The "Hypoplastic" Thumb
Assessment and outcome following reconstruction

De "hypoplastische" duim
Evaluatie en uitkomsten na reconstructie

Marjolein de Kraker

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Chapter 1

**General introduction
and outline of this thesis**

GENERAL INTRODUCTION

Thumb function

One of the subjects in which the human being can be distinguished from other species in the animal kingdom is the anatomy of the hand.

The human hand has four fingers and a thumb, where the thumb differs from a finger, since it has 2 phalanges instead of three, a thumb is shorter than a finger and has a special CMC-joint which allows circumduction. The thumb has thenar muscles (opponens pollicis, abductor pollicis brevis, adductor pollicis brevis, flexor pollicis brevis) next to extrinsics (flexor pollicis longus, extensor pollicis longus and brevis and abductor pollicis longus). The thumb is therefore strong in various directions. The features of the human thumb make it opposible to the other fingers, a unique property.

In contrast to the thumb, a finger has 2 flexors (flexor digitorum superficialis and profundus) and 1 or 2 extensors (extensor digitorum communis/ extensor indices proprius) making it stable and strong in flexion and extension, but not in the other directions. When using a finger to create a thumb this should be taken into account.

Opposability/ opposition is a complex motion in several planes by a combination of *extension* by the extensor pollicis longus and extensor pollicis brevis; *palmar abduction* by the abductor pollicis longus and abductor pollicis brevis, *pronation* by the opponens pollicis and finally *flexion* by the flexor pollicis longus to achieve opposition as described by Kapandji (1) and Tubiana (2).

Thumb rotation during opposition is possible because of the unique anatomy of the carpometacarpal joint (CMC-joint) which is formed by the first metacarpal and trapezium, creating a saddle joint with reciprocally concave-convex surfaces.

A main part of opposition is created by palmar abduction of the thumb. Palmar abduction is an essential motion, since it defines the width of a person's grip and the ability to pinch (3).

Adequate total thumb function implies a stable carpometacarpal, metacarpophalangeal and interphalangeal joint with extension, flexion, abduction, adduction and opposition. Together with a first web which is wide enough and good sensory thumb function (4). Due to the wide range of motion of the thumb, it contributes for 40-70% to total hand function (5). Already in ancient Roman times soldiers were compensated for 40% of their wages when they lost their thumb on the battlefield (6). Therefore, it is irrefutable that loss of (partial) thumb function results in significant disability in daily life, even today.

Loss of function: causes

Loss of thumb function in adults is mostly caused by trauma or degenerative conditions such as fractures, nerve damage, CMC osteoarthritis, spasticity and rheumatoid arthritis.

In contrast, the main cause of loss of thumb function in children is caused by congenital anomalies.

Congenital anomalies

Congenital anomalies affect 1-2% of newborns and approximately 10% of those children have a congenital malformation of the upper limb. Congenital thumb anomalies account for approximately 11,2 % of all birth deformities of the hand. Of these deformities approximately 93% consists of hypoplasia and aplasia of the thumb (7). At the Erasmus MC in Rotterdam, out of 650 consecutively recorded patients, 50% of all referred patients had a thumb anomaly, of which 15% a bilateral thumb condition; 71% had other anomalies of the upper limbs and more than 30% were born with a syndrome. Deficiencies can be unilateral or bilateral and they can occur isolated, in combination with other deformities, or as part of a syndrome. Known associated sydromes are Holt-Oram syndrome, thrombocytopenia-absent-radius syndrome, VACTERL association (vertebral abnormalities, anal atresia, cardiac abnormalities, tracheoesophageal fistula, esophageal atresia, renal defects, radial dysplasia, lower limb abnormalities) and Fanconi anemia (7). The etiology is multifactorial, most probably comprised of environmental and genetic influences (8).

Thumb hypoplasia classification

In 1937, Muller (9) initially classified hypoplasia/ aplasia of the thumb into four categories according to the degree of deficiency. Blauth (10) later expanded this classification (Figure 1) in to five categories and in 1992 Manske and McCarroll (11) proposed a modification (Figure 2):

Blauth Type I: minor hypoplasia in which the thumb, though smaller than the contralateral thumb, functions quite normal. *Type II:* The thumb is smaller and less stable than normal. The hypoplasia has three elements: 1) an adduction contracture of the first web 2) lack of thenar muscles and the hand compensates by exhibiting 3) laxity of the ulnar collateral ligament that allows abduction of the metacarpophalangeal (MCP) joint. The skeleton, although small, has normal articulations. *Type III:* This progression includes Type II plus skeletal hypoplasia in which the carpometacarpal (CMC) joint is vestigial, intrinsic muscles are absent and the extrinsic muscles, when present, are rudimentary and anomalous. *Type IIIA:* this subdivision comprises extensive intrinsic and extrinsic musculotendinous deficiencies with intact

carpometacarpal joint. *Type IIIB*: this second subdivision comprises extensive intrinsic and extrinsic musculotendinous deficiencies with basal metacarpal aplasia. *Type IV*: floating thumb (pouce flottant). *Type V*: total aplasia of the thumb (7).

FIGURE 1. Blauth classification Type I-V (10).
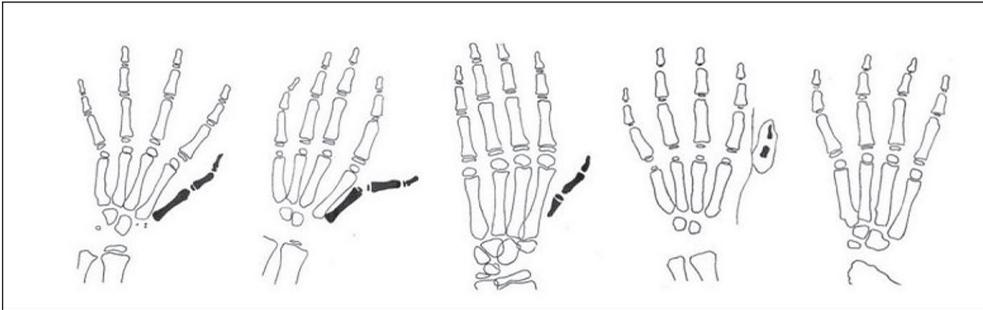
FIGURE 2. Blauth classification modified by Manske and McCarroll.

Type II thumb hypoplasia

Type IIIa thumb hypoplasia

Type IIIb thumb hypoplasia

Type IV thumb hypoplasia

Type V thumb hypoplasia

Longitudinal radial deficiency classification

Thumb hypoplasia is often part of a radial (pre-axial) underdevelopment of the upper extremity. Several classification systems have been developed to classify these longitudinal radial deficiencies. The most commonly used, is the system by Bayne and Klug (15) which has 4 sub-classifications: *Type I* displaying a short distal radius, *Type II* a radius in miniature, *Type III* partial radial absence and in *Type IV* there is complete absence of the radius (Figure 3).

Longitudinal radial deficiency often results in diminished pro- and supination of the wrist due to an abnormal position of the hand and wrist, referred to as "radial club hand" in literature.

Type I longitudinal radial dysplasia   Type II longitudinal radial dysplasia

Type III longitudinal radial dysplasia   Type IV longitudinal radial dysplasia

FIGURE 3. X-rays of longitudinal radial deficiency classification Type I-IV.

Interventions for thumb reconstruction

Interventions that are aimed at restoring thumb function can be divided into conservative and surgical. Due to the complexity of anomalies displayed in hypoplastic thumbs, surgical interventions are almost always mandatory to achieve sufficient functional and aesthetic results.

It is generally accepted that the type of surgical interventions depend on the severity of the hypoplasia. Blauth Type I is almost never treated, not conservatively nor surgically. This can be explained by the fact that it is often missed. When diagnosed, function is generally sufficient or good.

For Type II and IIIA thumb hypoplasia, tendon transfers with use of a flexor digitorum superficialis of the fourth finger (FDS IV) (Figure 4), the abductor digiti minimi (ADM) (16-23) or the extensor indices (EI) (4) can be performed to restore opposition. These tendon transfers are often combined with reconstruction of the ulnar collateral ligament, for example with use of one slip of a FDS4 tendon (24,25). In most cases widening of the first web space is needed to create a wide enough grip.

For Type IIIB opinions differ around the world. In some cultures, having a thumb and four fingers is mandatory. Therefore, some believe that reconstruction of the CMC joint, with for example microsurgical joint transfer, should be tempted (26-29). Others believe that amputation of the thumb followed by pollicisation of the index finger will result in better functional and aesthetic outcome (30-34).

Concerning Type IV and Type V there is little discussion. General consensus exists that in these cases, a pollicisation should be performed.

Pollicisation of the index finger is a well-established treatment; however, reports in literature assessing the postoperative success have been diverse (31,33,35-38). The diversity in outcome may be due to whether patients with LRD are included or not.

