The Effect of Isolated Finger Stiffness on Adjacent Digit Function

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Abstract

Background: Isolated stiffness in a single finger can affect the function of adjacent digits and decrease overall hand function due to the quadriga phenomenon. This study objectively quantifies the dysfunctional impact of each individual stiff finger upon the remaining digits. **Methods:** Twenty-five individuals (10 men and 15 women) with a mean age of 31 years (range, 18–58 years) without any upper limb pathology, neuropathy, or systemic illness were recruited. Volar-based finger splints were used to hold individual digits of the dominant hand (24 right and 1 left) sequentially in full extension at the metacarpophalangeal (MCP), proximal interphalangeal (PIP), and distal interphalangeal (DIP) joints. Motion of the remaining 3 nonsplinted digits was assessed using a finger goniometer and linear scale to measure the total active range of motion (TAM) and fingertip-to-distal palmar crease (DPC) distance. TAM before and after splinting for each digit was compared using 1-way analysis of variance (ANOVA). **Results:** Splinting of any individual finger resulted in a significant reduction in the TAM of all adjacent fingers, regardless of which finger was splinted ($P < .001$). Digits immediately adjacent to the splinted finger were more heavily impacted compared with nonadjacent digits. Splinting of the ring finger produced the greatest detriment, with a 26% to 47% reduction in the TAM and a DPC distance greater than 40 mm in a third of participants. The index finger caused the least disturbance to remaining digital motion. **Conclusions:** Isolated finger stiffness causes a variable degree of dysfunction on adjacent normal digits. This emphasizes the need for a focused and proactive approach to restore full active motion following isolated finger injuries to prevent persistent functional sequelae of the hand.

Keywords: finger stiffness, quadriga, total active range of motion, flexor digitorum profundus, isolated finger injury

Introduction

Injury to a single finger can impact the function of the adjacent fingers and decrease overall movement and strength of the hand.^{5,7} This was first described by Bunnell and was later termed as *quadriga* by Verdan.²⁶ This phenomenon is characterized by the limitation in full flexor digitorum profundus (FDP) excursion of an unaffected finger when the adjacent FDP tendon is restricted by finger stiffness or adhesions. While the quadriga syndrome can occur following injury to any of the 3 ulnar digits, limitation of full proximal excursion of the FDP tendons can also be elicited in the normal hand by holding an adjacent finger in extension.²⁵

This phenomenon is partially explained by the common FDP muscle belly of the ulnar 3 digits. This inspired Verdan to compare the flexor tendons with a 4-horse Roman chariot whose “muscular body can act efficiently only if the gliding amplitude of each of the four tendinous reins is normal.”²⁶ Leijnse elaborated on this idea by studying his own hands and found 4 additional levels of interconnections: within the muscle belly, the tendon fibers in the forearm, the synovial sheaths in the carpal tunnel, and the close proximity of lumbrical origins between adjacent tendons.^{11,12,14} Furthermore,

21% to 38% of the population have an anatomical variation of flexor digitorum superficialis (FDS) interdependence between the ring and small fingers which may also be contributory.^{1,2,20}

Although in the clinical setting quadriga syndrome has been observed to substantially limit hand function, the impact of quadriga exerted by each individual finger has not been defined. The present study was designed to objectively compare and quantify the impact on the digital motion of adjacent digits produced by each individual stiff finger. We hypothesize that individual finger stiffness will produce the greatest quadriga effect on the digits immediately adjacent to the affected finger and that this degree of dysfunction will vary depending on the affected finger. A secondary

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Figure 1. Volar-based finger splint used to immobilize each individual digit at the metacarpophalangeal, proximal interphalangeal, and distal interphalangeal joints.

hypothesis is that the index finger FDP, having its own individual muscle belly, will produce the least effect on the adjacent fingers, while ring finger stiffness will cause the greatest detriment. Furthermore, participants who demonstrate FDS interdependence between the ring and small fingers may exhibit greater dysfunction than those who do not.

Materials and Methods

A convenience sample of 25 healthy hospital staff and university students (10 men and 15 women) was recruited. Participants had a mean age of 31 years, ranging from 18 to 58 years. Exclusion criteria included previous or current hand and upper limb pathology, neuropathies, or any significant systemic illness. Participants received a letter of information, and informed consent was obtained from all individual participants included in the study. A questionnaire inquiring about age, sex, hand dominance, occupation, and history of upper limb injuries and pathology was administered prior to testing for both demographic data collection and participant screening purposes.

