Change in Hand Function and Dexterity with Age after Index Pollicization for Congenital Thumb Hypoplasia

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Background: Little is known about how performance on strength, range of motion, and dexterity measures changes as children with index finger pollicization mature. The authors reviewed performance in range of motion, strength, and dexterity over a 7-year period and report outcomes over time.
Methods: Data from children treated with index finger pollicization for congenital thumb hypoplasia from 2007 to 2014 were reviewed retrospectively. Children were followed for an average of 3.9 years (range, 1 to 7 years) during the study period. Standardized assessments included range of motion, grip, key pinch and tripod pinch strength, the Box and Block Test, the Nine Hole Peg Test, and the Functional Dexterity Test. Average score by age and average yearly change were calculated for each assessment, and scores were plotted against published age-matched scores of normal children when available.
Results: Twenty-three patients with 29 affected thumbs were included. Distal grasp span increased 0.17 inch and Kapandji opposition improved 0.26 point with each year of age; however, proximal web-space size did not increase over time. Grip strength improved an average of 2.69 kg/year, and tripod and key pinch improved 0.58 kg and 0.67 kg with each year of age. Box and Block Test scores improved an average of 4.11 blocks/year. Scores on the Nine Hole Peg Test improved 3.83 seconds/year, and scores on the Functional Dexterity Test improved 0.026 peg/second each year.
Conclusions: Children with pollicized thumbs improve in dexterity and strength with growth. Web-space size did not change with age; therefore, the thumb should be carefully positioned at the time of surgery. (*Plast. Reconstr. Surg.* 141: 691, 2018.)
CLINICAL QUESTION/LEVEL OF EVIDENCE: Therapeutic, IV.

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THERAPEUTIC

Index pollicization for congenital deficiency of the thumb does not produce a "normal" hand.[1–9] Grip and pinch strength are typically reduced compared with age-matched unaffected children.[2,3,6,9] Outcomes are strongly related to the degree to which a child is affected; children with more isolated cases of congenital thumb hypoplasia usually perform much better than children with forearm involvement and radial hypoplasia.[3,4,6,8]

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Received for publication November 8, 2016; accepted August 30, 2017.
Presented at the 71st Annual Meeting of the American Society for Surgery of the Hand, in Austin, Texas, September 29 through October 1, 2016.

DOI: 10.1097/PRS.0000000000004119

Various strategies have been used to judge outcomes in pollicization. Typically, assessments in congenital thumb hypoplasia combine objective measurements of bodily function, structure (range of motion, strength), and activity (dexterity tests) with subjective measures of patient- or parent-rated appearance and overall function.[6,7,10]

Disclosure: *The authors have no financial interest to declare in relation to the content of this article.*

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Measures are often compared to "normal" hands, either the child's contralateral hand or normal, unaffected controls. Some authors correctly point out that the contralateral hand is frequently not normal, although it may be only mildly affected.[4,9,11] They therefore argue that normally developing children are a more appropriate comparison group by which to gauge functional level.[2,12,13]

Long-term follow-up studies have suggested that the pollicized digit maintains or improves its strength and dexterity over time.[2,14] Several authors hypothesize that they may even undergo supranormal improvement and thereby "catch up" to typically developing peers.[2,14,15] One study found improved or stable performance on strength and dexterity measures in 16 thumbs measured 3.5 years apart.[6] Another 5-year study of seven children found average rates of improvement in strength and dexterity that exceeded those of typically developing children; however, the small sample size precluded detection of a statistically significant difference between rates.[2] The aim of the current study was to present data from a cohort of children with congenital thumb hypoplasia treated with pollicization followed for an average of 3.9 years to describe changes in strength and dexterity with advancing age.

PATIENTS AND METHODS

Institutional review board approval was obtained for a retrospective chart review of thumb function in children treated with index pollicization for congenital thumb hypoplasia. Twenty-nine patients were screened for inclusion in the study. Six patients were excluded because they had not undergone at least one full evaluation using the standardized assessment tools. All pollicizations were performed using the modified Buck-Gramcko technique with reattachment of the interosseous muscle to the proximal phalanx.

