EDITOR'S CHOICE

A New, Direct Measure of Thumb Use in Children After Index Pollicization for Congenital Thumb Hypoplasia

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Purpose After index pollicization for congenital thumb hypoplasia, time-based hand dexterity tests do not indicate whether the new thumb is being used by a child. The Thumb Grasp and Pinch assessment (T-GAP) is a new outcome measure that classifies grasp and pinch styles to quantify use of the new thumb. The goal of this study was to establish concurrent validity and construct validity in the T-GAP.

Methods Data from children treated with index finger pollicization for congenital thumb hypoplasia were retrospectively reviewed. Measures of strength, range of motion, and scores on the Box and Blocks Test (BBT), 9-Hole Peg Test (NHPT), Functional Dexterity Test (FDT), and Task 7 (Heavy Objects) from the Jebsen-Taylor Test (JTT7) were recorded. Patients also completed the T-GAP consisting of 9 age-appropriate tasks, during which grasp patterns were classified. Spearman correlation coefficients were calculated comparing the T-GAP score with scores on the BBT, NHPT, FDT, and JTT7.

Results We evaluated 21 thumbs in 21 children an average of 71.7 months after pollicization surgery (range, 9−175 months). The T-GAP score was significantly correlated with BBT, NHPT, FDT, and JTT7 (R = 0.69, −0.60,−0.59, and −0.60, respectively). The T-GAP score was significantly correlated with tripod pinch, key pinch, and grip strength (R = 0.77, 0.75, and 0.71, respectively) and with opposition and grasp span (R = 0.50 and 0.52, respectively). The T-GAP was the only functional measure correlated with parent and patient satisfaction with thumb function.

Conclusions Concurrent validity was supported by significant correlations between T-GAP score for all 4 dexterity measures. Construct validity was supported by significant correlations between strength and range of motion of the thumb and T-GAP score.

Clinical relevance This evaluation may help surgeons and therapists better understand results after pollicization and determine whether the new thumb is being incorporated into daily activities. *(J Hand Surg Am. 2018;43(11):978−986. Copyright © 2018 by the American Society for Surgery of the Hand. All rights reserved.)*

Key words Congenital thumb hypoplasia, dexterity measure, index pollicization, outcomes, thumb use.

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THE GOAL OF INDEX FINGER pollicization in congenital thumb hypoplasia (CTH) is to provide a child with an opposable thumb that can participate in multiple grasp, pinch, and stabilization patterns needed during everyday activities.[1,2] There is no agreed-upon comprehensive method to assess hand function after pollicization; however, most authors have used a combination of range of motion (ROM), strength, dexterity, and parent and patient subjective evaluations to assess outcomes.[3–12]

There has not been a robust attempt in the literature to measure or classify thumb use after pollicization, likely because no validated measure of thumb use is available. Measurements of hand dexterity have been used as proxies for thumb function in children treated with pollicization and have included the Jebsen-Taylor Test of Hand Function (JTT7),[5,12–14] the Functional Dexterity Test (FDT),[12,14] the Box and Blocks Test (BBT),[9] and the 9-Hole Peg Test (NHPT).[15] All of these tests have established normative values for a wide age range and children may easily be compared with their unaffected age-matched peers.

The JTT7 was intended for children aged 6 and older to simulate various hand activities that include, but are not specific to, the thumb.[16,17] The BBT was originally designed to measure gross manual dexterity in adults with cerebral palsy, and requires repeated grasp and release of 1-in blocks but does not measure method of grasp and whether the thumb was used.[18,19] The FDT was specifically designed to evaluate dexterity and in-hand manipulation by rotating 16 wooden pegs 180° within one hand.[20] Children with radial longitudinal deficiency with absent or poorly functioning thumbs are observed to compensate for the lack of a "3-jaw chuck" grasp pattern by using a digital scissoring grasp, rotating the forearm and shoulder, or setting pegs down to reposition them to attain better times in this test. The NHPT requires a moderate level of hand skill and is easy and quick to administer.

These timed assessments of dexterity and function of the hand are an excellent means to assess activity limitation, but they may not reflect the degree to which the thumb is incorporated into daily activities. As Buck-Gramcko[2] pointed out, children with thumb hypoplasia are often dexterous even without a thumb.

