SCIENTIFIC ARTICLE

Nonvascularized Free Toe Phalangeal Transfers in Congenital Hand Differences : Radiological, Functional, and Patient/Parent-Reported Outcomes

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Purpose To evaluate radiologically, functionally and by patient-reported outcome measures, nonvascularized free toe phalangeal transfer (NVFTT) in the reconstruction of congenital short fingers with redundant soft tissue.

Methods Nineteen children who underwent NVFTT in 40 digits were studied. Of these, 13 patients with a mean follow-up of 5.2 years were assessed radiologically for epiphyseal patency, growth, growth rate, and length comparison with the contralateral toe. Eight children were available for an in-person follow-up. In these patients, we measured the pinch strength and range of motion. The Pediatric Outcomes Data Collection Instrument; the upper extremity, depression, anxiety, pain interference, and peer relationships domains of the Patient-Reported Outcomes Measurement Information Systems; and the aesthetic component of the Michigan Hand Questionnaire were used for the assessment of psychosocial impact.

Results An open epiphysis was found in 24 of 31 grafts. Among these, 20 of 21 grafts were in 9 children younger than 18 months and 4 of 10 grafts were in children older than 18 months at the time of operation. The mean growth was 3.4 mm. The mean growth rate was 1.3 mm/y. Length was 71.8% of the contralateral phalanx. The key pinch strength was 1.3 kg (2.6 kg on the normal side). The mean range of motion at the metacarpophalangeal joint was −4° to 65° flexion. Two proximal interphalangeal joints were stiff and 2 had range of motion of 0° to 30°. Children evaluated with Pediatric Outcomes Data Collection Instrument had high mean scores in all domains. The Patient-Reported Outcomes Measurement Information Systems scores were low for the upper-extremity domain. On the aesthetic component of the Michigan Hand Questionnaire, children gave higher scores than parents. Donor toes, though short, did not cause a functional disability.

Conclusions NVFTT reliably provides length, stability, and movement in short fingers with redundant soft tissue. In addition to good radiological and clinical outcomes, the patient-reported outcome measures support performing NVFTT in children. Surgery before 18 months, extraperiosteal harvests of grafts, and avoidance of tight skin closures are important. *(J Hand Surg Am. 2021;■(■):1.e1-e9.*

Type of study/level of evidence Therapeutic IV.

Key words Bone graft, congenital hand, symbrachydactyly.

Online Exclusive

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Received for publication April 30, 2020; accepted in revised form March 10, 2021.

No benefits in any form have been received or will be received related directly or indirectly to the subject of this article.

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0363-5023/■ ■-0001$36.00/0
https://doi.org/10.1016/j.jhsa.2021.03.012

Nonvascularized free toe phalangeal transfer (NVFTT) is a treatment option for providing length and stability to congenital short fingers with redundant soft tissue (Fig. 1). It is useful in symbrachydactyly, transverse deficiencies, and constriction ring syndrome.[1] Many studies report radiographic analyses of the growth of transferred toe phalanges.[2−11] Studies reporting both functional and psychosocial outcomes using validated outcome measurement instruments are unavailable. In this study, we report our experience in 19 children in whom 40 digits were reconstructed.

MATERIALS AND METHODS

Study sample

Between 2005 and 2019, 19 children underwent NVFTT in 40 digits at the Department of Plastic, Hand and Reconstructive Microsurgery, Ganga Hospital. Basic demographic data were available for all patients. There were 13 patients (31 grafts) available for follow-up, with a median follow-up time of 4.4 years (range, 6 months to 11 years). Final follow-up radiographs of these 13 children were available for the assessment of epiphyseal patency, growth, growth rate, and length in comparison to the contralateral toe. Six months of follow-up was chosen as the minimum follow-up period based on the reports in similar studies by Cavallo et al.[7] and Gohla et al.[8] Eight children (19 grafts) and their parents were available for in-person follow-up, and we measured the pinch strength and range of motion (ROM; 15 metacarpophalangeal [MCP] joints and 4 proximal interphalangeal [PIP] joints) and conducted psychosocial assessments using the Pediatric Outcomes Data Collection Instrument (PODCI); the upper extremity, depression, anxiety, pain interference, and peer relationships domains of the Patient-Reported Outcomes Measurement Information System (PROMIS); and the aesthetic component of the Michigan Hand Questionnaire (MHQ).

