (OPP2). The superficial part (OPP1) is normal, as was the more proximal deep portion, not shown. (APB): abductor pollicis brevis. 1B(below): More proximal axial T1 image at the level of the Trapezium (T) in a different patient with CMC osteoarthritis. This demonstrates FI a discrete portion of the deep part of the opponens muscle (Asterisk), which we term the 'third' opponens belly.

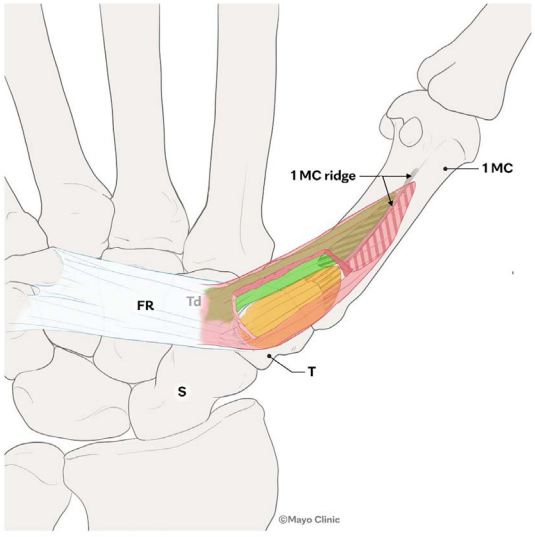

Fig. 2.- Drawing of the right hand (palmar view) to illustrate the three bellies of the OPP. There is a rectangular window in the superficial(first) belly(pink) to show the two deep bellies (second(green) and third(yellow)). The first and second bellies originate on the flexor retinaculum (FR) and insert radial/superficial and ulnar/deep to the first metacarpal (1 MC) ridge, respectively. The second belly has an additional origin from the palmar trapezium(T). The third belly has its origin primarily from the trapezium, and inserts on the base of the first metacarpal. S: scaphoid. Td: trapezoid (figure copyright Mayo Clinic).

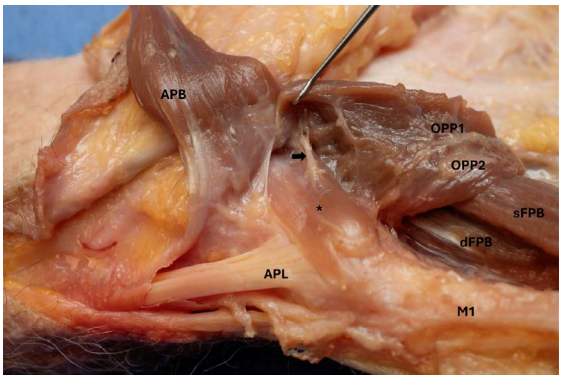

Fig. 3.- Palmar view of a right-hand dissection. The abductor pollicis brevis muscle (APB) is reflected proximally. The superficial opponens (OPP1) and the second (deep) belly (OPP2) are reflected on the ulnar side of the OPP third belly (asterisk*). A proper innervation (arrow) to the third belly originating from the motor branch of the median nerve is identified. The abductor pollicis longus (APL) tendon is inserted on the first metacarpal base (M 1) and shares fibers with the third belly. sFPB: superficial flexor pollicis brevis; dFPB: deep flexor pollicis brevis.