The goals of the current study were to present the Thumb Grasp and Pinch assessment (T-GAP) as a new measure of thumb use and to present evidence to support its validity in evaluating children with CTH who have undergone index finger pollicization. The T-GAP classifies grasp and pinch style and produces a quantitative score related to thumb use in children aged 18 months to 18 years while performing age-appropriate tasks. We correlated T-GAP scores with scores on commonly used dexterity measures including the BBT, the NHPT, and the FDT to show the concurrent validity of this new measure. Construct validity was demonstrated by correlating T-GAP score with measures of strength and ROM.

MATERIALS AND METHODS

With institutional review board approval, we undertook a retrospective review of children aged under 18 years who had CTH and had undergone index pollicization. Children needed to have participated in at least one T-GAP evaluation as well as a comprehensive evaluation by a senior occupational therapist between 2006 and 2014. Bayne and Klug classification and Manske's modification of Blauth's classification were recorded when applicable, as was the underlying diagnosis, if known.[21] Children were categorized as having isolated thumb hypoplasia if they had a Bayne type N, 0 or I, and were classified as having forearm involvement for type II or greater.

Comprehensive evaluation

After surgery, children underwent evaluation of upper-extremity ROM, strength, dexterity, object handling, and subjective satisfaction using a standard protocol.

Range of motion

Opposition was measured using the Kapandji grade with a maximum grade of 10 for thumb opposition to the distal volar crease of the hand at the base of the little finger.[22] Proximal active web space depth was measured by positioning a wooden dowel into the proximal web space with the thumb held in maximal abduction. Dowels of increasing diameter in 0.25-in increments were attempted until the best fit was found and recorded. Distal active grasp distance was measured with the thumb in maximal abduction and extension. The distance between the tip of the thumb and the tip of the index finger was measured in inches. Thumb arc was defined as the degrees circumscribed by the thumb from a position of abduction and extension to a position of abduction and flexion at the metacarpophalangeal (MCP) joint. This was performed by asking the child to place the hand flat on a table with the thumb off and held parallel to the surface (0°) (Fig. 1A). The thumb was then actively rotated downward into maximum palmer opposition (90°) (Fig. 1B).

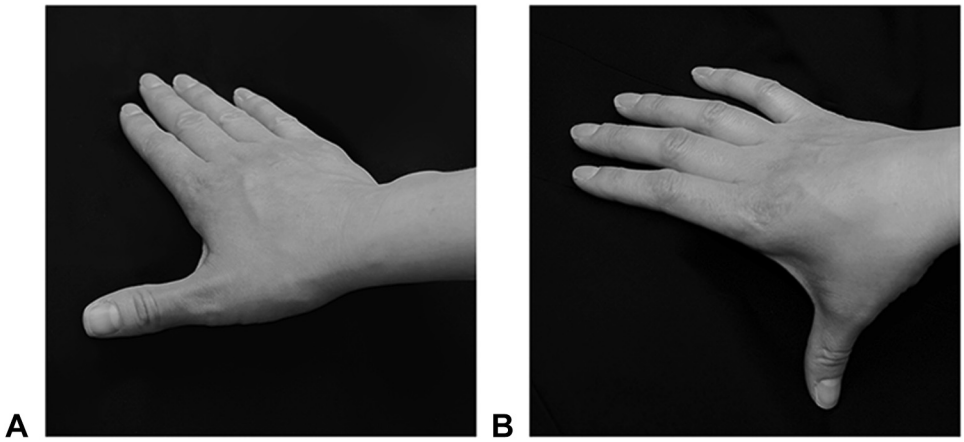

FIGURE 1: A Thumb arc is measured by having the child place the hand palm side down on a table, with the thumb in abduction and extension. **B** The thumb is then rotated so that it points to the floor and the arc of motion circumscribed is recorded as thumb arc.

Strength

Grip, key pinch, and tripod pinch strength were assessed using a Jamar handheld dynamometer (JAMAR Technologies, Inc., Hatfield, PA) and calibrated pinch gauges, with measurements recorded in pounds.[23] Key pinch and tripod pinch were recorded after a single maximum voluntary contraction. For grip strength, a single attempt was recorded for children aged 18 months to 4 years, whereas the average of 3 maximal attempts was reported for children aged 5 and older.