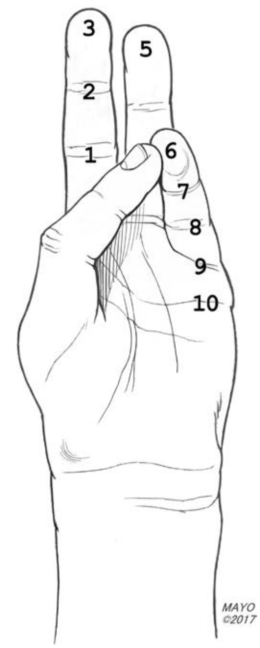

Fig. 1. The Kapandji opposition test assigns a score to the farthest location of thumb opposition. In hands with only three fingers, the scoring rubric was changed to exclude a score of 4, and instead was scored as shown above. (Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved.)

Fig. 2. A patient 4 years after pollicization for Manske type 3b hypoplasia demonstrates task 7 of the Jebsen-Taylor Hand Function Test (heavy objects). (Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved.)

Standardized assessment for each child included range of motion, dexterity, and strength testing. All evaluations were performed by a single therapist specializing in pediatric hand differences.

Table 1. Patient Demographics

Characteristic	No.
No. of evaluations per age group	
2-yr-olds	7
3-yr-olds	10
4-yr-olds	9
5-yr-olds	11
6-yr-olds	9
7-yr-olds	12
8-yr-olds	9
9-yr-olds	7
10- to 11-yr-olds	8
12- to 13-yr-olds	7
>14 yr	4
Diagnosis	
Five-finger hand	2
Triphalangeal thumb	4
RLD Blauth grade 5	9
RLD Blauth grade 4	8
RLD Blauth grade 3B	2
Not specified	4
Forearm involvement	
Thumb only	18
Bayne type 2	3
Bayne type 4	5
Unspecified radial dysplasia	3
Hand dominance	
Right	10
Left	12
Not documented	1
Hand included	
Right only	11
Left only	6
Both	6
Additional operations	
Opponensplasty	10
Centralization	6
Age at pollicization	
<12 mo	1
12–18 mo	10
19–24 mo	5
24–36 mo	10
>36 mo	3

RLD, radial longitudinal deficiency.

Range-of-Motion Assessment and Strength

Details of the measurements collected for range of motion and strength are shown. (**See Table, Supplemental Digital Content 1,** which shows the descriptions of all strength and range-of-motion measurements used in the standardized assessment, ***http://links.lww.com/PRS/C636.***) Kapandji opposition was modified to exclude a score of 4 when there were only three fingers present (Fig. 1). Strength values were compared to age-matched norms published by Lee-Valkov et al. and Mathiowetz et al.[16,17] Normal children improve their strength in all measures with growth.

Dexterity

The Nine-Hole Peg Test is a timed dexterity test that evaluates the ability to pick up nine 1¼-inch-long plastic pegs from a shallow dish, place them one at a time into a pegboard, and remove them one at a time back into the dish. A standardized test kit (Sammons Preston Roylan, Inc., Bolingbrook, Ill.) was used for all testing, and the total time to complete the task for each hand was recorded in seconds. Instructions from Mathiowetz et al.[18] were followed and test scores were compared to normative values for children aged 3 to 19 years.[19] In this evaluation, time to complete the test decreases with age in typically developing children.

The Box and Block Test evaluates manual dexterity by grasping, transferring, and releasing 1-inch wooden blocks repeatedly from one side of a large wooden box, over a raised partition, to the other side. A standardized test kit and instructions (Sammons Preston Roylan) was used to record the total number of blocks transported in 1 minute for each hand. Test scores were compared to normative data for children aged 3 to 19 years.[18,20] In this evaluation, the number of blocks increases with age in typically developing children.

Table 2. Range of Motion

Age Group (yr)	No.	Thumb Arc Average (SD) (degrees)	Thumb MP Flexion Average (SD) (degrees)	No.	Kapandji Opposition Score (SD)	Active Web Space (SD) (inches)	Distal Grasp (SD) (inches)
2	3	41.7 (17.6)	56.7 (32.1)	4	3.0 (1.1)	1.19 (0.13)	1.65 (0.82)
3	4	57.5 (17.1)	42.5 (17.9)	8	3.9 (2.5)	1.04 (0.84)	1.29 (0.65)
4	5	58.0 (21.7)	55.0 (30.5)	9	6.8 (1.5)	1.18 (0.67)	2.89 (0.96)
5	6	50.0 (20)	41.0 (21.8)	10	6.9 (2.4)	1.53 (0.77)	2.84 (1.10)
6	4	51.3 (26.3)	45.0 (10.0)	7	6.9 (2.4)	1.30 (0.48)	3.20 (0.99)
7	10	37.0 (15.8)	45.0 (31.8)	11	5.0 (3.2)	1.63 (1.11)	2.80 (0.83)
8	7	35.0 (9.1)	46.7 (30.9)	7	7.9 (1.5)	1.11 (0.67)	2.50 (0.88)
9	5	68.0 (29.5)	67.5 (15.5)	7	8.3 (1.3)	1.36 (0.45)	3.61 (1.27)
10–12	10	49.5 (27.8)	50.5 (19.8)	10	7.5 (2.2)	2.25 (0.67)	3.70 (1.10)
≥13	9	43.9 (22.9)	42.8 (30.1)	9	6.9 (1.9)	1.14 (0.69)	4.33 (1.26)

MP, metacarpophalangeal.