Interventions for longitudinal radial deficiencies

A patient with severe longitudinal radial deficiency (Type III-IV) presents with a wrist that is radially deviated. This can be corrected by distraction of the soft tissues at the wrist followed by positioning of the wrist on the distal end of the ulna. The affected forearm is also shorter. Distraction lengthening can be performed using an external fixator. It is possible to lengthen the forearm up to a maximum of 10-12 cm's.
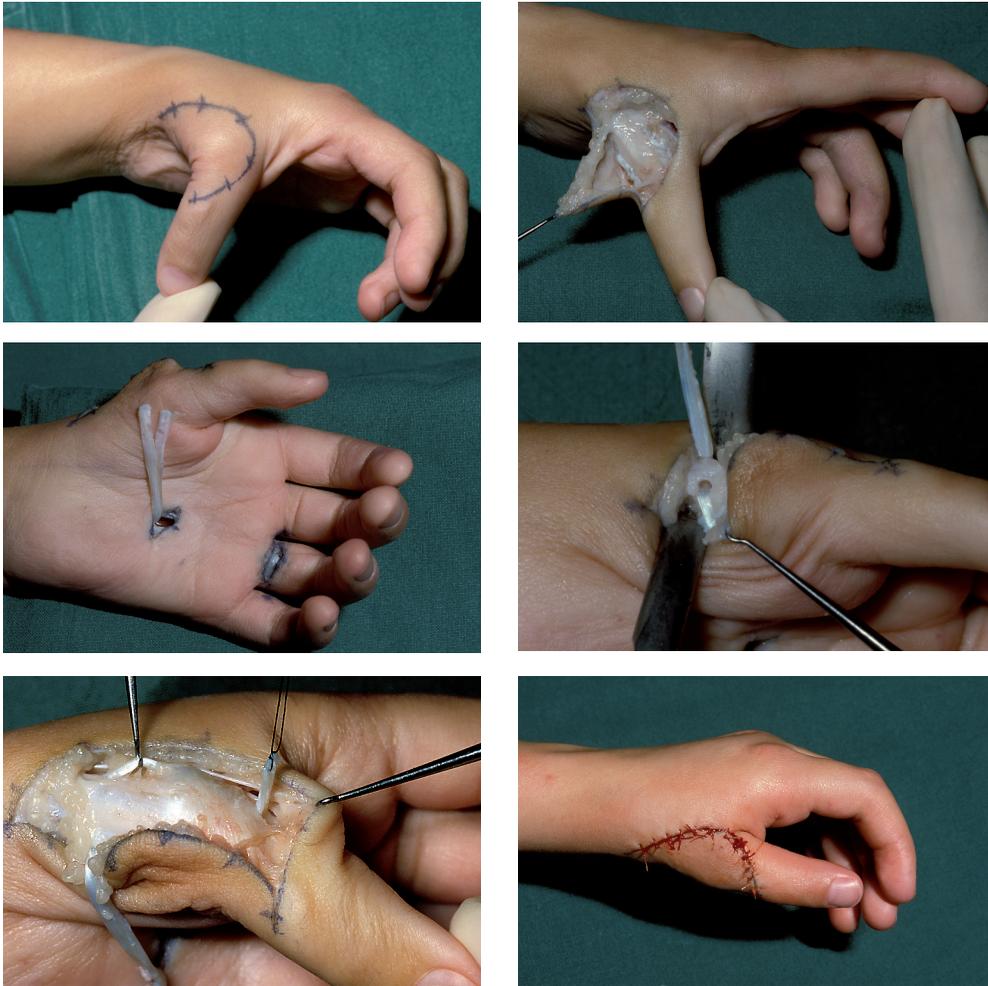
FIGURE 4. Technique displaying the use of a flexor digitorum superficialis of the fourth finger as tendon transfer.

OUTCOME EVALUATION

For evaluation of performed procedures, reliable and valid measurement methods are necessary. The patient needs to be studied from a holistic view. Several questionnaires are available to assess quality of life in patients with a hand deformity, such as the SF-36 (39). With these questionnaires health status can be assessed.

When looking specifically at the thumb, it's overall function is assessed based on range of motion, strength, joint stability and sensibility.

To assess grip strength of the hand, reliable measurement devices are available, for example the Jamar hand dynamometer (40,41), the Rotterdam Intrinsic Hand Myometer (RIHM) (41) which can be used to measure strength of individual intrinsic movements of the thumb, such as palmar abduction and opposition.

Joint stability is mostly assessed manually and possible laxity is measured with use of a conventional goniometer. The interphalangeal (IP) joint, metacarpophalangeal (MP) joint and carpometacarpal (CMC) joint were manually tested in the neutral position (42) and in 30° flexion (43). IP joints were classified as unstable when laxity was greater than 5°. Since there is no consensus on the threshold of MP joint stability, we defined the joint as unstable when the deviation was greater than 30°. CMC joints were classified as unstable when the dorsal shift test was positive.

Sensibility can reliably be tested in adults with use of the Semmes-Weinstein monofilaments (44), 2-point discrimination (2-PD) (45) and in children with the Sensibility Texture Index (STI) (46).

Range of motion (flexion and extension) is conventionally measured with a goniometer and was proven reliable in measuring these two movements of the four fingers. However, since the thumb is capable of more complex motions than just flexion and extension, a goniometer is limited in what it can reliably measure (47). Opposition is therefore mostly measured using the Kapandji score (1).

Although palmar abduction is a key parameter of hand function, it is rarely measured in standard clinical care, since a reliable instrument to measure palmar abduction was lacking.

In the past, several authors have measured palmar abduction angles (2,48,49) while others used distances between anatomical reference points (47,50,51). For these measurements, different devices have been used, such as goniometers, calipers, triangular pieces of wood with known angles, torque-controlled devices and 3D-video camera systems (1-3,48-50,52-58).

To simplify measurements, several authors have proposed to measure distances between anatomical landmarks instead of angles to determine palmar abduction. For example, Murugkar et al. (47) measured the Inter Metacarpal Distance (IMD) during maximum spread of the web space. For these measurements, the maximal distance between the middorsal points of the first and second metacarpal heads were measured.

The American Society of Hand Therapists (ASHT 1992) (51) adapted the "simple and conventional" method for measuring palmar abduction described in the "Guides to the Evaluation of Permanent Impairment" of the American Medical Association (50) in which they measure opposition. The ASHT measures the maximal distance from the distal palmar crease directly over the third MCP joint to the tip of the thumb.

THESIS OUTLINE AND AIMS

The goal of this thesis was to assess the efficacy of the procedures performed in patients with thumb hypoplasia, associated with or without longitudinal radial deficiencies.

This thesis is aimed at assessing outcome and comparing it to international outcome. Furthermore, we hope to assess whether and how to improve outcome and inform future patients and parents even better, prior to surgery.

To do so, there was a need for reliable measurement instruments. In our clinical setting it was concluded that for measuring palmar abduction, which is a key parameter of hand function, a reliable measurement instrument was lacking. After a thorough search, studying the measurement devices already developed, we listed all necessities for the design of a reliable and easy to use measurement device. In **Chapter 2** we present the design of our newly developed measurement device, the Pollexograph.

Its design is based on the concept that hand position should be standardized to obtain repetitive and reliable measurements. Since palmar abduction is a motion in one plane, it should be assessed in this plane along a smooth surface. The hand and thumb are placed in a manner that the Pollexograph measures the angle between the thumb and the index metacarpal, perpendicular to the plane of the palm.

In this chapter we show the first results of a reliability study performed with the Pollexograph, comparing it to the golden standard; a conventional goniometer. Hereafter, Pollexograph intra rater reliability was studied in a group of patients with a hypoplastic thumb.

The above-mentioned "Pollexograph-thumb" device measures the angle between the

1

first metacarpal and palm of the hand, plus the angle produced by possible laxity in the metacarpophalangeal (MCP) and interphalangeal (IP) joints. Therefore, we also evaluated an alternative Pollexograph application (59); the "Pollexograph-metacarpal" in which a ruler is placed over the first metacarpal to better resemble conventional goniometry measurements by leaving out laxity in these two joints. After a first pilot study, it was necessary to perform a more extensive reliability study.

In **Chapter 3** we studied intra and inter rater reliability of the Pollexograph-thumb and Pollexograph-metacarpal. Reliability was compared to 4 other palmar abduction measurement methods that were previously developed for healthy adults. The other measurement methods we studied were conventional goniometry (2,48,49), the Inter Metacarpal Distance (IMD) (47), the American Society of Hand Therapists method (ASHT method) (51), and the method described in "Guides to the Evaluation of Permanent Impairment" of the American Medical Association (AMA method) (50).

Many interventions aimed at improving palmar abduction are performed at an early age, such as in children with congenital hand deformities. However, to our knowledge, normative palmar abduction angles had not been reported in children before. We therefore collected normative data in 100 healthy children and we report on these data in **Chapter 4.** We also assessed intra rater reliability of the three most reliable measurement methods; the Pollexograph-thumb, the Pollexograph-metacarpal and the Inter Metacarpal Distance, in 63 healthy children.

Range of motion is classically measured in a static manner, for example with use of a goniometer. The Pollexograph is an example of such a static measurement device. However, range of motion and especially thumb workspace is dynamic. In addition to conventional, static methods, dynamic and more complex methods have been developed such as 3D-video cameras systems to measure range of motion of the thumb and fingers. A disadvantage of these systems is that one requires multiple markers and cameras and data analysis may be quite time consuming. We therefore tempted to assess range of motion in a dynamic, but relatively less complex manner, using an electromagnetic tracking device, the Minibird 500. The Minibird consists of one sensor, one receiver and one electronic unit connected to a personal computer or laptop. We measured maximal radial abduction, palmar abduction and circumduction in patients who underwent an FDS IV tendon transfer, patients that underwent a pollicisation and patients that underwent a pollicisation in combination with an abductor digiti minimi (ADM) tendon transfer. Additionally, these dynamic data were compared to the static data, measured previously. Minibird 500 results are presented and discussed in **Chapter 5**.

In thumb hypoplasia, several opponensplasties are available, the most used are the ADQ, EIP and FDS IV. In our center, for Blauth Type II/IIIA thumb hypoplasia the most common performed tendon transfer is the flexor digitorum superficialis IV (FDS IV). In general, one slip of this tendon is used to restore opposition and one slip is used to recreate the ulnar collateral ligament to stabilize the metacarpophalangeal joint.

Chapter 6 describes outcome of total thumb function in patients with a Type II and Type IIIA hypoplastic thumb that underwent an FDS IV tendon transfer. Joint stability, thumb and hand strength, sensibility and thumb range of motion were measured. Patient satisfaction regarding functional and aesthetic outcome was measured using a VAS-scoring system.