The study was approved by the institutional review board of Ganga Hospital. Necessary and appropriate consent was obtained from each patient, and the study protocol conformed to the ethical guidelines of the 1975 Declaration of Helsinki.

Radiological assessment

Radiographs were taken with the hand or foot placed 100 cm from the x-ray tube at settings of 250 mA, 48 kV, and an exposure of 16 msec. Radiographs taken at the final follow-up were studied. The epiphysis was considered to be open if it was seen distinctly with no bone bridging the gap. Total growth in length since the operation was studied by comparison with the radiograph taken at the time of surgery. The length of the transferred toe was compared with the corresponding contralateral toe phalanx. The mean yearly growth rate was calculated by studying the phalanges whose physes were open at the time of the final follow-up. As advocated by Radocha et al,[6] the sum of the millimeters of growth of all the phalanges transferred was divided by the sum of the number of years the physes were open following transfer. Radiographs were analyzed on Picture Archiving and Communication System, a digital imaging workstation.

Thirteen patients who had a radiograph at the final follow-up were grouped into those who underwent surgery at ≤18 months of age (group I) and those who underwent surgery after 19 months of age (group II) to allow comparison with preexisting series.[5,6,8,10]

Clinical assessment

Eight children who were available for in-person assessments had a mean age of 7.6 years (range, 23 months to 12 years). At a mean follow-up of 6.3 years, the pinch strength was measured in 7 children who used the reconstructed digit to hold the pinchmeter (Jamar; Performance Health Supply Inc), and ROM at the neo-joint was measured in all 8 children. All children were evaluated for donor site morbidity.

Patient-reported outcome measures

Patients were assessed using PODCI, PROMIS, and the aesthetic component of MHQ.[12−14] The domains of upper-extremity function, transfers and basic mobility, sports and physical functioning, comfort/pain, happiness, and global functioning in children aged 2−18 years were assessed using PODCI. The scores were on a scale of 0−100. Lower values indicated more disability, and higher values indicated better function or happiness.[15] Parents completed the questionnaire for children up to 10 years of age. Children older than 10 years completed it themselves. Only 7 children underwent a PODCI evaluation because 1 child was younger than 2 years of age.

The impact of a condition on the quality of life was assessed using PROMIS scales. Pediatric Short Form questionnaires covering the domains of social, physical, and mental health, including upper extremity, anxiety, depressive symptoms, peer relationships, and pain interference, were administered to the patients and their parents. The Patient-Reported Outcomes Measurement Information System was devised for children aged 5−17 years. Parents