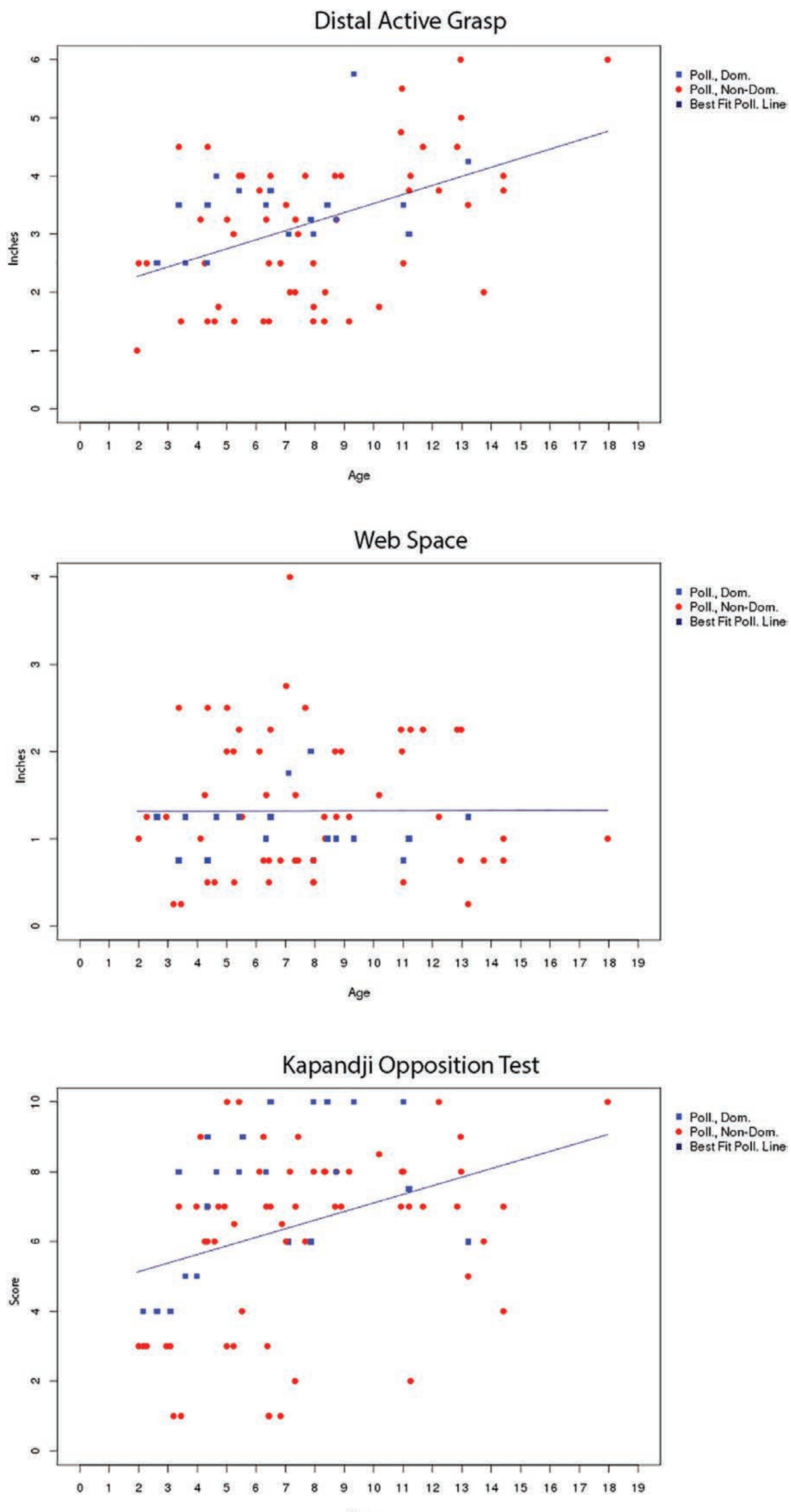

Fig. 3. Range of motion with age. Dominant hands are represented by *blue squares*, whereas nondominant hands are represented by *red circles*. Distal grasp span (*above*) was