From literature it is known that pollicisation of the index finger is a well-established treatment in Type IIIB-V hypoplastic thumbs (30,31,34). However, reports in literature assessing postoperative success have been diverse. There is a lack of quantative outcome studies and little is known about outcome differences between patients with mild (Type I-II) and severe (Type III-IV) longitudinal radial deficiencies (LRD). We therefore, quantitatively assessed thumb function after a pollicisation in mild and severe longitudinal radial deficiency and compared outcome to healthy controls. We report on these data in **Chapter 7.**

In **Chapter 8** we would like to address our points of discussion, the conclusions, recommendations and future plans that rised during working on this thesis.

REFERENCES

1   Kapandji, A. Clinical test of apposition and counter-apposition of the thumb. *Ann Chir Main* 1986; 5(1): 67-73.

2   Tubiana R, Thomine JM, Mackin E. Examination of the Hand and Wrist: Martin Dunitz Ltd, 1998.

3   Bhattacharya S, Pandey SD, Chandra R, Singh GK. Documentation of the first web space angle. *J Hand Surg* (Edinburgh, Lothian). 1989; 14:298-300.

4   Hovius SE, Versnel SL, Zuidam JM. Tendon transfers in reconstructive hand surgery. In: Tendon transfer in the congenital hand. London, Informa Healthcare, 2005: 121-132, Chapter 9.

5   Vekris MD, Beris AE, Lykissas MG, Soucacos PN. Index finger pollicization in the treatment of congenitally deficient thumb. *Ann Plast Surg.* 66:137-142.

6   Landi A. Reconstruction of the thumb. Chapmann and Hall Medical, 1989.

7   Gupta A, Kay SP, Scheker LR eds. Methods and results in aplasia and hypoplasiaof the thumb. The Growing Hand. 1st Ed. London. Mosby 2000 255-268.

8   Zguricas J, Bakker WF, heus H, Lindhout D, Heutink P, Hovius SE. Genetics of limb development and congenital hand malformations. *Plast Reconstr Surg* 1998 Apr; 101 (4): 1126-35.

9   Muller W. Die angeborenen Fehlbildungen der Menschlichen Hand. Leipzig, Thieme 1937.

10 Blauth W. Indication and technics of the index-finger thumb in aplasia of the thumb. *Handchirurgie.* 1969;1: 28-33.

11 Manske PR, McCarroll HR, Jr. Reconstruction of the congenitally deficient thumb. *Hand Clin.* 1992;8: 177-196.

12 Tonkin MA. On the classification of congenital thumb hypoplasia. *J Hand Surg Br.* 2014, 39: 948-55.

13 Smith P, SivakumarB, Hall R, Fleming A. Blauth II thumb hypoplasia: a management algorithm for the unstable metacarpophlangeal joint. *J Hand Surg Eur* 2012, 37: 745-50.

14 Hovius SE, van Nieuwenhoven C. Commentary on Tonkin. On the classification of congenital thumb hypoplasia. *J Hand Surg Eur* Vol 2014 Nov; 39 (9): 956-7.

15 Bayne LG, Klug MS. Long-term review of the surgical treatment of radial deficiencies. *J Hand Surg Am.* 1987,12: 169-79.

16 Cawrse NH, Sammut D. A modification in technique of abductor digiti minimi (Huber) opponensplasty. *J Hand Surg Br.* 2003, 28: 233-7.

17 Huber E. Hilfsoperation bei Medianuslähmung. *Deutsche Zeitschrift für Chirurgie.* 1921:271–275.

18 Latimer J, Shah M, Kay S. Abductor digiti minimi transfer for the restoration of opposition in children. *J Hand Surg Br.* 1994; 19:653-658.

19 Littler JW, Cooley SGE. Opposition of the thumb and its restoration by abductor digiti quinti transfer. *J Bone Joint Surg Am.* 1963, 45: 1389–96.

20 Manske PR, McCarroll HR, Jr. Abductor digiti minimi opponensplasty in congenital radial dysplasia. *J Hand Surg.* 1978, 3: 552-9.

21 Oberlin C, Gilbert A. Transfer of the abductor digiti minimi (quinti) in ra dial deformities of the hand in children. *Ann Chir Main.* 1984, 3: 215-20.

22 Ogino T, Minami A, Fukuda K. Abductor digiti minimi opponensplasty in hypoplastic thumb. *J Hand Surg Br.* 1986, 11: 372-7.

23 Upton J, Taghinia A. Abductor digiti minimi myocutaneous flap for opponensplasty in congenital hypoplastic thumbs. *Plast Reconstr Surg.* 2008;122: 1807-1811.

24 Cooney WP, Linscheid RL, An KN. Oppostion of the thumb: an anatomic and biomechanical study of tendon transfers. *J Hand Surg Am.* 1984: nov;9 (6): 777-86.

25 Kozin SH, Ezaki M. Flexor digitorum superficialis opponensplasty with ulnar collateral ligament reconstruction for thumb deficiency. *Tech Hand Up Extrem Surg.* 2010, 14: 46-50.

26 Foucher G, Greant P, Merle M, Michon J. Congenital abdnormalities of the thumb. Contribution of microsurgical technics. *Chirurgie* 1998; 114 (1): 60-66.

27 Foucher G, Medina J, Navarro R. Microsurgical reconstruction of the hypoplastic thumb, type IIIB. *J Reconstr Microsurg.* 2001 Jan; 17 (1): 9-15.

28   Shibata M, Yoshizu T, Seki T, Goto M, Saito H, Tajima T. Reconstruction of a congenital hypoplastic thumb with use of a free vascularized metatarsophalangeal joint. *J Bone Joint Surg Am*. 1998; 80: 1469-76.

29   Matsizaki H, Toishi S, Yoshizu T. A Blauth IIIB hypoplastic thumb reconstructed with a vascularized metatarsophalangeal joint transfer: a case report with 28 years of follow-up. *Hand Surg*. 2009;14: 63-68.

30   Ceulemans L, Degreef I, Debeer P, de Smet L. Outcome of index finger pollicisation for the congenital absent or severely hypoplastic thumb. *Acta Orthop Belg*. 2009 Apr; 75(2): 175-180.

31   Buck-Gramcko D. Pollicization of the index finger. Method and results in aplasia and hypoplasia of the thumb. *J Bone Joint Surg Am*. 1971;53: 1605-1617.

32   Taghinia AH, Littler JW, Upton J. Refinements in pollicization: a 30-year experience. *Plast Reconstr Surg*. 2012 Sep 130(3): 423-33.

33   De Kraker M, Selles RW, van Vooren J, Stam HJ, Hovius SE. Outcome after pollicisation: comparison of patients with mild and severe longitudinal radial deficiency. *Plast Reconstr Surg. 2013 Apr;131(4):544-5.*

34   Kozin SH. Upper-extremity congenital anomalies. *J Bone Joint Surg Am*. 2003;85-A:1564-1576.

35   Buck Gramcko D. Complications and bad results in pollicization of the index finger. *Ann Chir Main Memb Super*. 1991; 10(6): 506-12.

36   Foucher G, Medina J, Lorea P, Pivato G. Principalization of pollicization of the index finger in congenital absence of the thumb. *Tech Hand Up Extrem Surg*. 2005;9: 96-104.

37   Staines KG, Majzoub R, Thornby J, Netscher DT. Functional outcome for children with thumb aplasia undergoing pollicization. *Plast Reconstr Surg*. 2005;116: 1314-1323; discussion 1324-1315.

38   Clark DI, Chell J, Davis TR. Pollicisation of the index finger. A 27-year follow-up study. *J Bone Joint Surg Br*. 1998;80: 631-635.

39   Ware JE, Sherbourne CD. The MOS 36-item short-form health survey (SF-36). Conceptual framework and item selection. *Med Care* 1992 Jun; 30 (6): 473-83.

40   Molenaar HM, Zuidam JM, Selles RW, Stam HJ, Hovius SE. Age-specific reliability of two grip-strength dynamometers when used by children. *J Bone Joint Surg Am*. 2008;90: 1053-1059.

41   Schreuders TA, Roebroeck ME, Jaquet JB, Hovius SE, Stam HJ. Measuring the strength of the intrinsic muscles of the hand in patients with ulnar and median nerve injuries: reliability of the Rotterdam Intrinsic Hand Myometer (RIHM). *J Hand Surg Am*. 2004;29: 318-324.

42   Kozin SH, Ezaki M. Flexor digitorum superficialis opponensplasty with ulnar collateral ligament reconstruction for thumb deficiency. *Tech Hand Up Extrem Surg*. 2010 Mar;14(1): 46-50.

43   Catalano LW 3rd, Cardon L, Patenaude N, Barron OA, Glickel SZ. Results of surgical treatment of acute and chronic grade III (corrected) tears of the radial collateral ligament of the thumb metacarpophalangeal joint. *J Hand Surg Am*. 2006, 31: 68-75.

44   Weinstein S. Fifty years of somatosensory research: from the Semmes-Weinstein monofilaments to the Weinstein Enhanced Sensory Test. *J Hand Ther*. 1993; 6:11-22; discussion 50.

45   Lundborg G, Rosèn B. Hand function after nerve repair. Acta Physiol. 2007; 189: 207-217.

46   Jerosch-Herold C. Assessment of sensibility after nerve injury and repair: a systematic review of evidence for validity, reliability and responsiveness of tests. *J Hand Surg Br*. 2005; 30:252-264.

47   Murugkar PM, Brandsma J.W., Anderson A.M., Khadka Gurung, Yam Pun. Reliability of Thumb Web Measurements. *J Hand Ther*. 2004:58-63.

48   Brand PW. Deformity in leprosy. In Cochrane RG (ed) Leprosy in Theory and practice (ed2) Bristol UK; John Wright & Sons Ltd, 1964:485-496.

49   Hartigan BJ, Stern PJ, Kiefhaber TR. Thumb carpometacarpal osteoarthritis: arthrodesis compared with ligament reconstruction and tendon interposition. *J Bone Joint Surg Am*. 2001; 83-A:1470-1478.