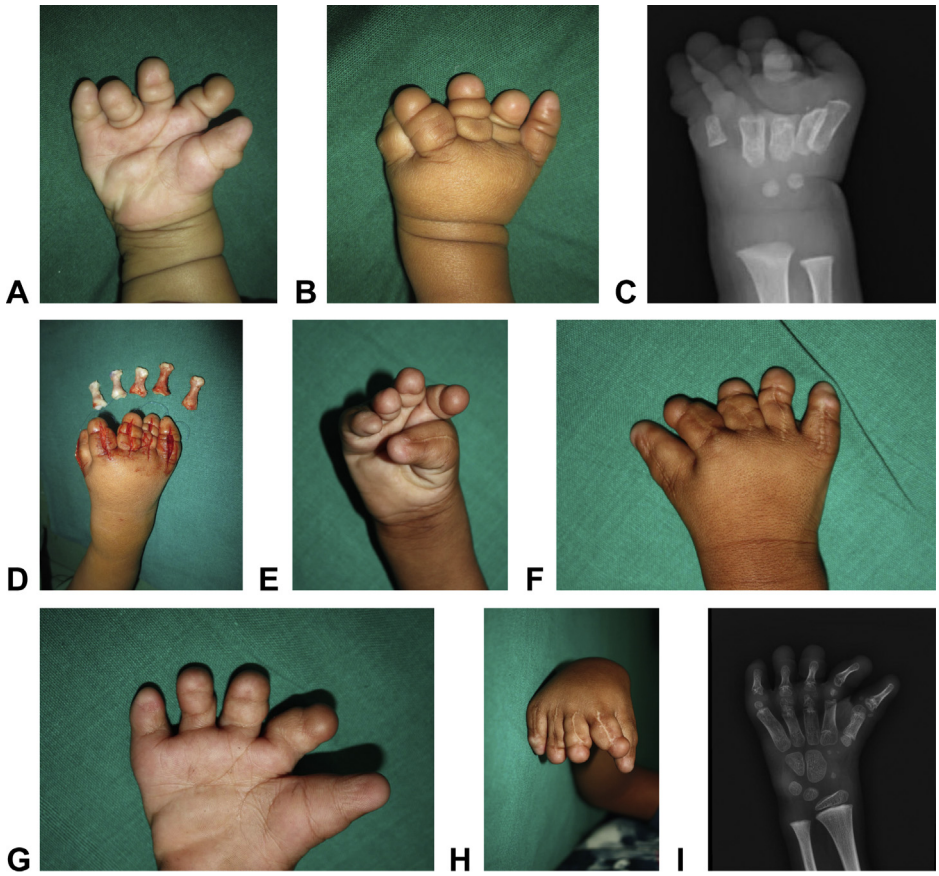

FIGURE 1: **A**, **B** Symbrachydactyly in a child at 1 year and 8 months with absent phalanges and redundant soft tissue. **C** Preoperative radiograph. **D** Harvest of 5 proximal phalangeal grafts, from the third and fourth toes of the left foot and the third, fourth, and fifth toes of the right foot. **E**–**H** Follow-up after 4 years and 5 months, at the age of 6 years and 1 month. **I** Final radiograph.

completed the forms for children younger than 8 years of age. The conversion tables available through the assessment center website were used for the calculation of PROMIS scores.[16] Only 6 children completed PROMIS because 2 were younger than 5 years. Parents completed the forms for the 2 children younger than 8 years.

The appearance of the hand was scored by administering the aesthetic component of the MHQ using responses on a 1–5 Likert scale. The sum of the scores ranged from 4 to 20. After conversion, the normalized score ranged from 0 to 100 (Table1).[17] Six children and 8 parents scored the form.

Surgical technique

Surgery was carried out under general anesthesia, supplemented by a brachial plexus block for postoperative pain relief. The digital stumps in the hand were opened through a dorsal longitudinal incision. A pocket adequate to insert the bone graft was made by soft tissue dissection. The importance of the size of the soft tissue envelope and the occurrence of skin necrosis secondary to an inadequate size has been reported.[8,9,11] The senior investigator's (S.R.S.) clinical observation was that the pockets that were too small were at the risk of tight closure and skin necrosis, early closure of the physis, and resorption of the bone graft. A longitudinal incision was made over the head of the metacarpal and soft tissue to expose the articular surface.

We chose the proximal phalanx of the fourth or third ray as the bone graft. In 2 patients where the pocket size was small, we harvested the middle phalanx of the fourth toe. A longitudinal incision was made over the toe phalanx, and the extensor tendon was retracted. An extraperiosteal dissection was made around the proximal phalanx. The metatarsophalangeal joint was opened, the collateral ligaments were divided, and the volar plate was incised. When the plantar side of the phalanx was reached, an incision was made in the flexor sheath at the site of its attachment to the phalanx, and the tendons were retracted to avoid injury to the flexor tendons. Harvest was completed by opening the proximal

TABLE 1. Aesthetic Part of the Michigan Hand Questionnaire*

Questions	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
1. I was satisfied with the appearance (look) of my hand.	1	2	3	4	5
2. The appearance (look) of my hand sometimes made me uncomfortable in public.	1	2	3	4	5
3. The appearance (look) of my hand made me depressed.	1	2	3	4	5
4. The appearance (look) of my hand interfered with my normal social activities.	1	2	3	4	5

*Please see Chung et al[17] for details on the Michigan Hand Questionnaire. In the evaluation of the aesthetic part, recoding of Question 1 was done such that the scores of 1 were changed to 5; 2 to 4; 4 to 2; and 5 to 1, and the raw scores were calculated. Raw scores ranged from 4 to 20. Normalization was done using the following equation: (raw score − 4)/16*100. Normalized scores ranged from 0 to 100.

interphalangeal joint and disarticulating the proximal from the middle phalanx. The flexor and extensor tendons were then sutured together to act as an "interposition spacer," as described by Buck-Gramcko and Pereira.[5] Bourke and Kay[18] have suggested inserting a cylindrical iliac crest bone graft as a spacer to reduce donor site morbidity. This technique was performed in 1 patient.