The Functional Dexterity Test is a standardized measure that requires the ability to pick up, rotate, and replace 16 medium sized wooden pegs to their opposite end using a single hand. A standardized test kit (North Coast Medical, Gilroy, Calif.) and administration guidelines from Gogola et al. were used.[21] Patients were instructed to pick up each peg and turn it over within the hand, and to refrain from supinating the forearm or touching the table, and then to reinsert it into the pegboard as quickly as possible. Timed scores for each hand were recorded in seconds and compared to normative values for children aged 3 to 17 years and 17 years or older.[21,22] The number of pegs completed is divided by the time to completion to give a score in pegs per second, which increases with age in typically developing children.

The Jebsen-Taylor Hand Function Test of is a standardized assessment for children aged 6 to 19 years.[23] Only subtest 7 (heavy objects) was included in the current assessment, as it assesses ability to grasp large cylindrical heavy objects with age-matched normative data. Subjects must lift five 1-pound cans from the table and place them on to a testing board (Fig. 2). The time to complete this task was recorded in seconds for each hand and compared to normative data; the time to completion decreases with age in typically developing children.[24]

Statistical Analysis

Data were grouped by age, rounding down to the nearest year. Because some children were evaluated multiple times, the same child may appear in more than one age group. Descriptive statistics including mean and standard deviation were calculated for each year of age. Best fit lines were calculated and slopes are reported for change in performance per additional year of age. When they were available, data from normally developing children are presented alongside our data. Statistical comparison between our data and data from normal children was not performed. Our data follow a cohort of children over time and therefore are not easily compared to standardized data, which take separate cohorts for each age group.

Fig. 3. (*Continued*). measured in inches as the distance between the tip of the pollicized (*poll.*) thumb and the tip of the adjacent finger. The best-fit line shows an increase of 0.17 inch with each year of age. Web-space size (*center*) was measured by inserting wooden dowels of increasing diameter into the web space without causing passive extension. Size was recorded to the nearest ¼ inch. The best-fit line here demonstrates that web-space size did not change as children grew. Kapandji opposition (*below*) increased at a rate of 0.26 point for each additional year of age.

RESULTS

Twenty-three children with 29 pollicized thumbs evaluated over 94 visits met inclusion criteria for this study. Demographics are summarized in Table 1.

Range of Motion and Strength

Averages for Kapandji opposition,[25] thumb arc, metacarpophalangeal joint flexion, active web span, and distal active grasp span are listed in Table 2. Thumb arc and metacarpophalangeal joint flexion did not change noticeably with age. As children aged, distal active grasp span increased by 0.17 inch/year. In contrast, active web space size did not change with age (slope = 0.001). Finally, Kapandji opposition increased an average of 0.26 point/year. Data for distal grasp span, web-space size, and Kapandji opposition score are plotted in Figure 3, and averages by age are shown in Table 2.

Scatter plots of strength measurements for dominant and nondominant hands are shown with age-matched comparisons in Figure 4. Grip strength improved by 2.69 kg/yr of age overall, with dominant hands improving by 3.65 kg/year and nondominant hands improving by 2.66 kg/year. Tripod pinch and key pinch demonstrated a similar pattern, with overall improvements by an average of 0.58 kg and 0.46 kg, respectively. In tripod pinch, dominant hands improved 0.97 kg/year and nondominant hands improved 0.57 kg/year. In key pinch, dominant hands improved 0.67 kg/year and nondominant hands gained 0.46 kg/year.

Dexterity

Children with index pollicization averaged an additional 4.01 blocks/year of age on their Box and Block Test score. Using the dominant hand, children improved by 5.11 blocks/year; they improved by 3.94 blocks/year with the nondominant hand (Fig. 5, *left*).

On the Nine-Hole Peg Test, children reduced their time overall by 3.83 seconds each year. Dominant hands improved by 3.49 seconds and nondominant hands improved by 4.39 seconds each year (Fig. 5, *right*).