50   American Medical Association. Guides to the Evaluation of Permanent Impairment. American Medical Association, 4th Edition 1993:(3) 28-29.

51   American Society for Therapy of the Hand. *Clinical Assessment and Recommendations*. 2nd ed, 1992.

52   Harvey L, de Jong I, Goehl G, Armstrong B, Allaous J. A torque-controlled device to measure passive abduction of the thumb carpometacarpal joint. *J Hand Ther*. 2006; 19:403-408; quiz 409.

53   Degeorges R, Parasie J, Mitton D, Imbert N, Goubier JN, Lavaste F. Three-dimensional rotations of human three-joint fingers: an optoelectronic measurement. Preliminary results. *Surg Radiol Anat*. 2005; 27:43-50.

54   Kuo LC, Chiu HY, Chang CW, Hsu HY, Sun YN. Functional workspace for precision manipulation between thumb and fingers in normal hands. *J Electromyogr Kinesiol 2009*; 19(5): 829-39.

55   Chiu, HY, FC Su. The motion analysis system and the maximal area of fingertip motion. A preliminary report. *J Hand Surg (Br)* 1996; 21(5): 604-8.

56   Kuo LC, Su FC, Chiu HY, Yu CY. Feasibility of using a video-based motion analysis system for measuring thumb kinematics. *J Biomech*. 2002; 35:1499-1506.

57   Su FC,   Kuo LC, Chiu HY, Chen-Sea MJ. Video-computer quantitative evaluation of thumb function using workspace of the thumb. *J Biomech* 2003; 36(7): 937-42.

58   Coert JH, van Dijke HG, Hovius SE, Snijders CJ, Meek MF. Quantifying thumb rotation during circumduction utilizing a video technique. *J Orthop Res* 2003; 21(6): 1151-5.

59   de Kraker M, Selles RW, Schreuders TA, Hovius SE, Stam HJ. The Pollexograph: a new device for palmar abduction measurements of the thumb. *J Hand Ther*. 2009, 22: 271-6.

1

PART I

Thumb Measurements

Chapter 2

The Pollexograph®:

a New Device for Palmar Abduction

Measurements of the Thumb

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ABSTRACT

Purpose: To introduce a new goniometer, the Pollexograph®, to easily measure palmar thumb abduction, and to compare its reliability with conventional goniometry.

Methods: Fourteen hand therapists measured palmar abduction on the same healthy subject with the Pollexograph and a conventional goniometer. In addition, intra rater reliability of the Pollexograph was studied in 21 patients with a hypoplastic thumb.

Results: Variance between measurements of the same subject measured by the hand therapist was 2-6 times smaller with the Pollexograph compared to conventional goniometry. Pollexograph intra rater reliability in hypoplastic thumb patients was excellent (ICC= 0.98-0.99).

Conclusions: We have introduced a new tool to measure palmar abduction in clinical care, the Pollexograph. The Pollexograph reduces variability between raters when measuring the same subject compared to conventional goniometry and had excellent reliability in hypoplastic thumb patients.

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INTRODUCTION

For hand function, palmar abduction motion of the thumb is essential, since it determines the width of a person's grip and ability to pinch with the thumb and oppose the other fingers of the hand (1). Palmar abduction is traditionally defined as the angle between metacarpal 1 and 2 with the thumb maximally abducted and is conventionally measured with a goniometer (see, amongst others, Hartigan et al (2), Brand (3) Tubiana (4)). Because this angle is difficult to measure and therefore the measurement is generally considered to have poor reliability, a number of alternative measurements or definitions have been proposed. For example, the International Federation of Societies for Surgery of the Hand (IFSSH) (5) has defined palmar abduction as the movement in which the thumb metacarpal moves away from the index metacarpal, perpendicular to the plane of the palm. The American Society of Hand Therapist (ASHT) (6) measures the maximal distance from the distal palmar crease directly over the third MCP joint to the tip of the thumb. The American Medical Association (AMA) (7) measures the maximal distance from the distal palmar crease directly over the third MCP joint to the IP joint.

Palmar abduction differs from radial abduction in which the thumb moves in the same plane as the palm of the hand. However, palmar abduction is an essential part of opposition which is composed by projection, abduction, adduction, rotation and finally opposition as described by Kapandji (8) and Tubiana (4). Palmar abduction is obtained by a combination of extension, opposition, abduction and rotation at the carpometacarpal joint (CMC-joint) and can be diminished in a number of pathological conditions, such as in patients with CMC osteoarthritis, hypoplastic thumbs, nerve paralysis, spasticity, rheumatoid arthritis, fractures, dislocation of the thumb and burns. A number of interventions are specifically aimed at increasing palmar abduction, such as splinting regimes, first web plasties and tendon transfers. For efficacy evaluation of these procedures, reliable and valid measure methods for palmar abduction are important.

Conventionally, palmar abduction is measured with a goniometer as the angle between metacarpal 1 and 2 with the thumb maximally abducted (2-4). In addition to the conventional method, more complex and time-consuming methods have been developed. 3D-video camera systems have been used to analyze motion of thumb and fingers (9-12). For this, a standardized set up with a minimum of 2 or more cameras and multiple markers are required as well as relatively time-consuming and complex data analysis. Besides motion analysis, a number of other devices have been developed to measure thumb abduction angles. For

example, Harvey et al. (13) designed a torque controlled device to measure passive palmar abduction of the right hand. Shrinivasan (14) placed triangular pieces of wood with known angles into the thumb web to measure web angles. Similarly, Schwanholt and Stern (15) used cone shaped models and Bhattacharya (1) used dental compound molded into the web space to measure passive palmar abduction. While some of these more complex methods may provide more detailed information than the conventional goniometer method, they seem to be impractical for use in daily clinical care.

To simplify measurements, several authors have proposed to measure distances between anatomical landmarks instead of angles to determine palmar abduction. For example, Buck-Gramcko (16) and the American Society of Hand Therapists (6) proposed to measure the maximal distance between palm plane and tip of the thumb in full palmar abduction. Similarly, Murugkar et al. (17) measured the Inter Metacarpal Distance (IMD) during maximum spread of the web space.

Most of these methods are associated with significant limitations. From our clinical experience we were not convinced that measurements with the conventional method had sufficient reliability. However, to our knowledge, extensive reliability studies have not been performed. Only Murugkar et al. (17) performed a study comparing this with the IMD and found poor reliability for goniometry. However, while distance-based measurements may be reliable and appropriate for follow-up of individual adults, they may not be very comparable between subjects due to differences in hand size and due to difference in landmarks used for measuring the linear distance. This limitation is even more pronounced in children, where differences in length of the segments are large and change with time.

In this study, a new tool, the Pollexograph (Figure 1A), is introduced to measure active and passive palmar abduction as the angle between palm of the hand and tip of the thumb. The tool was designed in such a way that it is simple, affordable, applicable to left and right hands of varying sizes, most importantly, valid and reliable. As a first test to determine applicability and inter rater reliability, 14 occupational and physical therapists (in training for hand therapy) performed measurements on the same subject with a conventional goniometer and with the Pollexograph to assess inter rater reliability. Additionally, Pollexograph intra rater reliability was assessed in 21 patients with a hypoplastic thumb (Blauth Type II-IV) that had undergone surgical treatment in our medical center.
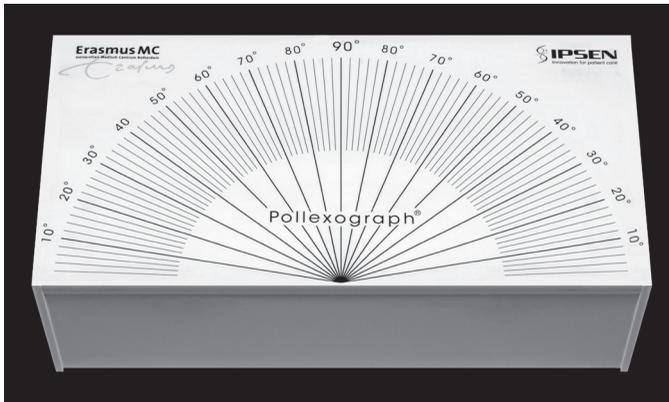
FIGURE 1A. The Pollexograph.

METHODS AND MATERIALS

Subjects

To obtain a first estimate of inter rater reliability, 14 occupational and physical therapists in training for hand therapist, were asked to measure active and passive palmar abduction with the Pollexograph and a conventional goniometer of the right hand of a 25-year-old right handed healthy female with no prior trauma to the upper extremity. The average age of the therapists was 38.8 years (range 24-53) and the average years of experience were 5.1 years (range 0-12). Eleven out of 14 therapists had experience with goniometry of the hand and the average number of hand goniometry measurements they performed per week was 8 (range 0-50). Four therapists had frequently performed palmar abduction goniometric measurements. Before measurements, all therapists watched an instruction video displaying the two measurement methods for palmar abduction (conventional goniometry and Pollexograph) for both active and passive measurements.

Additionally, Pollexograph test- retest measurements were performed by one of the authors on the hands of 21 patients with a hypoplastic thumb (Blauth Type II-IV) that previously had received surgical treatment in our medical center. The patient group consisted of 14 males and 7 males with a mean age of 12.6 years (range 4- 30 years) that visited the outpatient clinic for a regular consultation after surgery. A retest was performed during the same consultation. Time between surgery and palmar abduction measurements was at least 1 year. This study was approved by the Medical Ethics Committee of our medical center and written consent was obtained from all participating subjects or their parents.

Devices and measurements

Pollexograph design (Figure 1A) was based on the concept that hand position should be standardized to obtain repetitive and reliable measurements. Since palmar abduction is a motion in one plane, it should be assessed in this plane along a smooth surface. Thus, the Pollexograph measures the movement in which the thumb moves away from the index metacarpal, perpendicular to the plane of the palm.