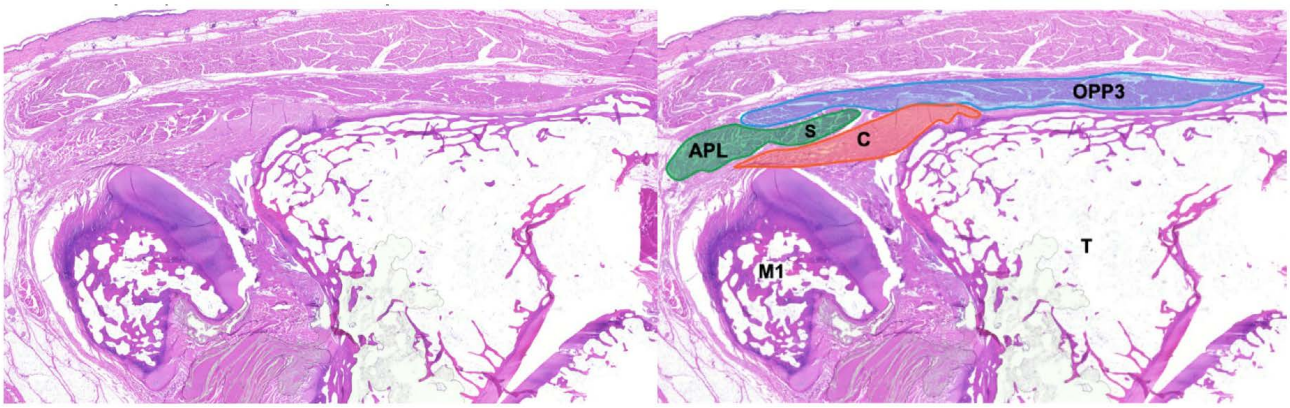

Fig. 4.- Axial histology section of a right adult hand. The third opponens (OPP3) is inserted on a large palmar surface of the trapezium (T). The OPP3 is attached to the T.CMC capsule (C) and receives a slip (S) from the abductor pollicis longus tendon (APL). (M1): first metacarpal.

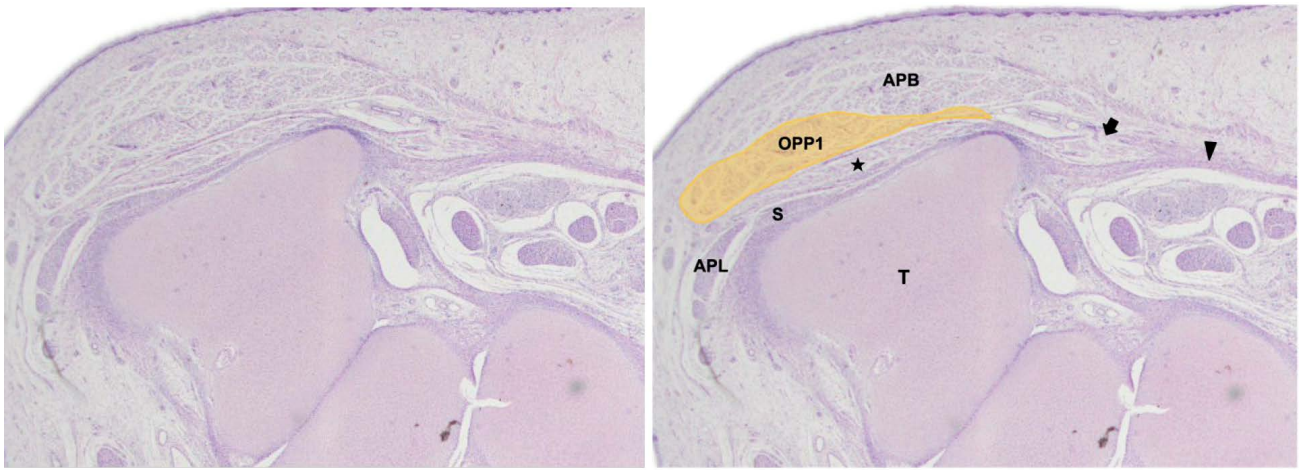

Fig. 5.- Axial histology section of a right embryonic hand (Landsmeer collection). Three OPP distinct bellies are identified: The superficial opponens (OPP1), the second belly (arrow) with its insertion on the flexor retinaculum (arrowhead) and the third belly (star*) with large insertion of the palmar trapezium facet (T). (APB): abductor pollicis brevis. A slip (S) from the abductor pollicis longus (APL) is visible.