Dexterity

Thumb use was tested as described by Goldfarb et al[7] using 4 tasks. Children were asked to grasp and release different objects (large empty soda can; medium wooden block; and small plastic bead) and to turn a key in a padlock. Use of the thumb was recorded as 0 (not used) or 1 (used) and the score for each task summed for a total Goldfarb score.

Children aged 3 to 18 years performed the BBT according to administration guidelines by Mathiowetz et al[18] and Jongbloed-Pereboom et al.[24] Children aged 3 years and older completed the FDT without the adult time penalties and norms described by Gogola et al.[25] Children aged 4 years and older performed the NHPT with administration guidelines outlined by Sammons, Preston and Rolyon and normative data by Poole et al.[26] The large weighted cans portion (Task 7) of the JTT7 was completed by children aged 6 years and older per standardization age guidelines.[17]

Subjective satisfaction

Children aged 4 years and older were asked by the therapist to "Point to the face that shows how happy you are with the way your thumb works," using a modified Wong–Baker faces scale.[27] This scale is validated to evaluate pain in children as young as aged 3 years, and was adapted to assess satisfaction of 1 (not at all happy), 2 (somewhat, sort of), 3 (pretty much), 4 (very much), and 5 (love it). No score was recorded if patients did not understand the scale. The occupational therapist asked parents to rate satisfaction with the way the thumb worked using the same scale.

Thumb Use Assessment (T-GAP)

The T-GAP is an activity-based participation measure that was developed specifically to examine grasp and thumb use patterns in children after index finger pollicization. It was modeled after the Unilateral Below Elbow Test by one of the lead developers, a senior pediatric occupational therapist and clinical researcher (W.A.T.). The T-GAP includes half of the original Unilateral Below Elbow Test tasks that were selected by an experienced panel of 10 pediatric occupational therapists from across the United States.[28] These tasks were selected by the panel as developmentally appropriate tasks for 3 separate age groups, which are safe and interesting. Tasks included in the T-GAP were selected to promote specific grasp and pinch styles for toddlers (18 months to 4 years) and early school-aged (aged 5–7) and older (aged 8–18) children. It consists of 9 goal-specific activities that elicit hand and thumb use patterns for small, medium, and large grasp; tip and lateral pinch; resistance; manipulation; school; and activities of daily living (Appendix A, available on the *Journal's* Web site at www.jhandsurg.org).

Scoring was based on principles of hand development and skill using a 7-point hierarchical scale

FIGURE 2: Grasp styles without thumb use. **A** Palmar grasp is first in the developmental path and is scored as 1 point. **B** Ulnar scissor pinch receives 2 points whereas **C** radial scissor pinch is assigned 3 points, because hand skills tend to develop from ulnar to radial in typically developing children.

including abnormal (scores of 1−3) and normal (scores of 4−7) grasp patterns, with more mature patterns receiving higher points. Abnormal grasp and pinch patterns included palmar grasp without thumb (1 point) (Fig. 2A), ulnar scissor pinch (2 points) (Fig. 2B), and radial scissor pinch (3 points) (Fig. 2C). These 3 abnormal grasp patterns were scored based on the level of hand skill required. These were included because tracking their use helps to identify the versatility of the hand and may identify whether index pollicization has taken away a pinch pattern that was previously useful. In addition, there is a need in the literature for consistent terminology to describe these patterns. For example, instead of "cigarette pinch" we prefer "radial scissor grasp." Normal grasp patterns included cylindrical grasp with thumb (4 points) (Fig. 3A), lateral key pinch (5 points) (Fig. 3B), tip pinch (6 points) (Fig. 3C), and tripod pinch (7 points) (Fig. 3D). Scores for each task are then summed to produce a final T-GAP score (Appendix A). A video of a T-GAP assessment can be viewed in the online supplementary materials.

The scoring system was designed to reflect the sequence of the development of grasp and pinch patterns seen in infants. Use of the hand begins with a reflexive grasp and no thumb use. Hand skills develop from the palm out to the fingers, and from the ulnar to radial side of the hand. As fine motor control continues to develop, children learn to use key pinch, tip pinch, and tripod pinch out at their fingertips to stabilize and manipulate small objects requiring precision.[29,30] Grip styles employed by children during the evaluation were accordingly graded, with patterns involving the thumb assigned more points than patterns that did not use the thumb. Pinch styles at the fingertips were assigned more points than palmar grips.