A box-shape (length= 21 cm, height=7 cm, width=13,5 cm) was chosen so that the thumb would be forced to move in the plane perpendicular to the hand. A protractor (radial length = 13 cm) on top was divided in steps of 2 degrees, conform the scale of many conventional goniometers. The protractor runs from 0-90 degrees from the left to the middle and from the right to the middle, making the Pollexograph applicable for left and right hands of all sizes. In addition, the examiner marked a number of anatomical points on the hand to optimally align the hand and to read the palmar abduction angle. First, to allow the thumb to move freely in the right plane, it was important to place the thenar crease exactly on the edge of the box. Therefore, the thenar crease was marked before placing the hand. In addition, since rotation during palmar abduction originates from the CMC-joint, we chose to mark this joint so that it could be aligned with the 90-degree line on the protractor. Finally, the middle distal part of the nail was marked to facilitate angle readings.

During Pollexograph measurements, subjects were seated at a table with the elbow in 90° flexion. The hand was placed on the Pollexograph with the thenar crease on the edge of the box and the CMC-marking aligned with the 90° line of the protractor. The lower arm was positioned parallel to the box with the fingers pointed slightly ulnar (Figure 1B).

During measurements, the other fingers were fixed against the box by the examiner. Fixation of the four fingers abeles the examiner to survey hand and wrist position and thereby whether the subject performs the movement correctly. With the Pollexograph, measurements were performed both actively (subject moves the thumb in maximal palmar abduction) and passively (examiner places the thumb in maximal palmar abduction). For active measurements, the patient was instructed to move the thumb to maximum palmar abduction in a single fluent movement. For passive measurements, the researcher moved the thumb to maximal palmar abduction while the subject was instructed to relax. In both measurements, the maximal palmar abduction was read from the position of the nail marking above the protractor.
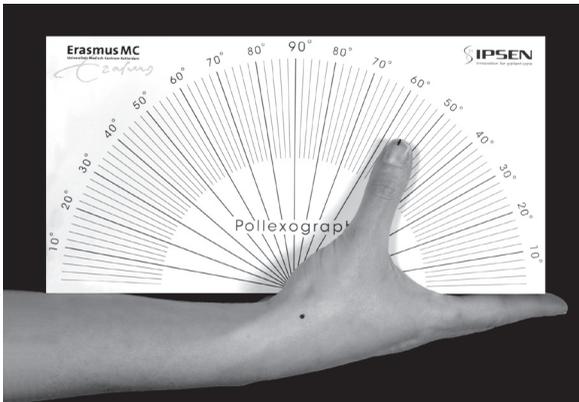
FIGURE 1B. Position of the arm on the Pollexograph.
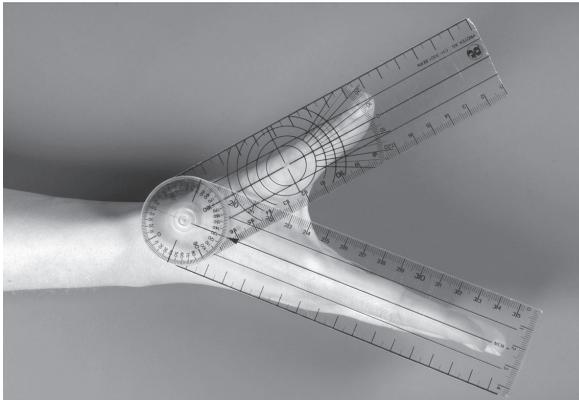
FIGURE 1C. Goniometer placed over the first and second metacarpal.

For the conventional measurement method a goniometer was used. We measured the angle between the first and second metacarpal with the thumb maximally abducted. For active palmar abduction, the subject was asked to hold the thumb in maximal abduction and the goniometer was placed over the first and second metacarpal (Figure 1C). For passive palmar abduction, the same measurement was performed while the examiner held the thumb in maximal palmar abduction.

Statistical analysis

To determine inter rater reliability we calculated means, standard deviations (SD's) and the 95% C.I. (mean ± 1.96 x SD) of the repeated measurements of the same subject. Mean values indicate systematic differences between measurement techniques. SD's indicate measurement differences between therapists when measuring the same subject. Therefore, a lower SD indicates better reliability (18). The Paired Sample T-Test was used to compare means of both methods. Levene's test was used to compare the equality of the variances. A p-value ≤ 0.05 was considered significant and SPPS 14.0 was used for all analysis.

Intra rater reliability of the Pollexograph was calculated using intraclass correlation coefficients (ICC). The ICC is a measure of agreement between test and retest values found for each subject. It ranges from 0 to 1, where an ICC of 0 means no agreement between test en retest, whereas an ICC of 1 means perfect test-retest reliability (19, 20).

Additionally, two absolute reliability indices were calculated: standard error of measurement (SEM) and smallest detectable difference (SDD). The SEM was calculated with the estimated variance components, where the SEM is the square root of the error variance (18, 21). From the SEM, the smallest detectable difference (SDD =1,96 x √2 x SEM) was determined. The SDD is specifically valuable for clinical use since with this index an examiner can distinguish between a measurement error and a real (treatment) change.

Only a difference that exceeds the SDD can be considered a real (non error) change in an individual patient (22). For example, a SDD of 5 degrees indicates that a follow-up measurement should differ by at least 5 degrees from a baseline measurement to be sure that there is a real (non-error) change in abduction angle in an individual subject.

RESULTS

Repeated measurements on a healthy subject

Table 1 shows means and ranges for active and passive measurements of both methods. The mean active and passive angles measured with conventional goniometry (64,5 and 69,1) were significantly larger (p = 0.013 and p = 0.004) than with the Pollexograph (57,7 and 60,9).

Levene's test showed that active and passive Pollexograph measurement variance of the repeated measurements of the same subject (the SD in Table 1) was significantly smaller (2-6 times) than goniometer measurement variance (p = 0.001 for active palmar abduction and p = 0.028 for passive palmar abduction), suggesting that the Pollexograph is more reliable in measuring palmar abduction than a conventional goniometer.

TABLE 1. Means, standard deviations (SD's) and 95% C.I. of the mean obtained from repeated measurement of the same healthy subject using conventional goniometry and the Pollexograph.

Method	Active/ Passive	Mean (degrees)	SD (degrees)	95 % C.I. of mean
Goniometer	Active	64,5	8,5	(47,8 - 81,2)
Pollexograph	Active	57,7	1,4	(55,0 - 60,4)
Goniometer	Passive	69,1	7,2	(55,0 - 83,2)
Pollexograph	Passive	60,9	3,7	(53,6 - 68,2)

C.I. = confidence interval

Reliability in hypoplastic thumb patients

Table 2 shows mean angles measured with the Pollexograph in 21 patients with a hypoplastic thumb. Mean Pollexograph angles were approximately 49 degrees, ranging from 24 to 78 degrees.

Intra rater reliability for Pollexograph in patients with a hypoplastic thumb is also shown in Table 2. For both active and passive Pollexograph measurements we found excellent ICC's (0.98-0.99). In addition, SDD's were smaller than 5 degrees, also indicating excellent reliability.

TABLE 2. Mean angles, standard deviation, ranges and reliability (SEM, SDD and ICC) for palmar abduction measured with the Pollexograph measured in 21 patients with a hypoplastic thumb.

Method	Active/ Passive	Mean (degrees) ± SD	Range (degrees)	SEM	SDD	ICC
Pollexograph	Active	47,5 ± 14.2	24 - 70	1,6	4,5	0,99
Pollexograph	Passive	50,2 ± 12.4	28 - 78	1,8	5.0	0,98

SD= standard deviation
SEM= standard error of measurement
SDD= smallest detectable difference
ICC= intraclass correlation coefficient

DISCUSSION

While palmar abduction is essential for normal hand function, little is known about optimal range of motion of the thumb and how to measure this. Conventional methods (e.g. goniometry) are generally considered to have poor reliability (17). We therefore developed a new tool, the Pollexograph, for measuring palmar abduction. To obtain a first estimate of its reliability, we compared variation between raters when assessing the same subject using the Pollexograph and conventional goniometry. Additionally, Pollexograph intra rater reliability was assessed in 21 patients with a hypoplastic thumb and showed excellent reliability. Overall, preliminary analysis showed that Pollexograph measurements were significantly more reliable of than conventional goniometry measurements.

Tubiana (4), Hartigan (2), and Brand (3) applied the conventional method of measuring palmar abduction with a goniometer. The mean values in the healthy population ranged from 40-80 degrees according to Tubiana, while Brand et al. quote normal range of the web angle as being 40-50°. Harvey et al (13) found mean passive palmar abduction to be 56° in healthy subjects. In our study, in the healthy subject, mean active and passive palmar abduction values with conventional goniometer methods were 64.5° and 69.1°, which is in accordance with Tubiana's results. The large variation between different reports may also indicate poor inter rater reliability although, to our knowledge, this has never been thoroughly investigated. We found that the mean palmar abduction in the patients (± 49 degrees) did not differ much from the mean measured in a healthy adult (± 58 degrees) and the data reported by Tubiana (40-80 degrees). However, more normative data measured with the more reliable Pollexograph is needed to conclude on differences between patients and controls. It is striking, however, that values in the patient group did show considerable variation (range 24 to 78°) as could be expected based on clinical experience with hypoplastic thumb patients.

Pollexograph design was based on the concept that hand position should be standardized to obtain repetitive and reliable measurements. Since, palmar abduction is a motion in one plane, it should be possible to perform and accurately assess this along a smooth surface. We therefore decided to design a tool in the shape of a box with a protractor on top. It is important that the thumb can move free which is accomplished by marking and placing the thenar crease on the edge of the box. Since rotation during palmar abduction originates from the CMC-joint, we chose to mark and align this joint. The middle distal part of the nail was then chosen as last landmark to facilitate angle readings.