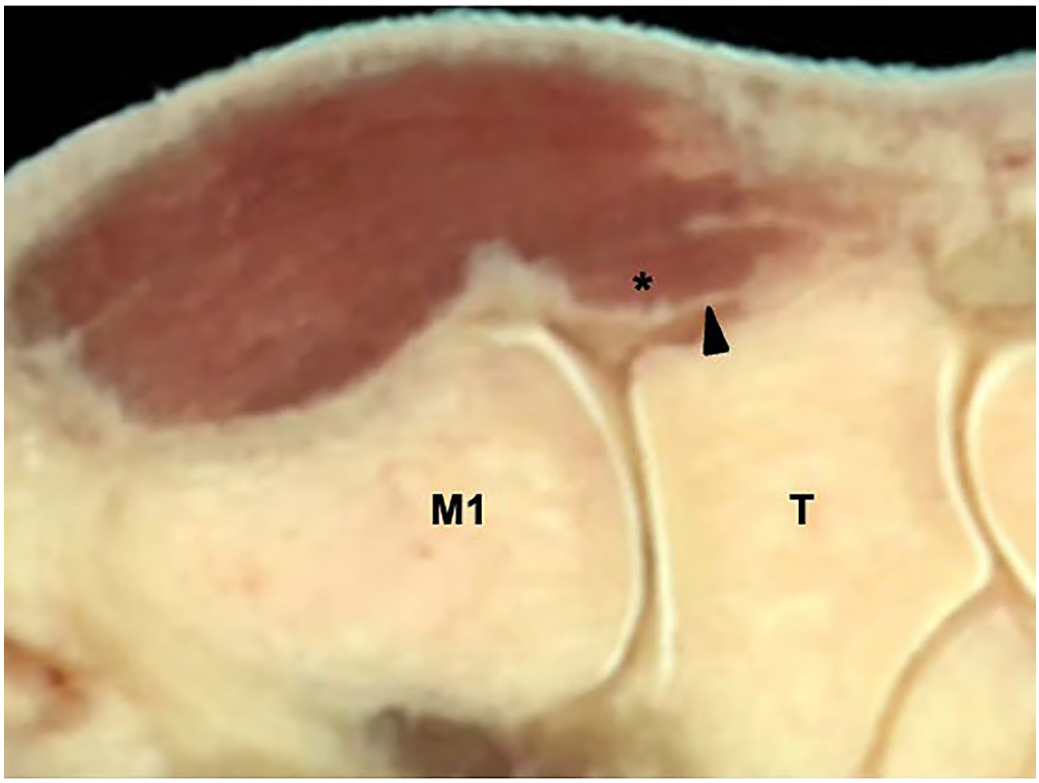

Fig. 6.- Sagittal section of the right thumb from the Visible Human Project (https://www.nlm.nih.gov/research/visible/visible human.html). The third belly is identified (asterisk*) with its origin on the trapezium (T) and on the T.CMC capsule (arrowhead). We can identify its short fibers with its distal insertion on the first metacarpal (M1).

3D Model of OPP muscle

The OPP osseous insertions were digitized for each belly (Figs. 7-8). The results were comparable to the anatomical and histology studies. Each OPP belly has a specific insertion area. The third belly has an independent belly insertion with the smallest area.

DISCUSSION

The OPP muscle is responsible for an important and specific function of the human hand, thumb opposition (Bay et al., 1998; Bowland et al., 2025; Karakostis et al., 2018; 2021). Understanding the anatomy of this muscle and its biomechanics is key to understanding a challenging condition that still not fully understood in its pathogenesis and therapeutic management, CMC OA.

Recently, we investigated 325 hand MRIs of patients with CMC OA and we identified OPP FI in 45% of them (El Hor et al., 2026). This FI was limited to the deep part of the muscle, in two distinct locations: proximal and palmar to the CMC joint or distal to the trapezium and medial to the first metacarpal diaphysis (Fig. 1). The superficial part of the OPP muscle was normal in all patients.

To explain this FI distribution, we hypothesized that the OPP muscle is organized in three distinct bellies: one superficial and two deep bellies, which is different from the literature description, where the OPP was either described as a two-belly muscle (Poirier and Charpy, 1896; Van Sint Jan and Rooze, 1994; Le Double, 1897), or as a one-belly muscle in most other literature (Gupta and Michelsen-Jost, 2012; Loss and Li, 2020; Norose et al., 2022; Okuno and Kasai, 1994) and in current anatomic textbooks (Hollinshead, 1982; Kaplan and Spinner, 1984; Standring et al., 2015; Tountas and Bergman, 1993).

In this study, we identified what we consider to be a three-belly organization of the OPP muscle in dissections of 14 cadaver hands, with supporting evidence from clinical imaging of 325 patients with FI of the OPP in cases of CMC OA. This third belly is a thin sheet of muscle fibers covering the CMC joint with its origins on the flexor retinaculum, the trapezium ridge, a large area of the palmar trapezium facet and on the CMC joint capsule

