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Original Article

Quantitative examination of isolated finger flexion associated with function of the flexor digitorum superficialis

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Abstract. [Purpose] Isolated finger flexion associated with function of the flexor digitorum superficialis has been qualitatively assessed using standard and modified tests. The purpose of this study was to quantify isolated finger flexion in healthy participants. [Participants and Methods] We assessed 100 volunteers (mean age: 44.6 years) without upper limb dysfunction using the standard and modified flexor digitorum superficialis tests. The sum of the isolated active flexion angles of the metacarpophalangeal and proximal interphalangeal joints of the test finger was also calculated, with the other three fingers held in an extended position with our original jig. [Results] The mean isolated flexion angles were, respectively, 152.4° and 154.8° for the right and left index fingers, 161.1° and 160.4° for the middle fingers, 160.6° and 158.2° for the ring fingers, 129.4° and 134.6° for the independent flexor digitorum superficialis function, 85.8° and 74.7° for the common flexor digitorum superficialis function, and 75.8° and 71.2° for absent flexor digitorum superficialis function in the small finger. The functional variations of the flexor digitorum superficialis of the small fingers showed symmetry in 65.0% of the fingers but asymmetry in 35.0%. [Conclusion] The data obtained in this study provide normal reference values for the examination of independent movement disorders of the fingers.

Key words: Quantitative examination, Isolated finger flexion, Flexor digitorum superficialis

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INTRODUCTION

The standard flexor digitorum superficialis (FDS) test reported by Kaplan[1)] and modified FDS test of Baker et al.[2)] have been used for examining functional variations in the FDS of the small finger caused by anatomical variations such as musculotendinous interconnections between the FDS of the small finger and those of the adjacent finger[1, 3–6)] and the flexor digitorum profundus (FDP) of the small finger[3)] as well as hypoplasia[1)] and complete absence of the FDS of the small finger[1, 3–6)].

Tan et al.[7)] also defined the functional variations in the FDS using an expanded version of Baker's examination technique which involved the serial release of the adjacent or multiple fingers. Moreover, Tan et al.[8)] developed a new examination method that does not require a strong external force when holding the non-test fingers in the extended position. The standard and modified FDS tests and the two examinations developed by Tan et al.[7)] and Tan et al.[8)] are all qualitative evaluation methods, and even if functional variations in the FDS can be determined, it is difficult to evaluate the degree of isolated finger

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flexion.

It has been reported that tendinous adhesions between the FDS and the FDP influence isolated finger flexion after multiple flexor tendon repair in zone V from the musculotendinous junction to the carpal tunnel[9–11]. Qualitative examination has been used to evaluate recovery with respect to independent FDS action as an outcome measure of isolated finger flexion[10, 11]. However, it is also necessary to develop a quantitative examination technique in order to accurately evaluate the degree of disability and continuous improvement in the isolated finger flexion angle accompanying the gliding of the FDS. The authors developed a quantitative examination technique based on the standard FDS test (quantitative FDS test; Q-FDS test) that can evaluate the degree of isolated finger flexion angle.

The purpose of this study was to quantify the isolated flexion angle of each finger in healthy participants using the Q-FDS test and to provide these data for use as normal reference values for the examination of independent movement disorders of the fingers.

PARTICIPANTS AND METHODS

One hundred healthy Japanese volunteers (fifty males and fifty females) were randomly recruited at our affiliated facilities. The mean age was 44.6 years (range, 20–69 years). Ninety-nine participants were right-hand and one participant was left-hand dominant. None of the participants had a history of osteoarthritis of the metacarpophalangeal (MP) or proximal interphalangeal (PIP) joints, neuromuscular disease, connective tissue disorders and injury or tendinitis. All the experimental procedures in this study were approved by the institutional review board of our hospital (Approval No. 24-2-57). Written informed consent was obtained from all participants.