The harvested phalanx was placed in the soft tissue pocket, and its size was assessed. If the pocket was small, further dissection was done. The toe phalanx had to be rested on the articular surface of the proximal bone. This was achieved using a K-wire reinforced by sutures or by using sutures alone. A 1-mm (0.0393 in) K-wire was passed retrograde from the base of the toe phalanx proximally to the distal articular surface. The graft was then introduced into the pocket, and the K-wire was driven distally through the skin until it was just visible at the base of the transferred phalanx. The bone graft was then placed over the articular surface of the metacarpal, and the K-wire was driven proximally. Prolene sutures were inserted into the soft tissues at each quadrant at the base of the phalanx and the head of the metacarpal, and the sutures were tightened. Alternatively, Prolene sutures alone were used (Fig. 2). In 34 digits, K-wiring was used to reinforce the sutures, and suturing alone was used in 6 digits. When the pocket was just adequate, we used only sutures as additional K-wiring made the tip pale due to vascular compromise. The skin was then closed.

The limb was placed in an above-elbow cast for 4 weeks. K-wires were removed at 4 weeks, and gradual use of the hand was encouraged. The foot was immobilized in plaster for 2 weeks.

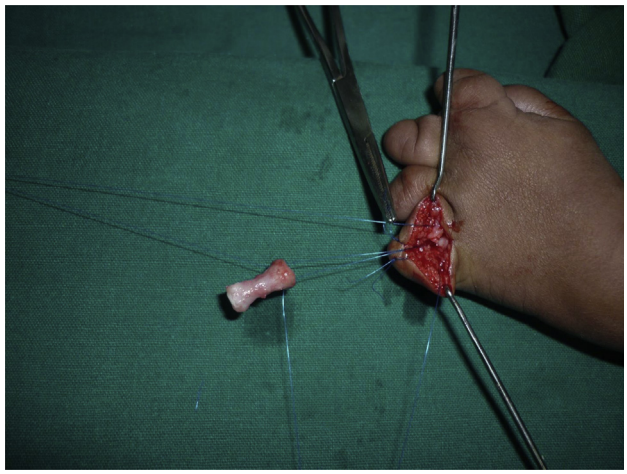

FIGURE 2: Technique of stabilizing the phalanx by sutures only. Sutures were inserted at 4 quadrants and then tightened.

RESULTS

Nineteen children (12 boys and 7 girls) underwent NVFTT reconstruction of 40 digits. Of the 19 children, 18 had symbrachydactyly and 1 had bilateral transverse deficiency. None had associated anomalies. Eight children underwent single-digit, 6 children 2-digit, 2 children 3-digit, 1 child 4-digit, and 2 children 5-digit reconstructions (Table 2). The age at surgery ranged from 6 to 29 months.

Radiographic assessment

Radiographic analyses were done on 31 grafts in 13 children. Nine of the 13 children with 21 grafts belonged to group I. Four children with 10 grafts belonged to group II. The epiphyseal patency, mean growth of the phalanges, yearly growth rate, and

TABLE 2. Number of Digits Reconstructed and Donor Toes Used

Serial Number	Number of Digits Reconstructed (n = 42)	Number of Grafts Used (n = 41)	Donor Toe Used
1	5	2 3	Bilateral 3 (surgery 1) Left 4, 5; Right 5 (surgery 2)
2	4	4	Bilateral 3, 4
3	1	1	Left 4
4	3	3	Left 3; Right 3, 4
5	1	1	Right 4
6	1	1	Left 4
7	2	2	Left 3, 4*
8	2	2	Left 3, 4*
9	2	2	Bilateral 4th
10	5	5	Left 3, 4; Right 3, 4, 5
11	1	1	Left 3
12	2	2	Left 3, 4
13	2	2	Right 3, 4
14	1	1	Left 4
15	1	1	Left 3
16	2	2	Bilateral 3
17	1	1	Right 4
18	1	1	Right 3
19	3	3	Left 3, 4; right 4

*The middle phalanx from the fourth toe was harvested along with the proximal phalanx from the third toe.