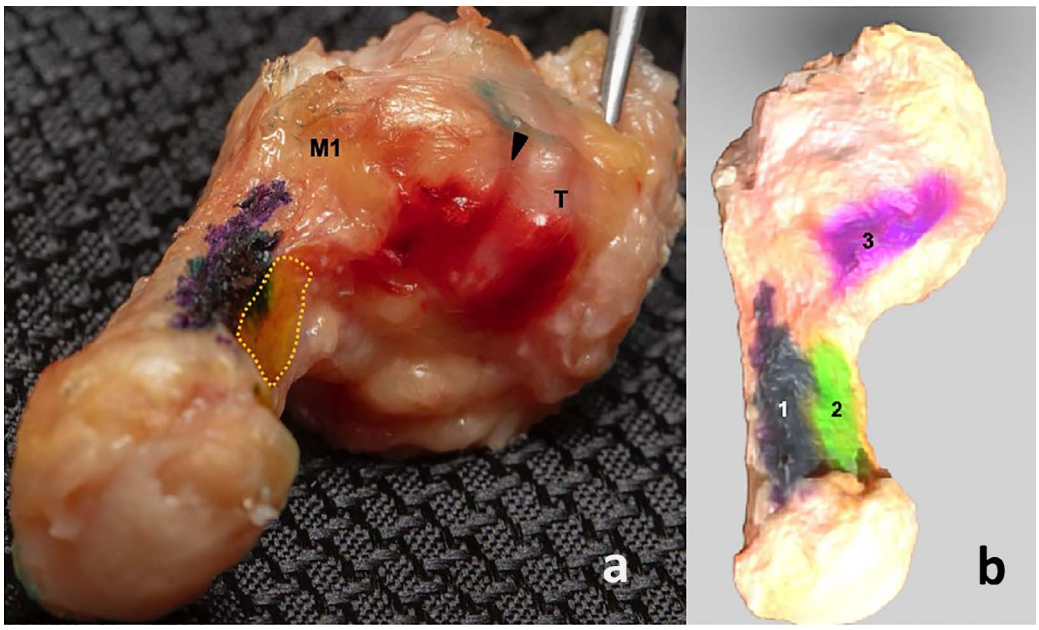

Fig. 7.- Identification of the osseus insertions of the OPP bellies in a cadaveric thumb. (a) Each OPP belly osseus insertion was outlined with a different color dye: dark blue for the superficial first belly, yellow for the second belly (outlined in dashed yellow for clarification) and red for the third belly. The third belly is covering the T.CMC joint (arrowhead). (T): trapezium. (M1): first metacarpal. (b) Creation of 3D model of the OPP osseus insertions using photogrammetry. Each opponens belly has a specific osseus insertion. Superficial first belly (1). Second belly (2). Third belly (3).