Statistical analysis

The data set was composed of the first complete evaluation on record for each included patient. In bilaterally affected children, one hand was randomly selected for inclusion. Spearman correlation coefficients were calculated to compare T-GAP scores with scores on the BBT, NHPT, FDT, and JTT7. Interpretation of correlation coefficients was based on similar validation studies from the hand surgery literature.[24,31] Correlation coefficients ranging from 0.26 to 0.4 were considered low, 0.41 to 0.69 was considered moderate, and greater than 0.7 was considered strongly correlated. Range of motion and strength values were also correlated with the T-GAP score. Satisfaction score was converted into a binary score in which 4 or 5 out of 5 was graded as satisfied and 1 to 3 was graded as not satisfied. Logistic regression was used for correlation of categorical satisfaction variables with continuous T-GAP scores. We used a *t* test to compare average T-GAP scores between children with and without radial hypoplasia. A post hoc power analysis was conducted.

RESULTS

Table 1 documents patient characteristics. Average age at the time of evaluation was 8 years (range, 3−14 years). Two children performed tasks from the 18-month to 4-year group, 8 children performed tasks from the 5- to 7-year group, and 11 children performed tasks from the 8- to 18-year group. Evaluations were performed an average of 71.7 months after surgery (range, 9−142 months).

Dexterity

The T-GAP scores averaged 35.8 points across the cohort (95% confidence interval [CI], 31.0−40.6; range, 17−57 of a possible 0−63). Table 2 presents