The FDS functions of four fingers for all participants were qualitatively evaluated using both the standard[1] and modified FDS tests[2]. The wrist was kept in a neutral position with full supination. In the standard FDS test, participants were asked to actively flex the test finger while the other fingers were held in extension by the examiner. If flexion of the PIP joint concomitantly occurred with flexion of the distal interphalangeal (DIP) joint of the same finger, the participants was requested to attempt to actively flex the PIP joint without flexion of the DIP joint. The examiner was particularly careful not to flex the DIP joint of the index finger of participants in order to eliminate compensatory FDP action as the index finger portion of the FDP is anatomically separate from the other finger components[12].

Active flexion of the PIP joint with no DIP joint flexion was regarded as indicating independent FDS function, while when it was impossible for the PIP joint to flex or possible for the PIP joint to flex with accompanying DIP joint flexion, it was regarded as indicating no independent FDS function[3, 7]. The modified FDS test was subsequently used to examine the participants demonstrating no independent FDS function. When the small finger was tested, the participants were required to actively flex the PIP joint of the small finger while the adjacent ring finger was released and the index and middle fingers were held in an extended position. If active flexion of the PIP joint of the small finger was possible or increased, it was regarded as common FDS function, and if it was still impossible for the PIP joint to flex or possible for the PIP joint to flex with accompanying DIP joint flexion, it was regarded as indicating absent FDS function[3, 7]. All participants were evaluated by the same examiner (Y.W.).

Quantitative measurement of isolated flexion of each finger for all participants was performed in a sitting position, with 90° of elbow flexion and full forearm supination. The fingers, hand and forearm were placed on a 10-mm thick transparent acrylic plate with the part corresponding to the test finger cut out (Fig. 1A), and the non-test fingers were fixed in the extended position by the parts of the thermoplastic splint material (1.6 mm Aquaplast, Sakaimed Co., Tokyo, Japan) molded in the form of each finger and Velcro. At that time, the wrist was held in a neutral position using the thermoplastic material and Velcro (Fig. 1B). Participants were asked to flex the MP and PIP joints of the test finger as far as possible for measurement. The maximum function provided by FDS gliding to the MP and PIP joints when both joints were actively flexed simultaneously was measured as the FDS contributes more to PIP joint flexion[13] and it is predicted that the terminal range of motion of the PIP joint can be easily reached by the action of FDS with the MP joint in extension. The participants were also required to actively flex the MP and PIP joints without DIP joint flexion.

The examiner measured the maximal flexion angles of the MP and PIP joints of each finger with a finger goniometer (Sakaimed Co., Tokyo, Japan) (Fig. 1C). The angles of both joints were measured 3 times and summed, and then the mean value for each finger was calculated. All measurements were carried out by an experienced therapist (Y.W).

The distribution of independent, common and absent functions in the qualitative assessment of independence of the FDS between the right and left side was compared using χ^2 test. As the values for isolated finger flexion angles obtained by the Q-FDS test showed a non-normal distribution by the Shapiro-Wilk test, a nonparametric test was used. One-way analysis of variance (ANOVA) with a Bonferroni multiple comparisons *post hoc* test was used to compare the isolated flexion angles between the right or left index, middle and ring fingers, and each FDS function in the small finger. Wilcoxon signed-rank test was also used to compare the isolated flexion angles between each finger on the right and left side. All analyses were performed using IBM SPSS Statistics 22 software. The level of significance was set at $p<0.05$.