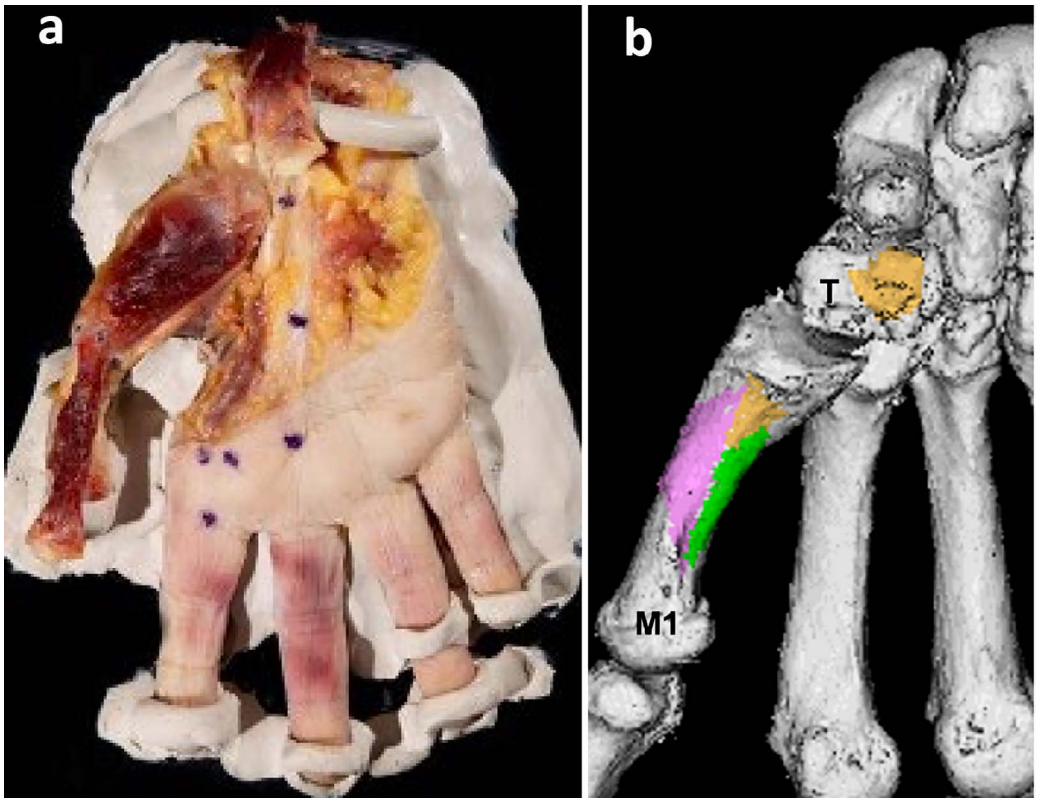

Fig. 8.- Creation of a 3D model of the OPP osseus insertions using a digital navigation system. (a) Hand dissected to expose the OPP muscle with placement of glass beads around the thumb (blue points). To avoid any digit or hand displacement, the thumb was fixed to the hand and all the hand was fixed by a clay modeled on its dorsal side and fixed to a large acrylic board during the CT scan, the dissection and the digitizing process. (b) A 3D reconstruction of the three opponens bellies osseus insertions. Each belly has its specific insertion: the third belly (yellow), the second belly (green) and the superficial belly (pink). The primary origin of the first and second bellies is to the flexor retinaculum rather than bone and is not shown. (T): trapezium, (M1): first metacarpal.

and possessing a fiber orientation different from that of the overlying OPP bellies.

We found this third belly regularly when using different modalities: by histological study in adult and in fetal hands; and by ultrasound, CT and MRI imaging, as well as by dissection in cadavers. The presence of the third belly as a distinct structure is enhanced on clinical imaging when it is replaced by FI in individuals affected by CMC OA (El Hor et al., 2026).

The results of this study provide a contrast to the description of the OPP from the literature, where the OPP is described as having a small, limited insertion on the trapezium ridge. We have found in all hands studied a large, albeit thin, third belly insertion on the palmar trapezium facet. The distal insertion of the third belly starts just distal to the anterior oblique ligament insertion, which it covers, and it extends to a proximal palmar and ulnar area of the first metacarpal epiphysis and metaphysis on the metacarpal beak. This distal insertion does not extend to the diaphysis, in contrast to the two more superficial bellies of the OPP.

The third belly has origins and insertions distinct from the other two OPP bellies. All three OPP bellies attach to the flexor retinaculum, but we can identify an additional, distinct origin for each belly. Understanding this organization of the OPP muscle helps explain the anatomy seen on clinical imaging such as US and MRI, and it also explains the focal distribution of FI inside the OPP muscle, which in our study of 747 consecutive clinical cases with and without FI or CMC OA (El Hor et al., 2026) was most commonly limited to the location of the third belly in the context of associated palmar CMC osteophytes secondary to CMC OA, with the more superficial bellies of the OPP remaining unaffected. When the third belly is affected, there is a focal area of FI palmar to the trapezium (Fig. 10). In patients with larger osteophytes, there is fatty infiltration in the ulnar region of the first metacarpal diaphysis (Fig. 1).

The third belly can be identified on ultrasound (Fig. 9) and MRI, and therefore clinical imaging of the third belly could become part of a routine clinical hand investigation, for example as an early marker of a biological response to CMC OA, which could possibly have some prognostic significance.

Our dissection study revealed a discrete innervation to the third belly, arising from the motor branch of the median (MBMN) nerve, which, again, along with the fiber length and orientation differences from the more superficial and distal portions of the OPP, is supporting evidence that the third belly is a true, separate functional subunit of the OPP.

We found that the APL tendon gives a tendinous slip to the third belly, which continues its path