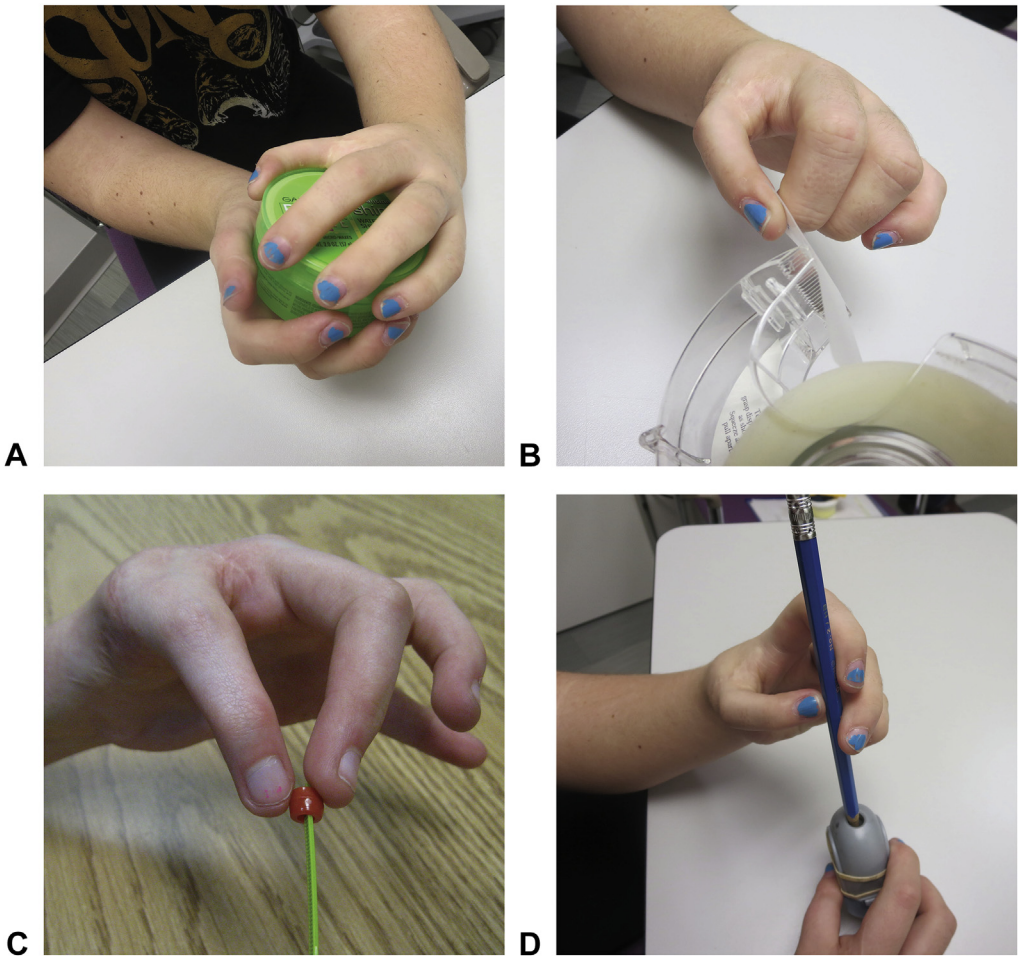

FIGURE 3: Grasp styles that employ the thumb. **A** Cylindrical grasp is more proximal and develops before the more distal grasps, which include lateral **B** key pinch, **C** tip pinch, and **D** tripod pinch. Tripod pinch is assigned more points in the T-GAP than tip pinch because it is often employed in manipulative tasks such as writing.

the correlation between timed dexterity tests and the T-GAP score. The T-GAP score was significantly correlated with all 4 hand dexterity tests ($P < .05$). The T-GAP scores were higher for children with hypoplasia limited to the thumb, compared with those with forearm involvement (40 and 29.1 points, respectively; $P < .05$). This study was not powered to determine whether children with thumb-only hypoplasia performed better on BBT, NHPT, FDT, and JTT7.

Strength and ROM

Factors associated with increased T-GAP score are presented in Table 3. Tripod pinch, key pinch, and grip strength were all strongly correlated with increased T-GAP score ($\rho = 0.77$, 0.75, and 0.71, respectively; $P < .05$ for all). Kapandji opposition score and active distal grasp were also significantly positively associated with a higher T-GAP score, but the relationships were moderate ($P < .05$ for all).

Pre-pollicization evaluations of the index finger were not widely available. Markers of index finger hypoplasia including lack of an MCP flexion crease, interphalangeal flexion crease, or MCP joint instability were not associated with a change in T-GAP score.

Thumb use

The Goldfarb score was moderately correlated with the T-GAP score ($\rho = 0.59$; $P < .05$). The Goldfarb score was significantly correlated with the BBT, NHPT, and FDT ($P < .05$ for all). Turning a key appeared to be the most difficult of the Goldfarb tasks; 8 of 21 children were unable to perform this task using the thumb. Scores on all 3 of these hand dexterity tests and the T-GAP were significantly higher for children who were able to use the thumb to turn a key in a lock ($P < .05$ for all), which implied that this task might be a good discriminator for thumbs with better function.

TABLE 1. Demographics of the Cohort

Diagnosis, n	
Five-fingered hand	1
Triphalangeal thumb	3
RLD Blauth grade 5	7
RLD Blauth grade 4	6
RLD Blauth grade 3B	2
Not specified	3
Forearm involvement, n	
Thumb only	13
Bayne type II	2
Bayne type IV	5
Unspecified radial dysplasia	1
Hand dominance, n	
Right	9
Left	11
Not documented	1
Hand included, n	
Right only	14
Left only	7
Additional surgeries, n	
Opponensplasty	8
Centralization	5
Age at pollicization, mo	
<12	1
12–18	11
19–24	1
24–36	6
>36	2

RLD, radial longitudinal deficiency.

TABLE 2. Spearman Correlation Coefficients Between the T-GAP and 4 Other Validated Hand Dexterity Measures

	Trial 1	
Dexterity Test	ρ	*P* Value
Box and Blocks Test	0.69	< .05
Functional Dexterity Test	−0.59	< .05
Nine-Hole Peg Test	−0.60	< .05
Jebsen-Taylor Test*	−0.60	.02

*Only Task 7, Heavy Objects, was performed.

TABLE 3. Spearman Correlation Coefficients Between T-GAP Score and Measures of Thumb Strength and ROM

	Trial 1	
Factor	ρ	*P* Value
Tripod pinch strength	.77	< .05
Key pinch strength	.75	< .05
Grip strength	.71	< .05
Active distal grasp span	.52	< .05
Kapandji opposition	.50	< .05
Thumb arc	.44	.05
Active web span	.22	.33

Visual analog scale satisfaction

Overall, 67% of parents and 69% of patients were satisfied with thumb function. Patients with higher T-GAP scores were significantly more likely to be satisfied with thumb function and to have parents who were satisfied with the thumb function (odds ratio [OR] = 1.2, 95% CI, 1.02–1.56; and OR = 1.17, 95% CI, 1.04–1.42; $P < .02$ for both) (Table 4). No other measures of hand dexterity were significantly correlated with patient or parent satisfaction (Table 4). Greater tripod pinch strength was associated with higher parent satisfaction with thumb function (OR = 1.73, 95% CI, 1.03–4.31) but not with patient satisfaction (OR = 1.51, 95% CI, 0.94–3.44).