Children improved their functional dexterity test score by 0.026 peg/second for each additional year of age. Using the dominant hand, scores

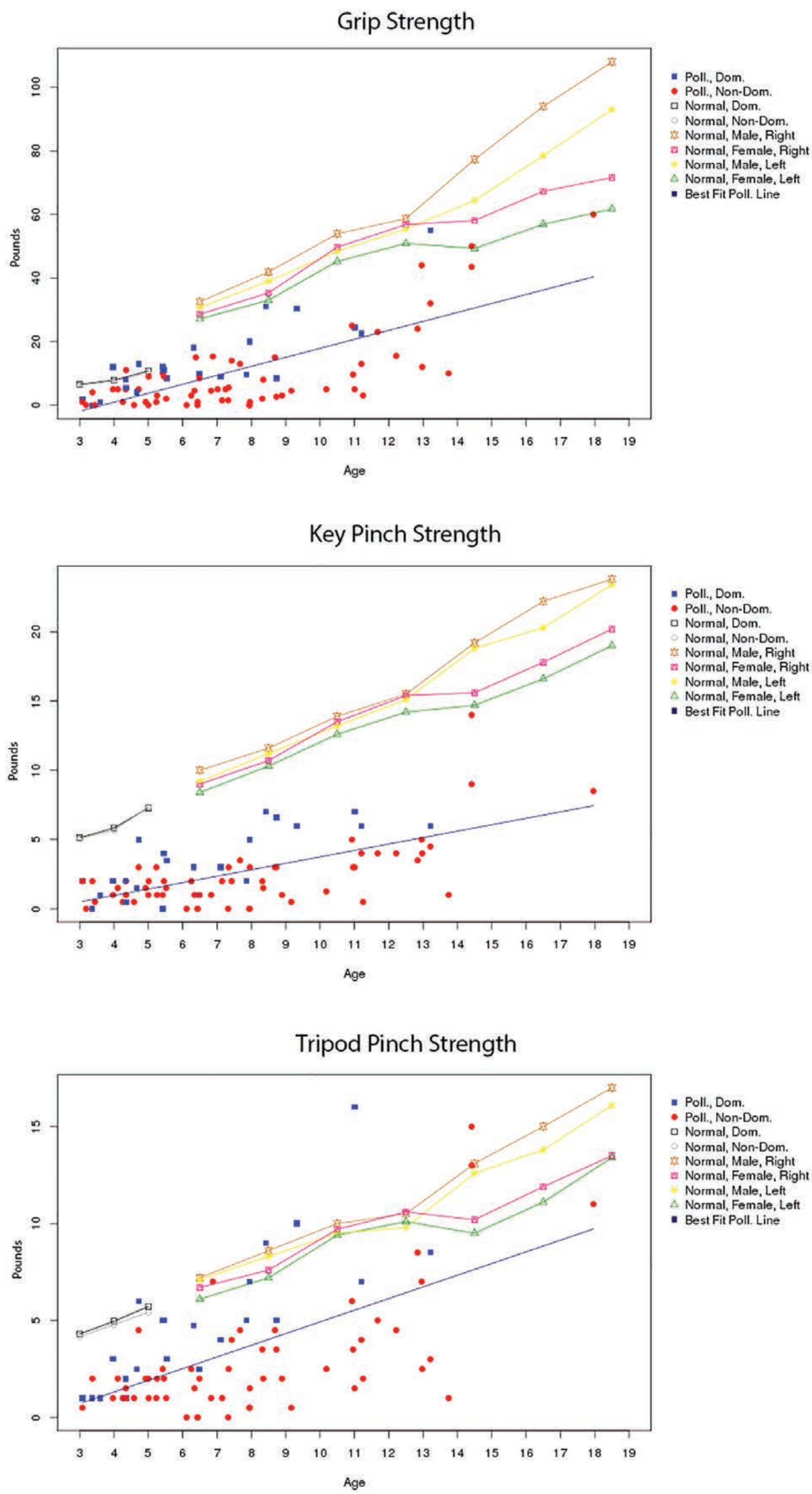

Fig. 4. Strength of pollicized thumbs. Dominant (*Dom.*) hands are represented by *blue squares*, and nondominant hands are depicted as *red circles*. Most pollicized (*Poll.*) thumbs performed

improved by 0.04 peg/second, whereas the nondominant hand scores improved by 0.026 peg/second for each year of age (Fig. 6, *left*).

On the Jebsen-Taylor Hand Function Test heavy objects portion, scores improved by 0.80 second overall for each year of age on average. Scores for dominant hands decreased by 0.54 second for each year and scores for nondominant hands improved by 0.95 second for each year (Fig. 6, *right*). Compared with age-matched normal hand performance, we found that dominant hands took an average of 120 percent of standard completion time and nondominant hands took 181 percent of standard completion time. Overall, our children took 154 percent longer than average for their age group to complete the task.