TABLE 3. Results of Radiographic Analysis

Follow-Up Examination	Results	Age at Operation	
		≤18 months	19–29 months
Number of grafts	31 (13 patients)	21 grafts (9 patients)	10 grafts (4 patients)
Open epiphysis	24/31	20/21	4/10
Mean growth in length, mm	3.4 mm	3.85 mm	1.3 mm
Growth rate, mm/y	1.3 mm/y	1.8 mm/y	0.5 mm/y
Comparative length, %*	71.8%	80.8% (6 patients)	59.2% (4 patients)

*A contralateral foot x-ray was available for 24 grafts in 10 children, with a follow-up of 5.4 years.

percentage of the growth compared with the corresponding contralateral phalanx are shown in Table 3.

The epiphysis was open in 24 of 31 grafts: 20 of 21 in group I and 4 of 10 in Group II. The mean increase in length was found to be 3.4 mm at an average follow-up of 5.2 years (range, 6–133 months). The average yearly growth rate for phalanges with open physes was 1.3 mm/y: 1.8 mm/y in group I and 0.5 mm/y in group II. In 10 children who had contralateral foot radiographs, with a mean follow-up period of 5.4 years, the length of 24 transferred toe phalanges was 71.8% of the length of the contralateral toe phalanx.

In 1 patient whose thumb and little finger were reconstructed, there was necrosis of the little fingertip with no involvement of the bone, but the transferred phalanx showed a resorption of 1.3 mm. The thumb phalanx showed a growth of 2.3 mm.

TABLE 4. Mean PODCI Scores for Parent Proxy and Adolescent Self-Report Groups With Normative Values[1]

PODCI Domains	Score (n = 7)	Parent of Child (n = 5)	Normative Values	Adolescents (n = 2)	Normative Values
Upper extremity	69.4	59.6	95.8 ± 9	94	99.3 ± 1.6
Transfers and mobility	97.0	95.8	99.1 ± 2.6	100	99.9 ± 0.6
Sports and physical functioning	91.0	88.2	91.8 ± 12.2	98	97.1 ± 3.8
Comfort/pain	91.4	92.4	92.0 ± 19.3	89	86.7 ± 14.5
Happiness with physical condition	99.3	99.0	86.8 ± 19.6	100	86.3 ± 12.5
Global functioning	87.1	84.0	94.6 ± 7.1	95	95.8 ± 3.8

TABLE 5. Mean PROMIS Scores for Parent Proxy and Self-Report Groups

PROMIS Domains	Score	Parent-Reported (n = 2)	Self-Reported (n = 4)
Upper extremity	42.7	29.7	49.2
Depression	38.2	39	37.7
Anxiety	44.4	43.6	44.9
Pain interference	36.5	37.8	35.9
Peer relationships	55.8	51.4	60.0

Clinical assessment

All children used their hands comfortably. The mean key pinch strength was 1.3 kg in 7 of 8 children (2.6 kg for the normal hand). Key pinch could not be measured in 1 child with an absent index finger.

The mean ROM at the MCP joint (15 digits) was 4° of hyperextension to 65° of flexion. There were 2 stiff PIP joints: 1 at a neutral position and the other at 45° flexion. The other 2 PIP joints had 0° to 30° of ROM.

Patient-reported outcome measures

The average PODCI scores were 69.4 (upper extremity; range, 13−100), 91 (sports; range, 67−100), 97 (transfers and mobility; range, 88−100), 91.4 (pain/comfort; range, 69−100), 99.3 (happiness; range, 95−100), and 87.1 (global functioning; range, 68−96; Table 4).