We believe that this design and these landmarks contribute to standardization of hand position and to the reliable measurements we found.

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It might be argued that results for the conventional method were poor because therapist where not highly experienced for this method. However, inspection of the data indicated that the four therapists with experience of palmar abduction goniometric measurement did not have more reliable measurements than therapists with no experience. However, during measurements we noticed that several therapists had difficulty applying the conventional goniometric method, especially during passive measurements. The largest difficulty was holding the goniometer over MC1 and MC2 and simultaneously spreading the thumb in maximal abduction. With the Pollexograph they found it easier to measure both active and passive palmar abduction and were more confident that they performed the measurement correctly. Furthermore, it can be expected that measurement reliability will only increase when examiners become more experienced with the new method.

We believe that the various definitions for palmar abduction ("conventional palmar abduction", "AMA definition", "IFSSH definition", "ASHT definition", and "Pollexograph definition") make it possible to answer different types of clinical questions concerning range of motion of the (whole) thumb. The different definitions offer examiners the possibility to choose which definition is clinically most informative in a specific patient. Indeed, it should be noted that Pollexograph values can not be directly compared with conventional goniometry measurements. One reason for this difference is that the conventional method measures the angle between MC1 and MC2, while the Pollexograph measures the orientation of the thumb relative to the palm. Measuring the orientation of the thumb relative to the palm is more in line with the recommendation of the International Federation of Societies for Surgery of the Hand (IFFSH), defining palmar abduction as the movement in which the thumb metacarpal moves away from the index metacarpal, perpendicular to the plane of the palm (5). A second difference between conventional palmar abduction and the Pollexograph measurement is that possible laxity in the MCP and IP joint is included in the Pollexograph measurement. A third difference may be that the second metacarpal (MC2) does not run perfectly parallel to the edge of the box. However, we believe range of motion of the thumb as a whole to be of clinical relevance and therefore this method justifiable. For a future study we could assess an alteration for the Pollexograph, allowing us to measure the same angle as the conventional method by placing a ruler over the first metacarpal reading the angle from the ruler position above the protractor.

In this study, due to its design, we were not able to calculate intraclass correlation coefficients (ICC's) for inter rater reliability; therefore it was not possible to compare our reliability results

with other inter rater reliability studies. For the intra rater reliability in the hypoplastic thumb patients, ICC's indicated excellent reliability. The high ICC's may partly be caused by the retest being performed during the same consultation. We choose to do the retest on the same day for practical reasons; the patients were measured as part of a large measurement protocol and visited us from a large region within the Netherlands. Therefore, we did not want to burden patients with a second visit to the out patient clinic. Another explanation for the high ICC's could be found in the fact that the range within measured angles is quite large (24-78°), resulting in higher ICC's.

We chose to assess Pollexograph intra rater reliability in patients with a hypoplastic thumb (Blauth type II-IV), because thumbs of these patients display a large spectrum of intrinsic, extrinsic and web space abnormalities, thereby including a wide range of thumb deformities. Some of the patients we assessed showed MCP joint laxity during manual testing. In our opinion, active range of motion is functionally most important in these patients and we did not see any MCP laxity during active measurements with the Pollexograph. During passive measurements we did find MCP laxity in several patients.

We did find that to properly position patients with abnormal anatomic features is more challenging than in "normal healthy "subjects. We experienced this in our patient group, however reliability doesn't seem to be influenced much by this. Future studies should indicate the usefulness of the Pollexograph in other patient groups with different deformities, such as patients with severe spasticity or patients with flexion contractures of the IP and MCP joints. This way, one may be able to assess reliability in a group where hand positioning may be troublesome in a different manner than in the patient population we studied.

CONCLUSIONS

In summary, these preliminary results suggest that the Pollexograph is more reliable than a conventional goniometer for measuring palmar thumb abduction. Future studies should indicate whether reliability when measured in a large group of healthy subjects would provide the same results.


Acknowledgements

REFERENCES

1   Bhattacharya S, Pandey SD, Chandra R, Singh GK. Documentation of the first web space angle. *J Hand Surg*. 1989; 14:298-300.

2   Hartigan BJ, Stern PJ, Kiefhaber TR. Thumb carpometacarpal osteoarthritis: arthrodesis compared with ligament reconstruction and tendon interposition. *J Bone Joint Surg*. 2001; 83-A:1470-1478.

3   Brand PW. *Deformity in leprosy*. Cochrane RG (ed2). *Leprosy in Theory and practice.* John Wright & Sons ltd. Bristol UK, 1964: 485-496.

4   Tubiana R, Thomine J, Mackin E. *Examination of the Hand and Wrist.* Martin Dunitz Ltd. 1998:195-196.

5   International Federation of Societies for Surgery of the Hand. *Terminology for Hand Surgery.* Edinburgh: Harcourt Health Sciences, 2001;5:p53.

6   American Society of Hand Therapists. *Clinical Assessment and Recommendations*, 2nd ed. Chicago IL, 64-65.

7   American Medical Association. *Guides to the Evaluation of Permanent Impairment*. Fourth ed. June 1993: 28-29.

8   Kapandji A. Rotation of the thumb on its longitudinal axis during opposition. Geometric and mechanical study of the trapezo-metacarpal joint (mechanical model of the hand). *Revue de chirurgie orthopedique et reparatrice de l'appareil moteur*. 1972; 58:273-289.

9   Degeorges R, Parasie J, Mitton D, Imbert N, Goubier JN, Lavaste F. Three-dimensional rotations of human three-joint fingers: an optoelectronic measurement. Preliminary results. *Surg Radiol Anat*. 2005; 27:43-50.

10   Chiu HY, Lin SC, Su FC, Wang ST, Hsu HY. The use of the motion analysis system for evaluation of loss of movement in the finger. *J Hand Surg* (Edinburgh, Scotland). 2000; 25:195-199.

11   Kuo LC, Su FC, Chiu HY, Yu CY. Feasibility of using a video-based motion analysis system for measuring thumb kinematics. *J Biomech*. 2002; 35:1499-1506.

12   Su FC, Kuo LC, Chiu HY, Chen-Sea MJ. Video-computer quantitative evaluation of thumb function using workspace of the thumb. *J Biomech*. 2003; 36:937-942.

13   Harvey L, de Jong I, Goehl G, Armstrong B, Allaous J. A torque-controlled device to measure passive abduction of the thumb carpometacarpal joint. *J Hand Ther.* 2006; 19:403-408.

14   Shrinivasan H. *Reconstructive Surgery in treatment of deformities of hand*: Dharmendra. 1978: 567-617.

15   Schwanholt C, Stern PJ. Brief or new: measuring cone for thumb abduction/extension. *Am J Occup Ther*. 1984; 38:263-264.

16   Buck-Gramcko D, Dietrich FE, Gogge S. Evaluation criteria in follow-up studies of flexor tendon therapy. *Handchirurgie*. 1976; 8:65-69.

17   Murugkar PM, Brandsma JW, Anderson AM, Gurung K, Pun Y. Reliability of thumb web measurements. *J Hand Ther*. 2004; 17:58-63.

18   Roebroeck ME, Harlaar J, Lankhorst GJ. The application of generalizability theory to reliability assessment: an illustration using isometric force measurements. *Phys Ther*. 1993; 73:386-395.

19   Fleiss J. *The design and analysis of clinical experiments.* New Jersey: John Wiley and Sons. 1986: 1-14.

20   Koch G. *Intraclass correlation coefficients. Encyclopedia of Statistical Sciences,* 4th ed. Samuel Kotz and Norman L. Johnson. New York: Wiley and Sons. 1982: 213-217.

21   Shavelson R, Webb N, Rowley G. Generalizability Theory. *Am Psych.* 1989;44: 922-932.

22   Roebroeck ME, Harlaar J, Lankhorst GJ. Reliability assessment of isometric knee extension measurements with a computer-assisted hand-held dynamometer. *Arch Physical Med Rehab.* 1998; 79:442-448.

2

Chapter 3

Palmar Abduction:

Reliability of 6 Measurement Methods

in Healthy Adults
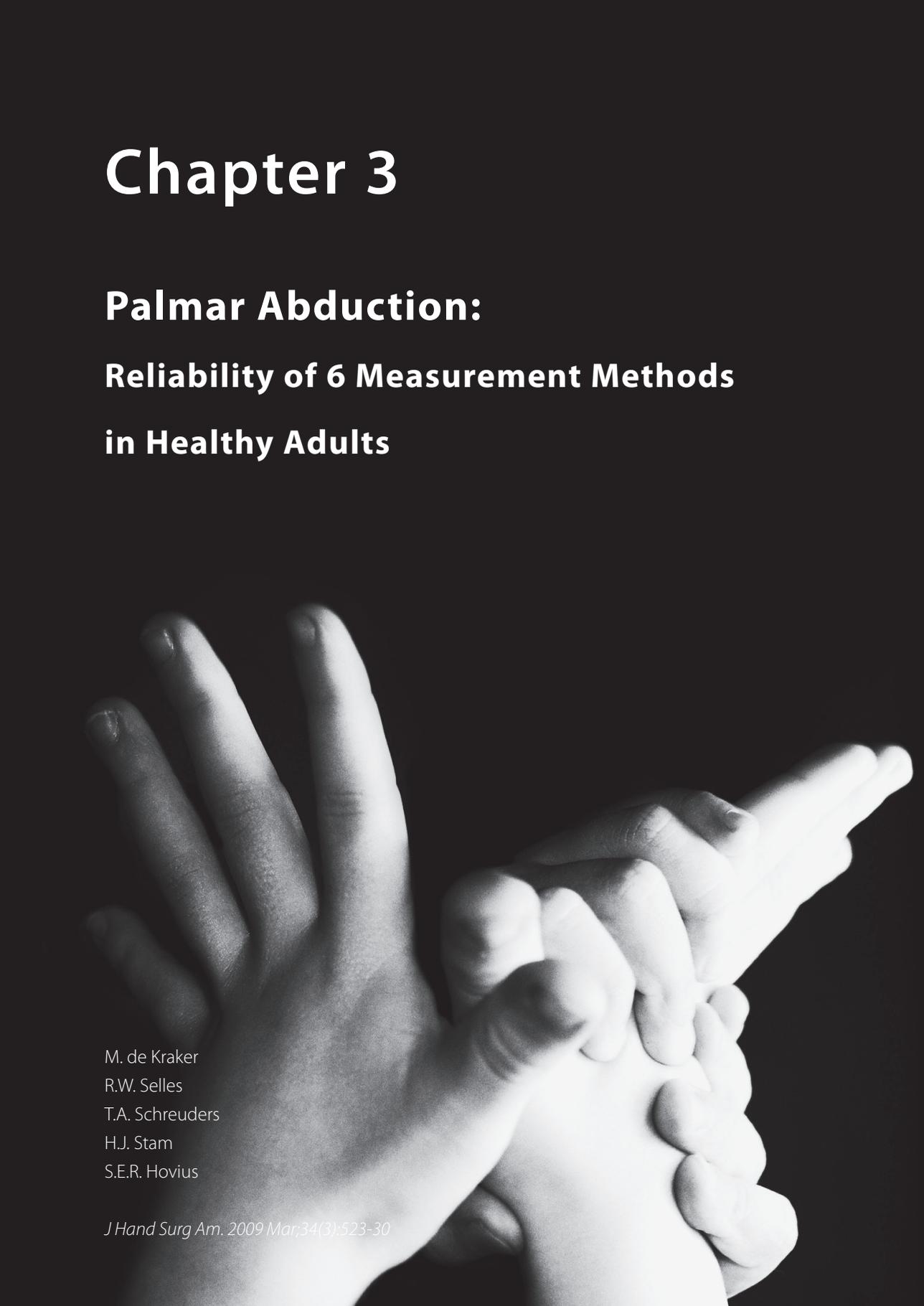
M. de Kraker
R.W. Selles
T.A. Schreuders
H.J. Stam
S.E.R. Hovius

ABSTRACT

Purpose: Aim of the present study was to assess reliability of 6 palmar thumb abduction measurement methods: conventional goniometry, the Inter Metacarpal Distance, the method described by the American Medical Association, the method described by the American Society of Hand Therapists and two new methods: the Pollexograph-thumb and the Pollexograph-metacarpal.

Methods: An experienced hand therapist and a less experienced examiner (trainee in plastic surgery) measured the right hand of 25 healthy subjects. Palmar abduction was measured both passively and actively. Means and ranges for palmar abduction were calculated and intra and inter rater reliability was expressed in intraclass correlation coefficients (ICC), standard errors of measurement (SEM) and smallest detectable differences (SDD).

Results: Mean active and passive angles measured with goniometry resembled values measured with the Pollexograph-thumb (approximately 60 degrees). Mean angles found with the Pollexograph-metacarpal were approximately 48 degrees. Mean active and passive Inter Metacarpal Distances were 64 mm. Mean distances found with the American Society of Hand Therapists method were 97-101 mm and means of the American Medical Association method were 67-70 mm for active and passive measurements.
ICC's of the Pollexograph-thumb, Pollexograph-metacarpal and the Inter Metacarpal Distance indicated good and significantly higher intra rater agreement (ICC's 0.71-0.95) for active and passive measurements than ICC's of conventional goniometry, the American Society of Hand Therapists method and the American Medical Association method showing only moderate agreement (ICC's 0.55-0.72). For inter rater reliability, the same measurement methods were found to be most reliable: the Pollexograph-thumb, Pollexograph-metacarpal and the Inter Metacarpal Distance.

Conclusions: We found that the Pollexograph-thumb, Pollexograph-metacarpal and the Inter Metacarpal Distance are the most reliable measurement methods for palmar abduction.

INTRODUCTION

For palmar abduction many different definitions have been reported in literature (1-5). One often used definition is "the movement in which the thumb metacarpal moves away from the index metacarpal, perpendicular to the plane of the palm" (2). Another frequently used definition is "the angle between the first and second metacarpals with the thumb maximally abducted" (1,3,4).

As there is no consensus on the definition, there is also no consensus on the most optimal measurement method for palmar thumb abduction (1,5-9). Several authors have measured palmar abduction angles (1-4,9), while others used distances between anatomical reference points (5,8,10). For these measurements, different devices have been used, such as goniometers (8), calipers (8), triangular pieces of wood with known angles (6), torque-controlled devices (9) and 3D-video cameras systems (11-14). All these existing methods have disadvantages that complicate daily clinical use, such as low reliability (e.g. conventional goniometry) (8) or measurement complexity (e.g. 3D- videocamera systems) (11-14). We therefore designed the Pollexograph (Figure 1A) to allow reliable and easy palmar thumb abduction measurements in daily clinical care.

Pollexograph design is based on the concept that hand position should be standardized to obtain repetitive and reliable measurements. Since palmar abduction is a motion in one plane, it should be assessed in this plane along a smooth surface.
Thus, the Pollexograph measures the movement in which the thumb metacarpal moves away from the index metacarpal, perpendicular to the plane of the palm. A box-shape was chosen so that the thumb would be forced to move in the plane perpendicular to the hand. A protractor on top is divided in steps of 2 degrees, conform the scale of many conventional goniometers. The protractor runs from 0-90 degrees from the left to the middle and from the right to the middle, making the Pollexograph applicable for left and right hands. To optimally align the hand and to read the palmar abduction angle on the Pollexograph, the examiner marks a number of anatomical points on the hand. First, to allow the thumb to move freely in the right plane, it is important to place the thenar crease exactly on the edge of the box. Therefore, the thenar crease is marked before placing the hand. In addition, since rotation during palmar abduction originates from the carpometacarpal (CMC)-joint, we chose to mark this joint so that it can be aligned with the 90-degree line on the protractor. Finally, the middle distal part of the nail is marked to facilitate angle readings.

The above-mentioned Pollexograph-thumb measurement measures the angle between the first metacarpal and palm of the hand, plus the angle produced by possible laxity in the metacarpophalangeal (MCP) and interphalangeal (IP) joints. Therefore, we also evaluated an alternative Pollexograph application; Pollexograph-metacarpal in which a ruler is placed over the first metacarpal to better resemble conventional goniometry measurements by leaving out laxity in these two joints.

In a previous study, 14 hand therapists measured active and passive palmar abduction in a healthy subject with the Pollexograph and with a conventional goniometer using the method as described by Brand (1), Hartigan (3) and Tubiana (4). We found systematic differences between palmar abduction measured with the Pollexograph-thumb and conventional goniometry that could be explained by systematic differences in the angle that is measured. However, more importantly, we found a large decrease in variation between measurements on the same subject with the Pollexograph compared to conventional goniometry, indicating better reliability. In addition, Pollexograph-thumb intra rater reliability was also assessed in 21 patients with a hypoplastic thumb, showing excellent reliability with intraclass correlation coefficients (ICC's) of 0.98 for passive range of motion and 0.99 for active range of motion.
Goal of this study was to compare intra and inter rater reliability of the Pollexograph (thumb and metacarpal) with the most common alternative measurement methods for palmar abduction: conventional goniometry (1,3,4), the Inter Metacarpal Distance (IMD) (8) the American Society of Hand Therapists method (ASHT method) (10) and the method described in "Guides to the Evaluation of Permanent Impairment" of the American Medical Association (AMA method) (5).

MATERIALS AND METHODS

Subjects

Measurements were performed on the right hand of 25 healthy subjects recruited at our medical center. Subjects had no prior injury to the upper extremity or systemic conditions affecting the muscular or nervous system. The group consisted of 9 men and 16 women of whom three were left-handed. Mean age of the subjects was 30 years (standard deviation ± 7 years).
This study was approved by the Medical Ethics Committee and written informed consent was obtained from each subject.

Measurements

All measurements were performed once by an experienced examiner (a hand therapist) and twice by a less-experienced examiner (a trainee in plastic and reconstructive surgery) to assess both intra- and inter rater reliability. To prevent testers from being influenced by the values of prior tests, retest values were written down on a new form by the other tester. Measurement order was also randomized to prevent examiners from remembering previous measurement values. After each measurement, skin markings were removed, since marking differences contribute to measurement errors and therefore affect reliability. Total time to perform all measurements by one examiner was approximately 10 minutes per subject. The retest was performed a few days after the test.

We performed active and passive palmar abduction measurements with the *angular methods*: 1) Conventional goniometer, 2) Pollexograph-thumb, 3) Pollexograph-metacarpal and with *distance methods*: 4) Inter Metacarpal Distance and 5) the American Medical Association method, 6) the American Society of Hand Therapists method.

For conventional goniometry measurements, the same 7-inch goniometer was used. During active measurements (Figure 1B), the subject was asked to hold the thumb in maximal abduction and the goniometer was placed over the first and second metacarpal. For passive measurements, the same angle was determined while the examiner held the thumb in maximal palmar abduction.

For Pollexograph-thumb measurements, three landmarks were indicated on the hand: 1) the middle, most proximal part of the first metacarpal, indicating the carpometacarpal joint, 2) the thenar crease and 3) the middle, distal part of the thumb nail. During measurements, the subject was seated at a table with the elbow in 90° flexion and the wrist in a neutral position. The hand was placed on the Pollexograph with the thenar crease on the edge of the box and the carpometacarpal joint mark aligned with the 90° line of the protractor (Figure 1C). The lower arm was positioned parallel to the box with the fingers pointed slightly ulnar. When the hand was placed accurately, the thumb could move without interference of the box surface or edge. During measurements, the other fingers were fixed against the box by the examiner. Maximal palmar abduction of the thumb was read from the nail marking position above the protractor.
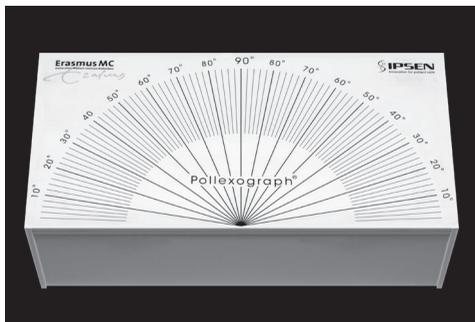
FIGURE 1A. The Pollexograph.

