A Novel Cadaveric Model of the Quadriga Effect

Abstract

Introduction: The quadriga phenomenon results from excessive shortening of the flexor digitorum profundus (FDP) tendon to the middle, ring, or small finger.

Methods: Five cadaveric specimens were used to create a model for quadriga. The FDP tendons to the middle, ring, and small fingers were shortened in 5-mm increments, and the tip-to-palm (TTP) distance of adjacent fingers was recorded.

Results: Shortening of the middle finger FDP by 10 mm resulted in an average TTP distance of 6 mm in the ring finger and 5 mm in the small finger. Shortening the ring finger FDP by 10 mm produced an average TTP distance of 11 mm in the middle finger and 9 mm in the small finger. Shortening of the small finger FDP by 10 mm resulted in an average TTP distance of 14 mm in the middle finger and 10 mm in the ring finger.

Discussion: Shortening the FDP by as little as 10 mm produced a significant quadriga effect, which was more pronounced with shortening of the small and ring FDP tendons compared to the middle finger.

The quadriga phenomenon refers to a flexion lag in fingers adjacent to a finger with a shortened flexor digitorum profundus (FDP) tendon owing to a common muscle belly for the small, ring, and middle FDPs.¹ Common causes of FDP tendon shortening include over-tensioning of the FDP tendon in a tendon repair or grafting procedure, over the top advancement in an amputation, and adhesions of the tendon.¹–³ Clinically, patients who experience the quadriga phenomenon complain of inability to form a fist and of grip weakness, and express concern that previously uninvolved fingers are now less functional than prior to surgery.⁴ Despite the original description of quadriga more than 90 years ago, there have been relatively few studies investigating the phenomenon.⁵ The original literature described great variability in the amount of permissible shortening, ranging from 7 mm to 20 mm.⁶ The most complete investigation of the quadriga phenomenon is a cadaveric study by Malerich et al⁶ in which the profundus tendon was advanced after detachment through drill holes in the distal phalanx in 5-mm increments. They found that their cadaveric model allowed for 10 mm of FDP shortening before significant quadriga occurred. An important limitation was that the study design altered the native anatomy.
Our goal was to study the quadriga phenomenon through a cadaveric model that did not notably alter the native anatomy. This would allow us to assess the effects of profundus tendon shortening in each sequential finger while preserving study reproducibility. We chose to shorten the middle, ring, and small fingers and not the index finger because of the relative independence of the FDP tendon to the index finger. The tip-to-palm (TTP) distance of the adjacent fingers in flexion served as a measure of flexion lag, and thus of clinical impairment.

**Methods**

Five fresh-frozen cadaveric specimens were used for this study. A longitudinal incision was made over the volar aspect of the forearm to expose the wrist flexors. The FDP tendons to the middle, ring, and small fingers were identified. Using a 2-0 braided suture, each tendon was captured using a modified Kessler suture just distal to the musculotendinous junction (Figure 1). The FDP tendons were then pulled to create a symmetric fist and, with the tension equalized, the sutures were gathered in a clamp to maintain tension throughout the study, recreating the consistent tension of the common FDP muscle belly. As an internal control for the quadriga phenomenon in each specimen, the tendons were pulled multiple times, each time ensuring that a symmetric fist was formed, both before and after experimentation on each finger.

A longitudinal incision was then made over zone 3 of the flexor tendons to the middle, ring, and small fingers. The FDP tendons were identified, and 5-mm increments, up to 20 mm, were measured and marked with a surgical marker on the middle, ring, and small finger FDP tendons. Prior to shortening any of the tendons in zone 3, we confirmed once more that pulling on the common origin created a symmetric fist, with each fingertip contacting the palm completely. Sequentially, each FDP tendon was shortened in 5-mm increments with a 3-0 braided suture placed in a horizontal mattress configuration (Figure 2). The common origin was then tensioned, creating a fist in which the finger with the shortened FDP contacted the palm, and the TTP distance was measured in the adjacent fingers using a surgical ruler with a precision of 1 mm (Figure 3). When measurements were complete, the suture was removed from the tendon, and the control test pull was repeated with all tendons at their original length to confirm the lack of any residual quadriga. Each finger was addressed in a similar manner.

**Results**

We sequentially shortened the FDP tendons in the five cadaveric
specimens and measured the TTP distance in the adjacent fingers (Table 1). When the middle finger FDP tendon was sequentially shortened from 5 mm to 20 mm in 5-mm increments, the average TTP distance in the ring finger was 1 mm, 6 mm, 14 mm, and 24 mm, respectively, and 1 mm, 5 mm, 11 mm, and 17 mm in the small finger, respectively. Shortening the ring finger FDP tendon in a similar fashion produced an average TTP distance of 6 mm, 11 mm, 17 mm, and 23 mm in the middle finger and 4 mm, 9 mm, 17 mm, and 21 mm in the small finger, respectively. When the small finger FDP tendon was shortened, the average middle finger TTP distance was 7 mm, 14 mm, 21 mm, and 24 mm, whereas the average ring finger TTP distance was 6 mm, 10 mm, 18 mm, and 21 mm, respectively. SDs are reported with average TTP measurements in Table 1. All the specimens returned to a normal composite fist with no residual quadriga after the study was completed, and the shortening sutures were removed.

### Discussion

The results of our cadaveric study show that shortening of the FDP tendon by 10 mm causes a flexion lag in the adjacent fingers, with a TTP distance ranging from a minimum of 5 mm to a maximum of 14 mm, resulting in a potentially significant quadriga phenomenon. This confirms the earlier work by Malerich et al.6 Furthermore, our results suggest a previously unreported differential quadriga effect, according to the finger involved, with two notable trends. First, the middle finger FDP tendon was the most forgiving of shortening, and the small finger was the least forgiving. Second, the quadriga effect appeared most pronounced in the radial-most adjacent finger. At 10 mm of shortening, the middle finger produced a quadriga effect with, on average, a TTP distance of 6 mm and 3 mm in the ring and small fingers, respectively. Shortening the ring and small finger FDP tendons produced nearly twice the flexion lag of the adjacent fingers (Table 1). This shows that extra care must be taken when advancing or tensioning the ring and small finger tendons. A possible explanation for these observations is that the normal resting flexion cascade of fingers exhibits a decreasing TTP distance from the index finger to the small finger. Thus, shortening the ring and small fingers brings the two fingertips already closest to the palm even closer, producing greater flexion lag in the middle finger with relatively less shortening. The relatively smaller increase in a TTP distance with the change in tension from 15 mm to 20 mm of shortening in ring and small fingers suggests that there may be a plateau of the quadriga effect.

The principal limitation of our study was the number of cadaveric specimens used. A power analysis using the SDs obtained from our measurements indicates that 50 cadaveric specimens, totaling 150 fingers, would be needed to reach a power of 0.9 and obtain statistically significant differences at \( \alpha = 0.5 \). We did not have access to this number of cadaveric specimens. Another limitation was the difficulty of shortening profundus tendons in increments smaller than 5 mm. If we could reliably and reproducibly shorten tendons in 1- or 2-mm increments, we might more precisely define the quadriga threshold. However, although increasing the precision in
this fashion would yield more accurate results, it is unlikely that, in a surgical setting, tendon shortening could be measured accurately in 1- to 2-mm increments.

Our new cadaveric model shows that a notable degree of quadriga was present in all fingers with 10 mm of profundus tendon shortening. This effect was most pronounced with the ring and middle fingers. Surgeons should aim to keep the amount of profundus tendon shortening less than 10 mm to limit the amount of quadriga.

References

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