The mean PROMIS scores for upper extremity (42.7; range, 25.7−49.3), depression (38.2; range, 35.2−45.3), anxiety (44.4; range, 34.6−52.9), pain interference (36.5; range, 34−41.5), and peer relationships (55.8; range, 40.9−64.4) domains were within normal limits when interpreted using the cut point scores given for each domain at the assessment center (Table 5).[19]

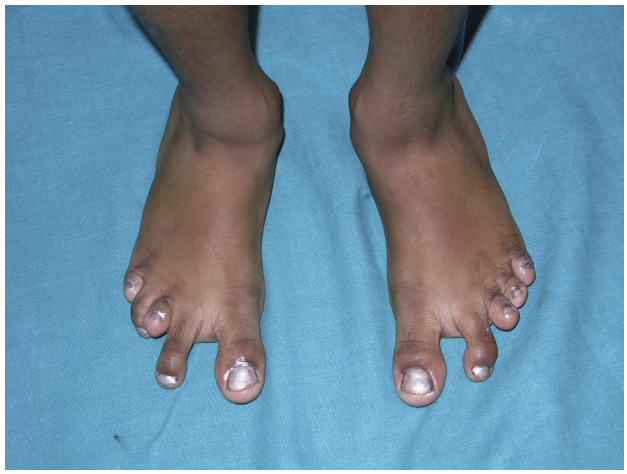

FIGURE 3: The donor feet of a child at 8-years follow-up. The proximal phalanges of the lateral 3 toes on the left side and the third and fifth toes on the right foot were harvested for the reconstruction of all 5 hypoplastic digits in the involved hand.

The aesthetic component of the MHQ was administered in 6 children and 8 parents. Children gave a high score of 78.1, whereas parents gave a score of 63.3 (out of 100).

Donor site morbidity

The donor toes were short in all 8 children, but there was no gait disturbance or toe instability (Fig. 3). No child had difficulty in wearing footwear or walking and running. Two parents expressed concern over the short toes. The child with a bone graft in the donor toe had minimal shortening and a better appearance but was lost to follow-up (Fig. 4).

DISCUSSION

The management of congenital short fingers with redundant soft tissue ranges from no reconstruction to microvascular-free toe transfer.[20] NVFTT is a simple, reliable, quick procedure with the following advantages: the phalangeal graft stabilizes and lengthens a

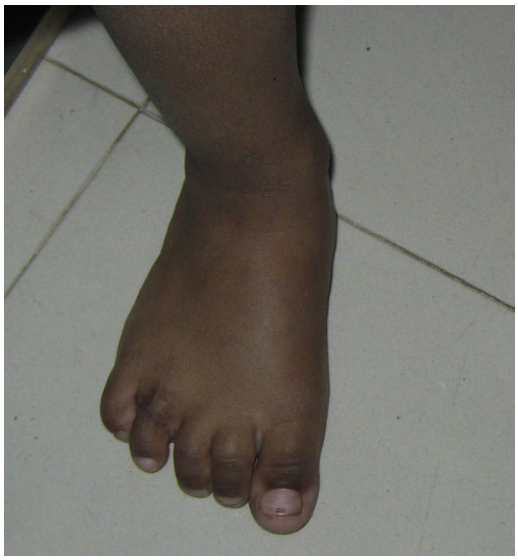

FIGURE 4: The donor foot of a child where the toe phalanx was reconstructed using a bone graft at 6-months follow-up. The proximal phalanx of the fourth toe from the right foot was harvested to reconstruct the hypoplastic little finger.

hypoplastic digit or allows the reconstruction of either an MCP or a PIP joint and can be the part of an overall plan for gaining prehension with procedures like microvascular toe transfer to reconstruct other digits (Fig. 5).[1]

Our experience is consistent with the literature in showing that 2 variables have a bearing on outcome: the technique of harvest (whether done subperiosteally or extraperiosteally) and the age at operation. Two studies published prior to 1980 have showed no growth of the graft.[2,3] Carroll and Green[2] performed 159 NVFTTs in 79 children and found epiphyseal closure in all. There was neither growth nor resorption. Rank[3] reported on 2 children, each aged 6 years, in whom the proximal segment of the toe phalanx was transferred. Of these, 1 child had complete resorption and the other had partial resorption but with an open physis when followed at 12 years and 7 years after surgery, respectively. The series by Carroll and Green[2] was of subperiosteal harvests, whereas that by Rank[3] did not mention the technique of harvest.