The dominant hand (24 right hands and 1 left hand) of each participant was tested. Volar-based finger splints were used to hold each individual digit in full extension simulating finger stiffness, defined as decreased tendon excursion (Figure 1). The metacarpophalangeal (MCP), proximal interphalangeal (PIP), and distal interphalangeal (DIP) joints were splinted at 0° of flexion. Participants were tested with each of the 4 fingers splinted separately and without any splinting as a control, for a total of 5 testing configurations. For each testing configuration, a goniometer (JAMAR;

Patterson Medical) was used to measure the total active range of motion (TAM), defined as the sum of active flexion at the MCP, PIP, and DIP joints minus any deficit from maximal extension, in each of the remaining 3 fingers.⁸ Fingertip-to-distal palmar crease (DPC) distance was used as a surrogate measure for hand function. The distance from fingertip to the distal palmar crease during maximal active flexion was measured in each remaining unsplinted finger using a vertical linear scale. The measured distance was subcategorized into the Medsger severity scale, developed for stratifying the severity of hand dysfunction in systemic sclerosis patients and ranged from normal (0-mm DPC) to very severe (>50-mm DPC).¹⁷ Given that potential FDS interdependence between the ring and small fingers can potentially confound quadriga effects exerted by individual finger stiffness, each participant was tested to determine FDS dependence or independence. The participant was asked to flex the PIP joint of the little finger while keeping the ring finger in full extension. The inability to do so demonstrated FDS interdependence. All participants were also tested to confirm normal FDS and FDP tendons in other digits with intact flexion at the PIP and DIP joints. All testing was done in a standardized setting with the participant sitting in an upright position with both arms adducted, elbow flexed at 90°, and forearm and wrist in neutral position. Testing was done in the same order for all participants with splinting of the index, long, ring, and small fingers sequentially. Each measurement of TAM and DPC was obtained once and recorded by a single observer to maximize intrarater reliability.³ The participants were blinded to the purpose of the study. Approval for the study was obtained from the institutional ethics review board (REB 103610).

Data Analysis

The primary outcome measure was the change in the TAM of each individually splinted finger compared with the control, unsplinted condition. Presplinting and postsplinting TAM was analyzed using 1-way analysis of variance with the effect of each individual stiffened finger as the independent variable and subsequent change in flexion range of motion in adjacent normal fingers as the dependent variable. The Student *t* test was used to compare the degree of impairment produced by FDP quadriga of each stiffened finger. The Spearman rank correlation coefficient was also calculated to determine correlation between TAM reduction and DPC severity. Significance for all calculations was set at $P < .05$.

Results

Splinting of an individual finger caused a decrease in the TAM in all adjacent digits, regardless of which finger was

Figure 2. Mean percent reduction in TAM of adjacent fingers produced by splinting either the index, long, ring, or small finger (N = 25).

Note. All values were found to be significant at $P < .05$. TAM = total active range of motion.

splinted ($P < .001$ by analysis of variance). Each splinted digit caused the highest percentage of TAM reduction in the adjacent fingers compared with nonadjacent fingers. Splinting of the index finger generated the least impact on the range of motion in the remaining fingers, whereas simulated ring finger stiffness resulted in the greatest functional detriment to the remaining fingers, causing a 47%, 35%, and 26% decrease in the TAM of the little, long, and index fingers, respectively (Figure 2). The significant quadriga effect exerted by splinting of the ring finger was still observed after excluding the 3 participants with FDS interdependence. However, given only 3 of 25 participants demonstrated FDS interdependence compared with the cited 21% of the population,⁴ the present analysis may not have captured the full effects.

There was a positive relationship between the reduction in the TAM and DPC severity score (Spearman $R_s = 0.514$), and as expected, fingers immediately adjacent to the splinted digit had more severe DPC scores than distant digits (Table 1). With the index finger splinted, the remaining fingers demonstrated mild to no impairment in ability to touch the distal palmar crease, despite a decrease in the TAM (9%-17% reduction depending on the measured finger). Thirty-six percent of participants were still able to touch the distal palmar crease with their middle finger, 52% with their ring finger, and 80% with their little finger. In contrast, ring finger stiffness caused moderate to severe dysfunction in the majority of participants. The DPC distance was greater than 40 mm in a third of participants.

Discussion

The human hand displays a vast diversity of functional dexterity and patterns of movements yet is intrinsically limited

Table 1. Stratification of Hand Dysfunction in Participants by Medsger Score.