DISCUSSION

In this study, improvement was seen with age in all strength and dexterity scores. Dominant hands improved more than nondominant hands in all tests except for the Jebsen-Taylor Hand Function Test heavy objects portion. Range-of-motion scores improved in Kapandji opposition with age. Distal grasp span increased with age, but web-space size did not. Averages for grip, key pinch, and tripod pinch strength reported here are similar to what is seen in the literature for pollicized thumbs.[2,9,12,26]

Several authors have hypothesized that children with pollicization may undergo a greater-than-expected improvement in strength or dexterity for their age that might allow for "catching up" to their peers.[2,14] We did not observe a greater-than-expected rate of improvement in our study. Dominant hands matched the rate of improvement for typically developing children. Overall improvement averaged 0.026 peg/second for each year of age. Our cohort tended to perform better on the Functional Dexterity Test compared with outcomes reported in other studies.[2,9,12]

Visual inspection of the results of the Nine-Hole Peg Test compared to age-matched norms reveal that dominant hands perform nearly normally on this task after pollicization. Several nondominant hands also performed within the normal range in nearly every age group. Our cohort appeared to perform better than that reported by Lightdale-Miric et al., who published z-scores from −10.4 ± 10.7, with 100 percent of participants performing below the normal range for their age.[4]

Children in our study did not appear to "catch up" to typically developing children on the Box and Block Test. Lightdale-Miric et al. reported nine of 10 patients performing below average for their age, with z-scores of −3.4 ± 1.5.[4] Ekblom et al. report Box and Block Test scores ranging 11 to 63 blocks (average, 33.8), well below reported norms for typically developing children.[27] These reported scores were similar to our cohort's performance on this test.

Although the Jebsen-Taylor Hand Function Test is commonly used in the literature, many authors omit the heavy objects task because it is difficult for young children with very small hands to complete.[2,9,12] Tonkin et al. and Manske et al. found that the heavy objects portion of the test was the most useful task for discriminating between severe and mild forms of radial longitudinal deficiency.[6,11] Our cohort performed similarly to previously reported measures on this task.[6,11]

Kapandji opposition score increased with age. This may correspond to increasing strength observed with age, as more strength is required to bring the thumb toward the small finger. Unsurprisingly, distal active grasp span increased with age, likely because of the increasing size of the hand. In contrast, active web span did not change over time. Our thumbs appeared to lack active extension even when good flexion was present, and we did not observe any "rebalancing" of extensor tendons with time. This lack of extension positions the thumb at a relatively fixed angle with the adjacent finger even as the child grows. We were unable to determine the cause of this relative lack of extension from the data collected. Our results suggest that abduction and extension should be carefully positioned during pollicization surgery, because it is unlikely to increase as children age.

Strengths of the study include the length of follow-up, the repeated evaluations, and the thorough and consistent evaluation that each child underwent at each follow-up. These assessments allowed us to investigate trends in performance changes for several years after surgery. The majority of studies report outcomes measured at a single follow-up visit between 2.8 and 9.4 years after index pollicization had been performed.[1,3–7,9,13]

Our preferred dexterity test for children with thumb hypoplasia is the Nine-Hole Peg Test. The Box and Block Test may be easily performed without use of the thumb, whereas the Functional Dexterity Test may be too challenging for children who cannot use a "three-jaw-chuck" grasp.

Fig. 4. (*Continued*). below aged-matched normally developing children (*lines*) in grip strength (*above*), key pinch strength (*center*), and tripod pinch strength (*below*).