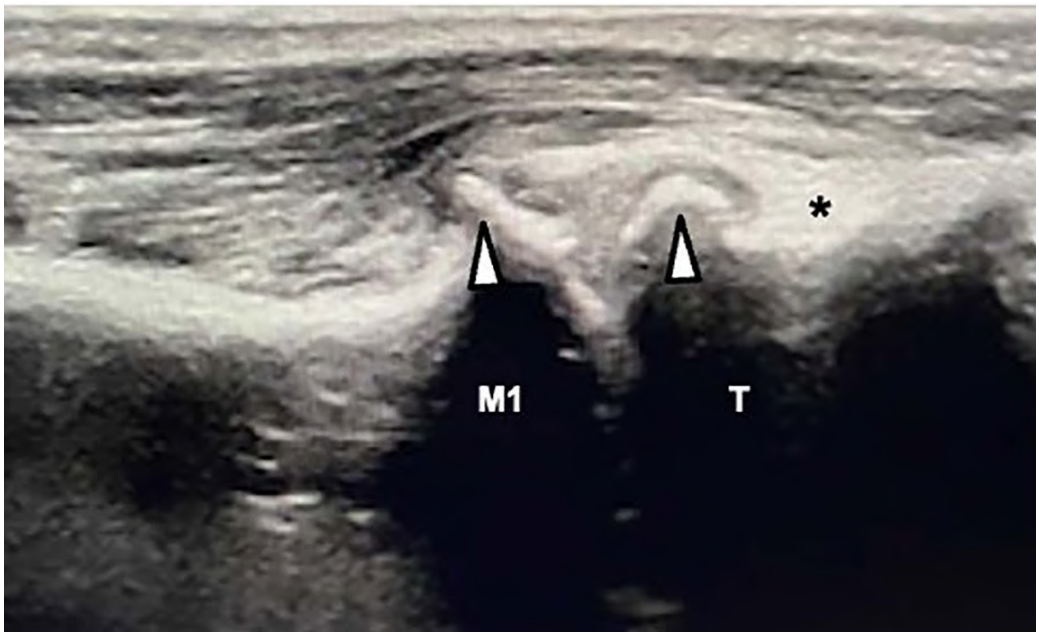

Fig. 9.- Ultrasound sagittal view in a volunteer with CMC osteoarthritis showing a fatty infiltration of the OPP third belly {asterisk*) in its location palmar to the trapezium (T). Osteophytes of the T.CMC joint {arrowhead). {M1): first metacarpal.

inside the muscle on its radial side that is visible on gross dissection. This connection with the APL tendon is in favor of a functional synergy between OPP and APL.

The 3D images of the OPP osseous insertions (Figs. 7-8) were similar between the photogrammetry and the navigation system methods. This latter has the advantage of providing a coordinate system, which is essential in order to create in the future a digital hand or to use in finite element modeling (FEM). Beyond the educational purpose of the 3D model, there is clinical value to conducting computational simulations and biomechanical studies for such a small muscle in a complex regional anatomy. A biomechanical study of the specific function of each OPP belly has not been studied before and ongoing investigations are important.

This study has some limitations. First, we did not study the innervation of the first and second belly as our focus was on the third belly. Secondly, we provided only two 3D reconstruction models of the OPP osseous insertion. We believe that more 3D reconstructions are needed to study the variability in the population and to quantify the insertion area of each belly. Third, we could not include in our histological study an investigation of muscle fiber type (I and II) as this staining needs fresh tissue, and we only had access to cadaver specimens. Studying the distribution and the proportion of each fiber type could be another argument for different ultrastructure and function for each OPP belly, and we do plan to harvest deep OPP tissue during CMC surgery in the future to obtain fresh tissue for histology and structural biological analysis. Finally, our sample size was modest, as we only dissected 14 hands for this study. However, our approach to the study of the OPP was not to understand the prevalence of a novel anatomic variation in the number of OPP muscle bellies, but rather to question whether there might be some previously unobserved details in OPP anatomy to explain our clinical finding of a fairly localized OPP FI, which in retrospect seems to be quite common in individuals with CMC OA.

CONCLUSION

In conclusion, we have observed that he OPP muscle has three distinct bellies. The first two, which are commonly described, arise from the flexor retinaculum and trapezium, and insert superficial and deep to the lateral ridge of the first metacarpal. The third belly is thin, and covers the palmar trapezium, CMC joint, and proximal metacarpal. Importantly, this third belly overlies the palmar trapeziometacarpal "beak" ligament, which is a key stabilizer of the thumb CMC joint. This study described the insertion, structure, innervation and imaging characteristics of the OPP third belly. The OPP muscle is critical to the unique ability of the human hand to rotate the thumb into opposition of the fingers. The OPP may contribute to the evolution of CMC osteoarthritis, a disabling and challenging condition with major consequences for hand function. Studying OPP anatomy and function could improve our understanding and management of this common condition.

ACKNOWLEDGEMENTS

This work was supported by funding provided by Mayo Clinic. The authors sincerely thank those who donated their bodies to science so that anatomical research and teaching could be performed. Results from such research can potentially increase scientific knowledge and can improve patient care. Therefore, these donors and their families deserve our highest respect.

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