Goldberg and Watson[4] published their experience using extraperiosteal harvests in 29 transfers in 15 children and found epiphyseal patency in 10 of 11 children who had operations between 6 and 18 months of age, in 8 of 12 children between 1.5 and 5 years of age, and in 2 of 4 children between 5 and 13 years of age. All subsequent studies have used extraperiosteal harvests, with some using collateral ligaments and volar plates for anchoring at the new site. Our results mirror those of the previous studies.[4,5,6,11] There is a universal agreement that early surgery with an extraperiosteal harvest yields better outcomes.

Tension-free skin closure is also a determinant of outcomes. Inadequate pockets cause skin necrosis, infection, and an increased resorption rate. Kawabata and Tamura[11] trimmed the heads of 7 toe phalanges to accommodate the grafts into the soft tissue pockets. Despite this, 3 exhibited partial skin necrosis and showed little or no growth in the first 5 years. Conversely, the 4 trimmed phalanges that had no skin complications demonstrated open physes and a growth rate of 0.80 mm/y at the 5-year follow-up.

Many studies mention that, although postoperative growth was limited and ROM was modest, improvement in the hand function was satisfactory.[8,10] The reconstructed MCP joints moved better than the PIP joints. Even in patients who had stiff joints, the increased length and stability helped achieve better grip strength. When the thumb or the index digit undergoes reconstruction, children use the key pinch very well. Although some aspects of the hand function can easily be assessed by measuring grip strength, pinch strength, and ROM, these measures do not always reflect disability, which is a patient-reported construct.[21] The use of instruments such as PODCI, PROMIS, and MHQ give a clearer picture of the value of the surgical procedures. While analyzing PODCI scores, we found that the upper-extremity scores were lower compared with the normal population, as expected. However, these children had higher happiness scores than the normal population. High PODCI scores in all domains have been reported in children with congenital hand differences previously.[22] Parents (5/7) scored 99 and adolescents (2/7) scored 100 compared with normative values of 86.8 and 86.3, respectively.

The analysis of mean PROMIS scores revealed that although the parents (2/6) gave a low score (29.7) for upper-extremity function, the children who provided their own scores (4/6) gave a score of 49.2. This score shows that the self-reported upper-extremity function is essentially indistinguishable from that of the normal population. The scores for depression, anxiety, and pain were similar to normative values. In the domain of peer relationships, the children scored higher values in the good and excellent range when compared with parent scoring, suggesting that they adapt well to their disability and are good candidates for reconstructive efforts.[22–25] This suggests that when the children are too young,