DISCUSSION

The major goal of index finger pollicization in CTH is to produce a useful thumb that enables the child to perform a wider variety of activities with greater ease. Thumb use after pollicization has been difficult to assess directly; nevertheless, authors have noted that many children and adults will avoid using the thumb and continue to rely on trick movements and scissoring between fingers to grip and pinch.[5,11,32,33] Therefore, a direct measure of thumb incorporation into grasp and pinch styles would be of major value in assessing outcomes of pollicization.

Normal hand function relies heavily on good thumb function. Traditionally, it has been assumed that dexterity tests would assess thumb use adequately. The current results suggest that good dexterity correlates with more sophisticated grasp and pinch styles as measured by the T-GAP. The moderate correlations seen between T-GAP and established dexterity measures (BBT, FDT, NHPT, and JTT7) suggest that although they are related, hand and thumb function are not necessarily equivalent.

Another element to consider in this population is that of growing children following a typical pattern of

TABLE 4. Odds Ratios for Satisfaction With Thumb Function

Measure	Parent Satisfaction			Patient Satisfaction		
	OR	95% CI	*P* Value	OR	95% CI	*P* Value
T-GAP score	1.17	1.04–1.42	< .05	1.20	1.02–1.56	< .05
Key pinch	1.34	0.90–2.68	.18	1.70	0.97–4.71	.07
Tripod pinch	1.73	1.03–4.31	< .05	1.51	0.94–3.44	.09
Grip strength	1.09	0.99–1.33	.08	1.10	0.99–1.39	.09
Box and Blocks Test	1.03	0.96–1.10	.39	1.08	0.99–1.24	.08
Functional Dexterity Test	0.99	0.95–1.03	.56	0.98	0.92–1.04	.51
Nine-Hole Peg Test	0.99	0.96–1.03	.85	0.96	0.87–1.01	.11
Jebsen-Taylor Test	1.04	0.91–1.40	.63	1.00	0.89–1.17	.99

Patients with higher T-GAP scores were more likely to be satisfied with thumb function. The same cannot be said of the other dexterity measures.
CI, confidence interval; OR, odds ratio.

hand skill development from palmar to distal and from gross to fine motor movements. Several studies have found that affected children continue to develop strength and dexterity at a rate similar to the general population.[12,14] The T-GAP attempts to capture information regarding the maturity of a patient's hand skills through its grading system, which assigns more points to more highly refined grasp patterns. Using this framework, the goal of pollicization could be restated as enabling the child to continue to develop more mature grasp patterns. Finally, the T-GAP also collects information regarding atypical grasp patterns employed only by children with CTH, including palmar grasp without use of the thumb and radial and ulnar scissoring.

Some authors have attempted to evaluate the thumb by asking children to hold or manipulate objects of varying sizes.[3,7,13] Percival et al[3] recorded whether the thumb was used in activities requiring tip pinch and large grasp, and graded the difficulty of these 2 tasks. Alternative methods of completing the task were not allowed; therefore, scores may not have reflected the child's true preferred pinch patterns. Manske et al[13] classified thumb use as normal, modified, or absent for large and small objects. Finally, in an unvalidated measure, Goldfarb et al[7] recorded thumb use as a binary variable in 4 tasks. Although we found the T-GAP and Goldfarb scores to be correlated, this relationship was attributable to a single task: turning a key in a padlock. Because both tests include key pinch assessment, the correlation is unsurprising.

Strong correlations between thumb strength and ROM and T-GAP score lend evidence to the construct validity of the T-GAP. These relationships support the hypothesis that the T-GAP measures function of the thumb. Other studies have also found that strength and ROM are important factors for success after pollicization.[3,9,11,34,35] We found that the Kapandji opposition score and active distal grasp span were also significantly correlated with the T-GAP score, but this relationship was moderate. Strength is required to produce opposition, whereas grasp size determines the maximum-sized object with which a child can interact; therefore, these correlations are logical.