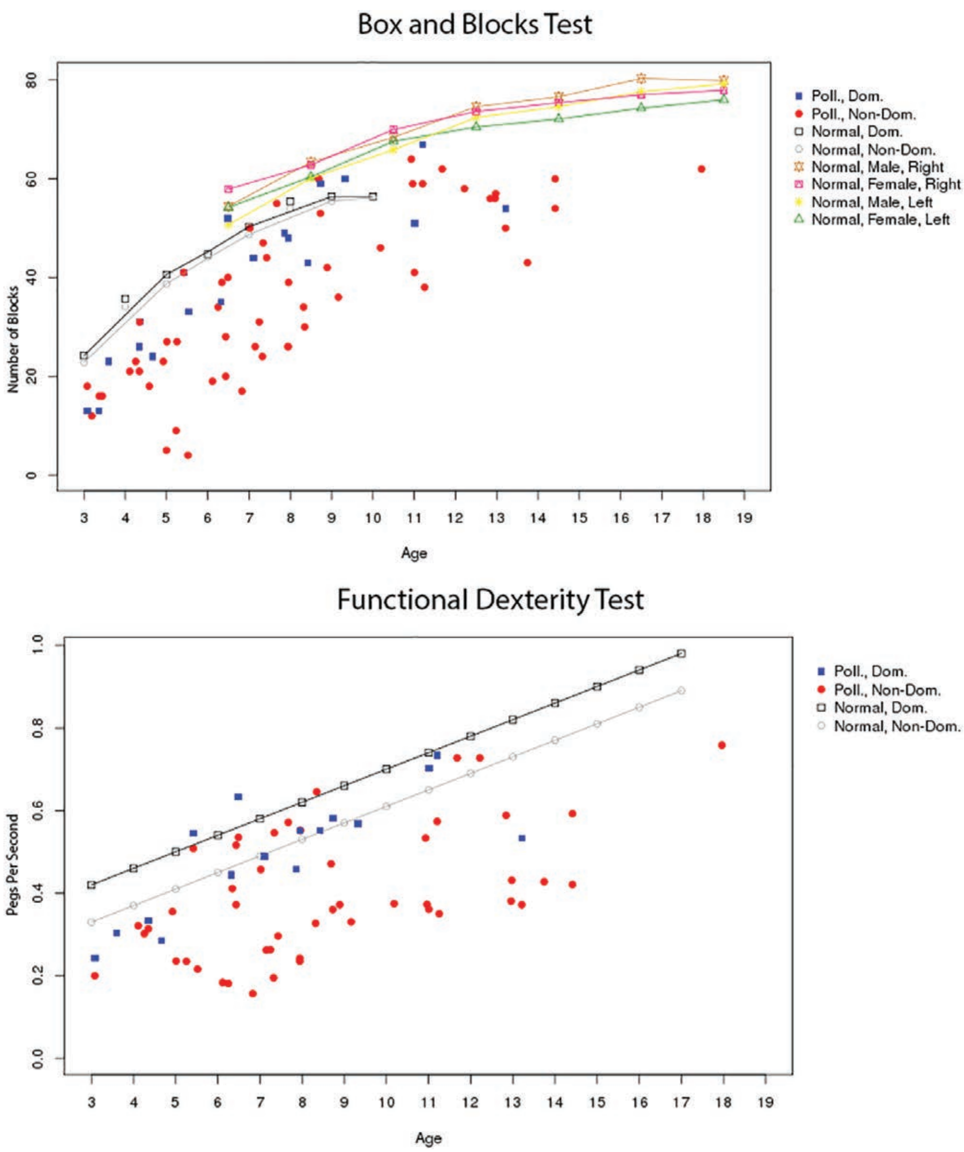

Fig. 5. Dominant (*blue squares*) and nondominant (*red circles*) pollicized thumb performance on the Box and Block Test (*left*) and the Functional Dexterity Test (*right*) compared with age-matched normally developing children (*lines*).

The Nine-Hole Peg Test presents a "just-right" challenge for most of our patients, including a manipulative task that can be accomplished with or without a well-functioning thumb.

We recognize several limitations to our study's design. First, our data were collected retrospectively and follow-up was scheduled on an as-needed basis at the convenience of the patient and clinician rather than on a set schedule. As a result, age groups contain differing numbers of children based on each child's follow-up schedule. We were unable to further stratify age groups based on isolated thumb involvement versus more severe forms of radial longitudinal deficiency, although this is recognized as a key factor in thumb performance after pollicization. Similarly, we were unable to perform subgroup analysis on children who had undergone either centralization or opponensplasty. Although these two adjunct procedures may certainly affect the outcomes of pollicization, we simply did not have adequate numbers to perform this subanalysis. Our goal was to report on outcomes reflective of our clinical practice, inclusive of children who undergo centralization and opponensplasty.