Comparison		Participants distributed by Medsger score in each testing configuration (%)				
		Normal	Mild	Moderate	Severe	Very severe
Splinted	Measured					
	Index					
	Long					
Long	Index	36	64	0	0	0
	Ring	52	48	0	0	0
	Little	80	20	0	0	0
Ring	Index	0	4	72	24	0
	Long	4	56	32	8	0
	Little	0	76	16	4	4
Little	Index	0	16	76	8	0
	Long	0	16	68	12	4
	Little	0	4	68	28	0
Very severe	Index	8	68	24	0	0
	Long	0	80	20	0	0
	Ring	0	40	42	4	4

by its anatomic interconnections. The present study quantifies the restriction of FDP excursion exerted by the quadriga phenomenon with stiffness of each of the 4 fingers. Commonly, the 4 FDP tendons are inaccurately depicted as 4 separate tendons coursing along the palmar aspect of the phalanges to attach to the base of the distal phalanx. Moving proximally along the tendons reveals an increasing number of interconnections. The 3 ulnar digits share a common muscle belly, with the ring and little fingers being especially entwined, sharing common muscle fibers. Within the palm, the FDP tendon gives rise to the origin of the lumbricals. Further proximally, all 4 FDP tendons are bound by a strong fascia at the level of the wrist, a thick synovial sheath within the carpal tunnel, and a fibromembranous retinaculum securing them to the floor of the carpal tunnel.^{6,13,22}

Given this intricate network of connections, it is not surprising that splinting of one digit produces the greatest decrease in the range of motion on the immediately adjacent digit. Kilbreath et al demonstrated that fingertip flexion of a single digit generated tension in the surrounding digits as well.¹⁰ Attributed to the spatial distribution of tension through the muscle fibers and connective tissues of adjacent fingers, this results in an “enslaving phenomenon” causing involuntary muscle activation where it was not intended.¹⁵ Muscle fibers of shared tendons cannot be activated without the recruitment of muscles controlling both tendons. Mimicking stiffness of one finger can limit the recruitment of shared muscle fibers and thus can prevent volitional movement. Ring finger stiffness demonstrated the greatest reduction in the range of motion of other fingers, followed by the long and small fingers. This may be explained by the 2 ulnar third and fourth bipennate lumbricals which arise from the ring finger profundus tendon and share origins with the long and little fingers, respectively, compared with

the radial unipennate lumbricals which each originate from a single tendon.

The index finger generated the least impairment on the range of motion of the remaining digits; however, there was still some limitation on the remaining digits, suggesting that the index finger profundus is not wholly independent. This is in agreement with the study by Horton et al, which examined the impact of the quadriga phenomenon on grip strength where index finger stiffness resulted in a decrease in grip strength of the other 3 digits.⁷ They posit this could be explained by an oblique connection between the index FDP and the combined musculotendinous unit of the long, ring, and little fingers or by the interconnections within the carpal tunnel. Furthermore, tendinous “quadriga-like” connections between the flexor pollicis longus and the index and middle finger profundus tendons have also been described.¹⁶ All of these inhibit complete independence of the index finger.

These results highlight the clinical implications of the quadriga phenomenon following injury. A wide variety of conditions leading to tendon adhesions (fractures, tendon resection following amputation, tendon tightening with advancement too distally, or short tendon grafts during repair) can result in deficiency in FDP function.^{9,19,21,27,28} This emphasizes the need for timely and aggressive hand therapy to restore active flexion and extension. Silfverskiöld et al describe a rehabilitation program after zone II flexor tendon repair that includes dynamic traction on all 4 fingers even if not all injured.²⁴ This exploits the normal quadriga interconnections between the FDP tendons, so the uninjured fingers help increase excursion of the repaired tendon.²³ This method resulted in 17.8-mm median tendon excursion, almost twice of what was previously achieved with the standard Kleinert splint placing traction on solely the injured finger.²⁴ Similarly, grip strength exercises involving all fingers also promote maximal tendon gliding.

In our study, ring finger stiffness was associated with causing the greatest functional detriment to the adjacent fingers, followed by the long finger. These findings support current recommendations against single-digit zone II replantation, especially of the ring finger, due to the associated burden of dysfunction placed upon the adjacent fingers if stiffness develops. Our results also highlight the potential impact of DIP joint arthrodesis on the adjacent fingers and the importance of the position of DIP fusions. Melamed et al simulated DIP joint arthrodesis of the index and long fingers in either 0° or 20° flexion and found that grip strength and dexterity were better with the index finger in slight flexion but unaffected by long finger position.¹⁸ In our study, fingers were splinted in full extension to intensify the quadriga effect exerted on adjacent fingers. Flexed posturing decreases tension on the FDP tendon. The impact of quadriga on the range of motion may be less pronounced in patients with stiffened flexed fingers, and this warrants

future study with simulated stiffness in varying degrees of flexion.

Limitations of the study include a standard sequential order of splinting digits for testing that was not randomized. Fatigue may have confounded the results and accounted for some of the increased impairment of ring finger splinting upon adjacent digits. Future fully randomized studies with defined intervals of rest time would help to remove the confounding effects of exertional fatigue.

Ethical Approval

Approval for the study was obtained from the institutional ethics review board (REB 103610).

Statement of Human and Animal Rights

All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008.

Statement of Informed Consent

Informed consent was obtained from all individual participants included in the study.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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