The link between satisfaction with thumb function and T-GAP score would seem to support this measure as a meaningful outcome for thumb function. A tool intended to rate thumb function should correlate with subjective satisfaction with thumb function. The T-GAP score was the only functional test that was significantly correlated with both parent and patient-rated satisfaction. Tripod pinch score predicted parent satisfaction but not patient satisfaction. The CI for patient satisfaction and tripod pinch was 0.94 to 3.44, which suggests that the sample size may not have been adequate to make definitive conclusions regarding that relationship. Further complicating the relationship between satisfaction and functional outcome, it is common in the literature to find high levels of patient and parent satisfaction after pollicization, which are not correlated with more objective measures of function.[5,10,12,14,15] This discrepancy is not well-understood, and prior authors did not offer an explanation for the relatively high levels of satisfaction with pollicization observed even in

the absence of good function or appearance. Nevertheless, some suggested that parent satisfaction scores should not be considered in outcome evaluations.[8]

In our opinion, the T-GAP has several advantages over existing assessments by allowing children to use any grip they like to complete the test, and because the selected tasks are short enough to hold a child's attention. In the authors' experience, the BBT may be difficult to complete for children aged 2 or 3 years because they may become distracted from the task before the full minute has elapsed. The FDT is difficult for children to complete without a well-functioning thumb. The NHPT presents an appropriate challenge and is quick to administer, but it can be performed quickly even without using the thumb.

The current study had several important limitations. First, the data set was small and consisted of 21 patients. Although we offer evidence in favor of the validity of the T-GAP as a measure of thumb use in CTH, more studies should be undertaken to verify the current results and establish their validity.

Any new assessment must be shown to be effective in 3 areas for robust testing: construct validity (the test measures what it sets out to measure), concurrent validity (agrees with existing measures) and interrater and intra-rater reliability. We have shown evidence that the T-GAP has both construct validity and concurrent validity, but interrater and intra-rater reliability must also be demonstrated and are currently under study.

Validated assessments of global hand function and dexterity are important in assessing overall function after pollicization for children with CTH. Existing time-based assessments do not provide insight into whether the child employs multiple grasp and pinch styles or whether a functional thumb has been produced. We have described a new, direct method of assessing thumb use in children after pollicization for CTH. Although further validation is necessary before we can recommend widespread adoption, the initial results are promising.

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APPENDIX A. Thumb Grasp and Pinch Assessment by Grasp Style, Task, and Age Group

Grasp Style	Tasks		
	Aged 18 mo to 4 y	Aged 5 to 7 y	Aged 8 to 18 y
Tip pinch	Pick up 3 pieces of cereal one at a time and release into container	Pick up 3 pennies one at a time and release into a piggy bank	Thread 5 plastic beads onto a zip tie
Lateral key pinch	Open a zipper pouch and remove 2 markers	Fold a 5 × 7-in paper in 2 and crease the fold line flat	Tear off a 2-in piece of tape from a tape dispenser
Small grasp	Pull cap off a chunky marker	Pull cap off a 0.5-in-diameter marker	Remove cap from a pen
Medium grasp	Separate 3 small plastic construction bricks	Make a telescope with a 5 × 7-in sheet of paper and a rubber band	Make a telescope from a 5 × 7-in sheet of paper and a rubber band
Large grasp	Open a jar of bubbles	Turn the end of a kaleidoscope 3 times	Twist off cap from a 3-in-diameter plastic container
Manipulation	Form a cupped shape out of play dough	Form a bowl out of play dough	Rotate a pencil 3 times in a handheld pencil sharpener
Resistance	Open a drawstring bag	Pull the string back on a slingshot	Pull the string back on a slingshot
School	Open a box of crayons	Color the inside of a circle shape using a crayon	Write name with a pencil
Activities of daily living	Put a sock on the foot over the toes	Tie shoelaces into a knot	Tie shoelaces into a bow

Grasp and pinch style scoring: 1 = palmar grasp, finger flexion (no thumb use); 2 = scissoring of ulnar digits (no thumb use); 3 = scissoring of radial digits (no thumb use); 4 = cylindrical grasp (thumb to proximal fingers); 5 = lateral key pinch (thumb to index); 6 = tip pinch (thumb to fingertip); 7 = tripod pinch (thumb to distal index/middle).