Another limitation of our study is that grasp and pinch style during each task was not routinely recorded. Other studies in the literature have attempted to distinguish between typical and atypical grasp or pinch styles by assigning specific tasks and then noting whether the thumb was used for

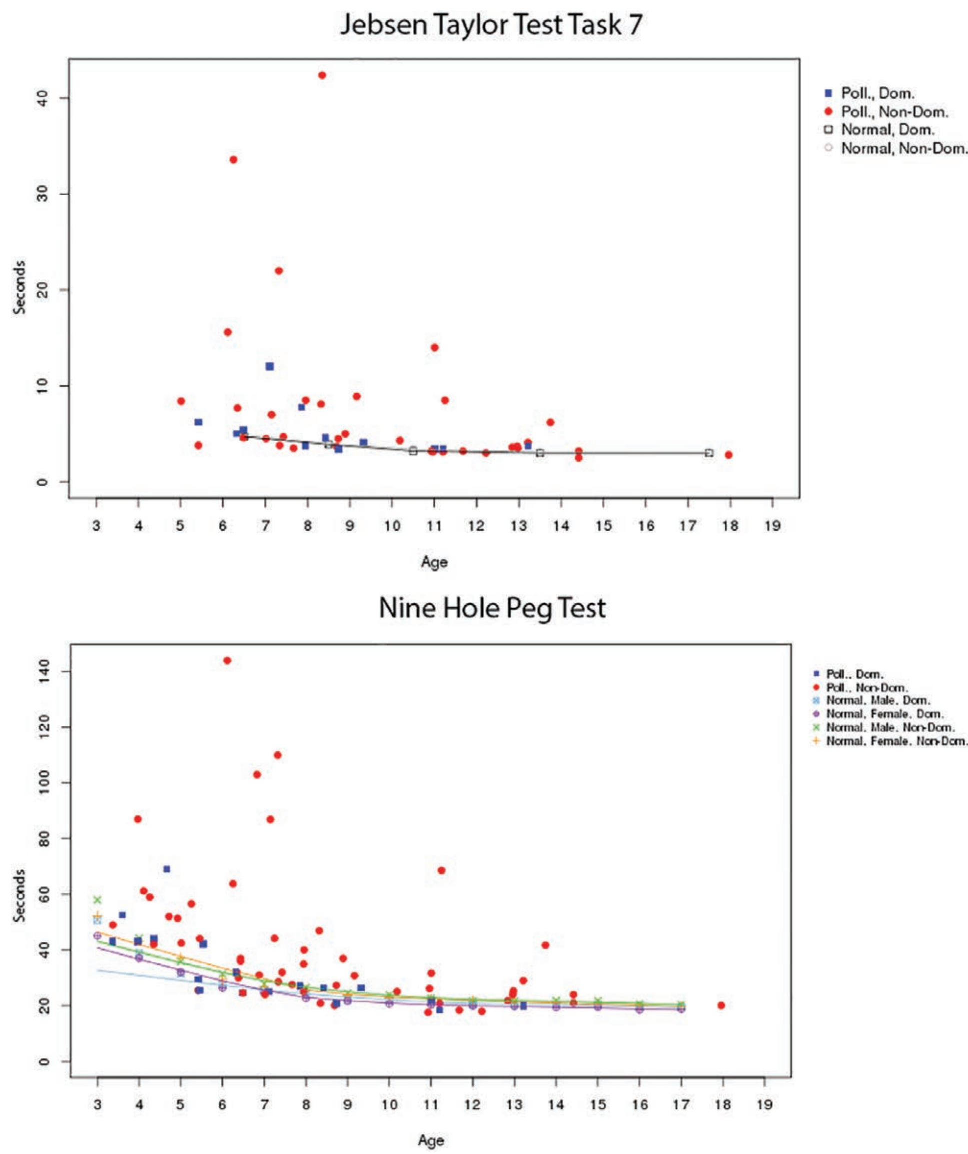

Fig. 6. Dominant (*blue squares*) and nondominant (*red circles*) pollicized thumb performance on the Jebsen-Taylor Hand Function Test heavy objects portion (*left*) and the Nine-Hole Peg Test (*right*) compared with age-matched normally developing children (*lines*).

the activity.[5–8,10,28] Although these evaluations add to the understanding of the successful outcome of pollicization, there is no standardized, validated measure of thumb use currently available.

Our study provides a better understanding of how motor development proceeds in children after index finger pollicization for congenital thumb hypoplasia. It also highlights that both hand dominance and age are confounders when looking at outcomes after pollicization. Wherever possible, researchers should avoid grouping children of disparate ages together when reporting results.

Three clinical recommendations follow from our results. First, we observed that the size of the first web space did not increase in children as they aged, and we therefore recommend careful positioning of the thumb at the index operation. Second, children who exhibit a loss of strength or dexterity from one visit to another should undertake more aggressive therapy programs, as this does not conform to expectations of function after pollicization. Finally, a direct assessment of thumb use is needed to better understand outcomes after pollicization surgery.

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