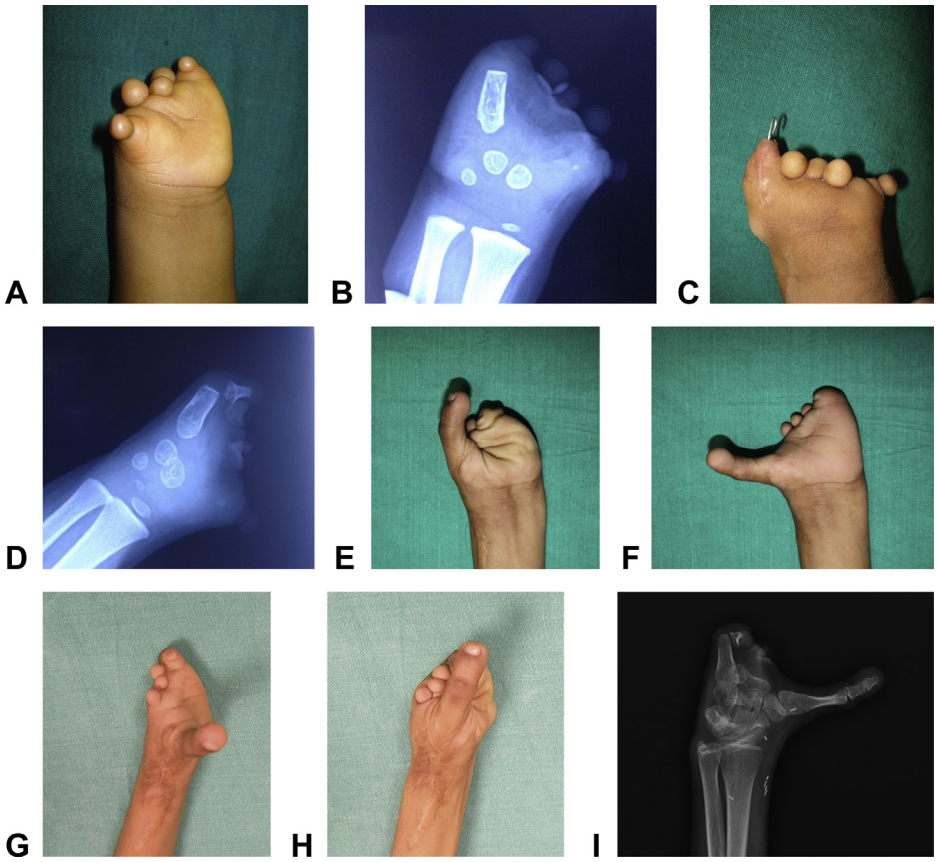

FIGURE 5: **A** Symbrachydactyly with the presence of only the fifth metacarpal. **B** Radiograph. **C** Nonvascularized free toe phalangeal transfer to augment the ulnar post. **D** Postoperative radiograph showing the bone graft, where the graft is flexed into the palm. **E–H** Following the second toe transfer. **I** Radiograph showing the survived phalanx 11 years after the free toe phalanx surgery and 8 years after the toe transfer, when the child was 13 years old.

a different form of assessment is probably more appropriate than a parent-proxy form.

It would be ideal to compare our results with the outcomes in children of a matched group who were not operated on; however, in our practice only 2 children did not undergo surgery. Such a comparison is absent in the literature.[26–28] Though Bae et al.[22] and Wall et al.[23] used these patient-reported outcome measures in children with symbrachydactyly, the sample population was not segregated in a way that allowed a comparison with our sample.

The aesthetic component of the MHQ was administered to 6 of 8 children and all 8 parents. Children gave a higher score when compared to the parents' score. Hand appearance can be a source of stress for children, and demonstrating the aesthetic benefits provides reassurance that surgical correction of deformities is worth pursuing.[29] The aesthetic part of the MHQ has not been validated in the pediatric population.[30] The MHQ has been administered to parents of pediatric patients to give responses on behalf of their children.[31]

Garagnani et al.,[32] in their study of 40 children with 126 donor toes stated that donor site morbidity for NVFTT was greater than previously documented and should be considered during surgical decision-making. Raizman et al.[33] reported that toe phalanx harvesting caused almost no measurable lower-extremity morbidity or dysfunction over mid- to long-term. In our practice, no child had functional problems, with the longest follow-up being 11 years. One child had bone grafting of the donor site. Anecdotally, it was thought that the aesthetic result was better with less shortening of the toe. Bourke and Kay[18] showed that this step causes better toe stability and length.

Microvascular toe transfer is another good option for reconstruction in these children. Kaplan and Jones[34] showed that children with hypoplastic digits achieved remarkable gains in function, sensation, and the ability to perform daily activities after microvascular toe transfer. A considerable percentage of these children had similar function compared with the normal population. NVFTT can be a complementary

procedure to toe transfer. In 1 child in our study group, we did NVFTT over the fifth metacarpal and a microvascular toe transfer for thumb reconstruction (Fig. 5). Because we used the third and fourth toes for NVFTT, the option of doing a second toe transfer still remains as the children grow up.

Although the main limitation of the study is the small number of patients who were available for clinical assessment and administration of patient-reported outcome measures, our study confirms the benefits of NVFTT in providing length, stability, and movement to short fingers with redundant soft tissue. Attention to well-established principles such as early surgery before 18 months of age, extraperiosteal harvests of bone grafts, and an adequate soft tissue pocket for tension-free skin closure are important to achieving good outcomes.

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