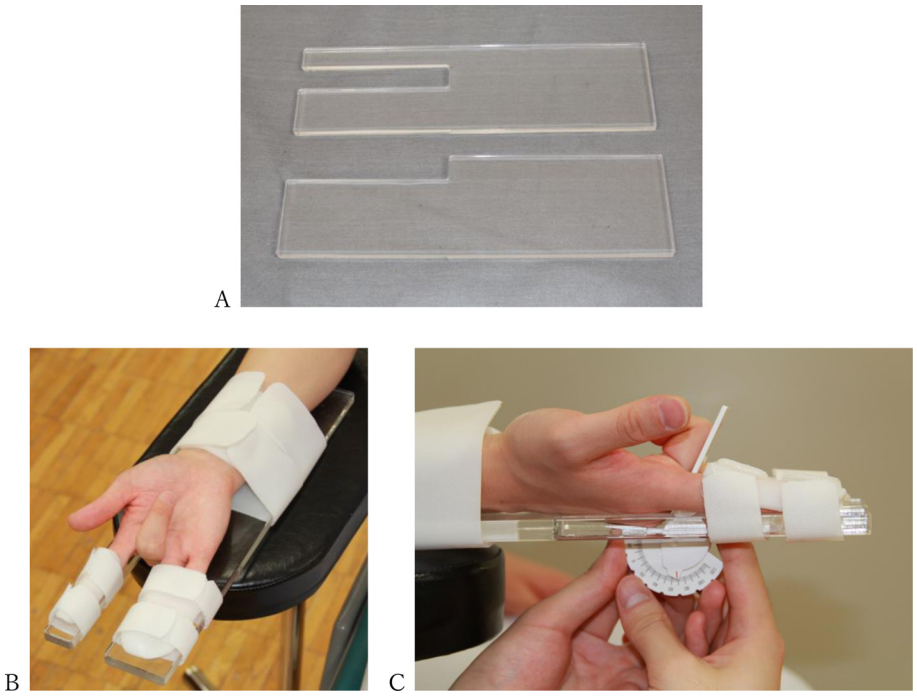

Fig. 1. (A) Original acrylic plate with part corresponding to the test finger cut out. (B) Fixation position of the test finger and wrist with thermoplastic material parts and Velcro. (C) Measurement of the MP joint angle of the middle finger with a goniometer.

Table 1. Functional FDS variants in the small finger noted on examination

	Independent function[a]	Common function[b]	Absent function[c]
Total (200 fingers)	135 (67.5%)	24 (12.0%)	41 (20.5%)
Right (100 fingers)	67	11	22
Left (100 fingers)	68	13	19

FDS: flexor digitorum superficialis.
[a] The small finger can flex actively at the PIP joint by the standard FDS test.
[b] The release of the adjacent ring finger (the modified FDS test) allows an increase in PIP flexion of the small finger.
[c] The small finger is unable to flex actively at the PIP joint by the modified FDS test.

RESULTS

The index, middle and ring fingers showed independent FDS function in all hands. In the small fingers, 135 of 200 fingers (67.5%) showed independent FDS function, and 65 fingers (32.5%) showed no independent function. The 65 small fingers showing no independent FDS function were further categorized as showing common FDS function in 24 fingers (12.0%) and absent FDS function in 41 fingers (20.5%) by the modified FDS test (Table 1). There were no significant differences in these distributions between the right and left side ($p>0.05$). The functional variations in the right and left small fingers showed symmetry in 65.0% of fingers, but 35.0% were asymmetric (Table 2).

The mean values for the isolated flexion angles of the index, middle and ring fingers, and each FDS function in the small finger on the right and left side are shown in Table 3. The mean isolated flexion angles and mean ratio of flexion angles of the MP and PIP joints of the index, middle and ring fingers, and each FDS function in the small finger on the right and left side are also shown in Table 4.

One-way ANOVA showed a significant difference between each finger on both the right and left side ($p<0.001$, respectively). A Bonferroni multiple comparisons *post hoc* test revealed that the mean values for the isolated flexion angles of the middle and ring fingers were significantly greater than that of the index finger on both sides ($p<0.05$, respectively). The value for the isolated flexion angle of the small finger which showed independent FDS function was also significantly lower than that of the index, middle and ring fingers, and was significantly greater than that of the small finger which showed common

Table 2. Right-left symmetry of the small finger for each variant (N=100)

Overall symmetry	65.0%
Symmetric independent function	52.0%
Symmetric variant	13.0%
1 finger independent + 1 finger variant	30.0%
2 different variants	5.0%

Table 3. The isolated flexion angles for right-left index, middle and ring fingers, and each FDS functions in the small finger

Side	Finger					
	Index	Middle	Ring	Small		
				independent	common	absent
Right	152.4° (10.9°)	161.1° (16.5°)	160.6° (12.6°)	129.4° (24.5°)	85.8° (23.5°)	75.8° (27.3°)
Left	154.8° (10.5°)	160.4° (15.5°)	158.2° (13.8°)	134.6° (23.2°)	74.7° (22.8°)	71.2° (26.2°)

Values are shown as mean (standard deviation).

Table 4. The mean isolated flexion angles and mean ratio of flexion angles of the MP and PIP joints

Side	Joint	Finger					
		Index	Middle	Ring	Small		
					independent	common	absent
Right	MP	63.5° (41.7%)	60.0° (37.2%)	57.0° (35.5%)	55.7° (43.0%)	65.7° (76.6%)	64.8° (85.5%)
	PIP	88.9° (58.3%)	101.1° (62.8%)	103.5° (64.5%)	73.7° (57.0%)	20.1° (23.4%)	11.0° (14.5%)
Left	MP	65.8° (42.5%)	58.8° (36.7%)	56.1° (35.4%)	59.5° (44.2%)	58.9° (78.8%)	60.2° (84.6%)
	PIP	89.0° (57.5%)	101.6° (63.3%)	102.1° (64.6%)	75.1° (55.8%)	15.8° (21.2%)	11.0° (15.4%)

MP: metacarpophalangeal; PIP: proximal interphalangeal.

or absent FDS functions on both sides ($p<0.05$, respectively). There were no significant differences in the isolated flexion angles between each finger on the right and left side ($p>0.05$, respectively).

DISCUSSION

The value of the isolated flexion angle of each finger obtained by the Q-FDS test in this study provide normal reference values for the examination of independent movement disorders of the fingers. In particular, they provide valuable reference data for patients with bilateral injuries or disorders that cannot be compared with the contralateral side.

The distribution of functional variations in the FDS obtained in this study was quite similar to those in previous studies[2, 3, 7, 8, 14–18]. The symmetry of functional variations in the FDS between the right and left small fingers also supports the findings of previous reports although there are some variations in these studies[3, 7, 8, 19]. When the independent FDS pattern was shown in the small finger, a similar pattern existed on the opposite side in 52.0% of the participants. On the other hand, if the one small finger showed a common or absent FDS pattern, the right and left small fingers were likely to be asymmetric in the present study, and the mean value of the isolated finger flexion angle differed depending on the independence of the FDS function of the small finger. Therefore, the evaluation of the isolated flexion angle of the small finger based on the opposite side as a reference value should be done carefully.

The isolated flexion angle for each finger obtained by the Q-FDS test was substantially smaller than the simultaneous active flexion angle for four fingers shown in previous studies[20, 21]. Bain et al.[20] reported that the mean summed angle of the MP and PIP joints during simultaneous active flexion for four fingers was 191°. Chiu et al.[21] also demonstrated that these angles were 201° and 204° for the right and left index finger, respectively, 201° and 208° for the middle finger, 202° and 205° for the ring finger, 185° and 194° for the small finger. It has been shown that FDP contributes not only to DIP joint flexion but also to PIP and MP joints flexion to the same degree as FDS[13]. The differences between the isolated finger flexion angles obtained in the present study and the simultaneous flexion angles for four fingers in the previous studies can be presumed to be related to the participation of FDP contraction.

The isolated flexion angle for each finger also was similarly large in the middle and ring fingers, and larger in the index finger followed by the small finger which showed independent FDS function. These results may reflect the tension fraction

and excursion distance of the FDS in each finger. Brand et al.[22] demonstrated that the tension fraction of the FDS was the largest for the middle finger, with the index and ring fingers being the next largest, and the small finger being the smallest. Lieber et al.[23] also calculated the excursion potential from the architectural features of the FDS and showed that the middle and ring fingers were larger, and the small finger and index finger were smaller in this order.

The isolated flexion angle of the PIP joint was also similarly large in the ring and middle fingers, and larger in the index finger followed by the small finger which showed independent FDS function. Experimental biomechanical study using cadavers revealed that loading of the FDS alone contributes more to active flexion of the PIP joint than that of the MP joint[13]; therefore, the tension fraction or excursion potential of the FDS of each finger[22, 23] contributed to the flexion angle of the PIP joint of each finger. Further, the angle of the MP joint obtained in this study may also be due to the action of intrinsic muscles such as the lumbricales, dorsal and volar interosseous muscles. In particular, the MP joint flexion angles of the small finger showing common and absent FDS functions were greater than the MP joint flexion of the other fingers and the small finger showing independent FDS function, suggesting that the intrinsic muscles may have contributed strongly to these MP joint flexion. In fact, it has been reported that activation of the intrinsic muscles is required to produce MP joint flexion beyond 60°[24].

Impaired independent FDS function after flexor tendon repair in zone V of the hand has been reported[9–11]. Stefanich et al.[9] reported independent FDS and FDP function in only 7 of 23 patients (30%) of patients who underwent zone V flexor tendon repairs mobilized using the Kleinert technique. Yii et al.[10] also demonstrated that independent FDS function was achieved in only 107 of 161 fingers (66%) after flexor tendon repairs in zone V using controlled active flexion exercises. Moreover, Wilhelmi et al.[11] reported that 88 of 103 fingers (85%) had isolated finger flexion after repairing zone V flexors with a technique such as the Massachusetts General Hospital flexor tenorrhaphy. The cause of this decrease was thought to be an adhesion between the FDS tendon and either other FDS tendons or the FDP tendons due to the adjacent anatomical features of the FDS and FDP tendons at the wrist, resulting in limited gliding of these tendons. Yii et al.[10] used qualitative evaluation with a 3-point grading scale to clarify whether postoperative isolated finger flexion was possible in all, some fingers, or no fingers. Wilhelmi et al.[11] also evaluated differential glide of the FDS for each finger using the standard FDS test after flexor tendon repairs in zone V, and revealed that differential glide was obtained when the PIP joint could flex by more than 90°. However, these qualitative examinations are limited in their ability to reflect detailed isolated finger flexion angles or changes in angles over time. The Q-FDS test, which was developed for the present study, provides a tool for the quantitative evaluation of such pathological conditions, as well as for the sequential degree of improvements and postoperative results. The clinical indication for the Q-FDS test is at 3 or 4 weeks after single flexor tendon repair as the isolated gliding exercise of the FDS begins at these periods[25, 26]. On the other hand, it is expected that resistance will be added to the repaired tendons of the finger that is kept in the complete extended position after multiple tendon injuries such as a spaghetti wrist. Therefore, the test should be done after 8 weeks postoperatively, when light strengthening exercises are allowed[11, 27].

The FDS increases grip and pinch strength and provides stability to the PIP joint[28], but the effect of superior individual finger flexion on hand dexterity has not been clarified. Godwin et al.[29] reported that elite violinists and viola players usually have independent FDS function, with very few showing no independent FDS function. Watson et al.[30] also reported that after operative separation of the communications between the ring and small FDS tendons for a professional guitarist who was unable to flex the left small finger independently while complaining of pain during performance, the symptoms improved. These reports suggest that independent FDS function is important for professional musicians who require advanced hand dexterity. Further studies are necessary to assess the usefulness of this test for the clinical evaluation of postoperative results and clarify the effects of isolated finger flexion on hand dexterity.

The limitations of our study are that as this study was performed without intuitive dissections, electrophysiologic examinations and soft tissue imaging with ultrasound or magnetic resonance imaging support, we can only speculate on the variations in the FDS using the standard and modified test, and quantified independent finger flexion. Therefore, anomalous variations other than FDS and FDP and some asymptomatic diseases may have been overlooked.

In conclusion, the isolated finger flexion angle was clarified using the Q-FDS test. The results of the present study provide normal reference values for independent movement disorders of the fingers. The Q-FDS test may also be able to provide a tool for the quantitative evaluation of pathological conditions and sequential change in isolated movement disorders of the fingers.

Funding and Conflict of interest

None.

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