FIGURE 1B. Conventional goniometer measurement.

FIGURE 1C. Pollexograph-thumb measurement: the angle between the mid-nail of the thumb and the palm of the hand, including possible laxity in the MCP- and IP joints.

FIGURE 1D. Pollexograph-metacarpal measurements: a ruler was placed over the carpometacarpal marking, the metacarpal 1 marking and the protractor.
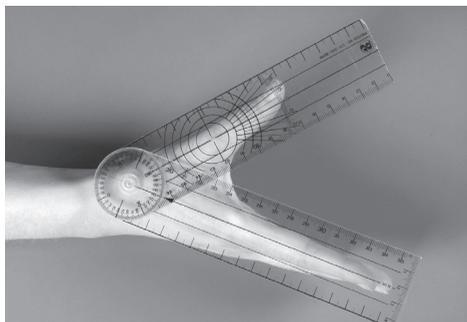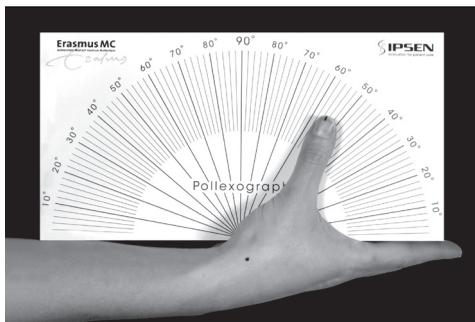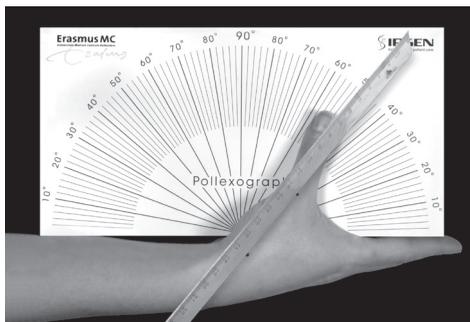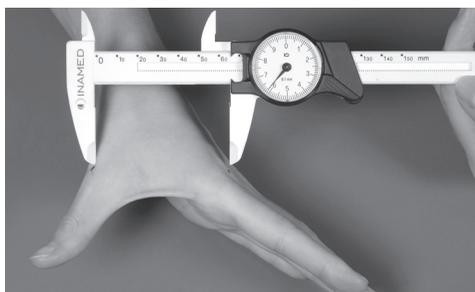

FIGURE 2. Inter Metacarpal Distance measurement.

The Pollexograph-thumb measures the angle between the mid-nail of the thumb and the palm of the hand. This angle is influenced by possible laxity in the MCP and IP joints (Figure 1C). Therefore, we also evaluated an alternative Pollexograph application measuring the angle between the first metacarpal and the palm of the hand. These Pollexograph-metacarpal measurements were performed largely similarly as described for the Pollexograph-thumb. The first 2 skin markings (carpometacarpal joint and thenar crease) remained the same; the third marking was placed on the middistal head of the first metacarpal (metacarpal 1-marking). During measurements, a ruler was placed over the carpometacarpal marking, the metacarpal 1 marking and the protractor (Figure 1D). When the thumb was maximally abducted, the value was read from the ruler position above the protractor.

We performed a distance measurement method of the thumb web space, the Inter Metacarpal Distance (IMD), introduced by Murugkar et al. (8). For these measurements, the middorsal points of the first and second metacarpal heads were marked and two caliper points were placed on the markings while the thumb was in maximal palmar abdution (Figure 2). The maximal distance was read in millimeters from the scale.

The second distance method was adapted from the opposition measurement method described in "Guides to the Evaluation of Permanent Impairment" of the American Medical Association (5). An adaptation was made because only methods for measuring radial abduction and opposition were described and not for palmar abduction.
Following this method, the largest possible distance was recorded from the distal palmar crease directly over the third MCP joint to the flexor crease of the IP joint. Normal distance to the IP crease is described as 80 mm in adults (5).

The third distance measurement method we performed was the method as described by the American Society of Hand Therapists (ASHT) (10). The maximal distance was measured from the distal palmar crease directly over the third MCP joint to the tip of the thumb. A normal range from the distal palmar crease to the thumb tip is unknown.

Statistical analysis
Using SPSS 14.0, we calculated means, standard deviations (SD's) and ranges of the whole group. Differences in mean values of the different methods indicate systematic differences between measurement techniques.

Both intra rater reliability (examines the ability of a single tester to obtain consistent results on repetitive measures) and inter rater reliability (the amount of agreement between measurements by different testers) were assessed. Reliability was calculated using ICC's and its 95% confidence interval. The ICC is a measure of agreement between test and retest values measured in the same subject. It ranges from -1 to 1, where an ICC of 0 means no agreement between test and retest, whereas an ICC of 1 means perfect test-retest reliability (15,16). The first test of the less experienced examiner and the test of the more experienced examiner were used to assess inter rater reliability.

Additionally, two absolute reliability indices were calculated, expressing the difference between test and retest in the original measurement units (degrees and millimeters): standard error of measurement (SEM) and smallest detectable difference (SDD). Not being proportional, as ICC's, the SEM is only determined by physical causes of error and statistical uncertainty of estimating that error. The SEM includes both random and systematic components of measurement error and was calculated with the estimated variance components, where the SEM is the square root of the error variance (17-19).

From the SEM, the smallest detectable difference (SDD =1,96 x $\sqrt{2}$ x SEM) was determined. The SDD is specifically valuable for clinical use since with this index an examiner can distinguish between a measurement error and a real (treatment) change. Only a difference that exceeds the SDD can be considered a real (non error) change in an individual patient (19). For example, a SDD of 5 degrees indicates that a follow-up measurement should differ by at least 5 degrees from a baseline measurement to be sure that there is a real (non-error) change in abduction angle in an individual subject.

To test for statistically significant differences among reliability, standard error of measurements (SEM's) for all measurement methods were compared by using the methods described by Schreuders and colleagues (20) and Stratford and Goldsmith (21) for dependent samples. Calculating statistically significant differences allows differentiation between reliability data that may appear rather similar. A p-value ≤ 0.05 was considered significant.

RESULTS

Mean values

Table 1 shows means, standard deviations (SD's) and ranges of angular and distance measurement methods for palmar abduction. It can be seen that mean active and passive angles measured with goniometry were comparable with Pollexograph-thumb values. Goniometry and Pollexograph-thumb means ranged from 56-64 degrees, while Pollexograph-metacarpal mean angles were smaller ranging from 47 to 49 degrees.

Mean distances of the American Medical Association method were 67-70 mm from the distal palmar crease to the IP joint. Mean distances of the American Society of Hand Therapist method were 97-101 mm to the thumb tip for active and passive measurements, while mean active and passive Inter Metacarpal Distance distances were 63-64 mm.

TABLE 1. Means, standard deviations (SD) and ranges of angular and distance methods for palmar abduction.

Method		Mean ± SD (degrees)	Range (degrees)
Goniometer	Active palmar abduction	57 ± 6	45-70
Goniometer	Passive palmar abduction	64 ± 8	49-78
Pollexograph-thumb	Active palmar abduction	62 ± 5	54-72
Pollexograph-thumb	Passive palmar abduction	63 ± 4	56-70
Pollexograph-metacarpal	Active palmar abduction	47 ± 5	35-56
Pollexograph-metacarpal	Passive palmar abduction	49 ± 6	36-58
		Mean ± SD (mm)	Range (mm)
AMA (IP joint)	Active palmar abduction	67 ± 7	53-80
AMA (IP joint)	Passive palmar abduction	70 ± 6	56-85
ASHT (thumb tip)	Active palmar abduction	97 ± 8	75-111
ASHT (thumb tip)	Passive palmar abduction	101 ± 8	84-115
IMD	Active palmar abduction	63 ± 6	53-76
IMD	Passive palmar abduction	64 ± 5	55-76

Reliability data

Table 2 shows intra- and inter rater reliability for angle and distance measurements for palmar thumb abduction. Five out of six intra rater ICC's of the Pollexograph-thumb, Pollexograph-metacarpal and IMD indicated excellent agreement (ICC's 0.81-0.95) for active and passive

measurements, whereas ICC's for conventional goniometry, the ASHT-method and the AMA-method showed less agreement between test and retest (ICC's 0.55-0.78). SDD's for the Pollexograph (thumb/ metacarpal) were significantly smaller than for conventional goniometry and SDD's for the Inter Metacarpal Distance were also significantly smaller than for the ASHT method and AMA method.

Table 3 shows p-values of the standard error of measurement comparison of the intra and inter rater reliability data for angular and distance measurement methods. For intra rater reliability, Pollexograph (thumb/ metacarpal) SEM's were significantly smaller (p= 0.016 and p= 0.004) than conventional goniometry SEM's. The Inter Metacarpal Distance had significantly smaller SEM's (p<0.001 and p< 0.001) compared to American Medical Association method and the American Society of Hand Therapists method, indicating that the IMD method is more reliable. For inter rater reliability, the same measurement methods were found to be most reliable: the Pollexograph-thumb, Pollexograph-metacarpal and the Inter Metacarpal Distance.

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TABLE 2. Intra and inter rater reliability for all methods for palmar abduction expressed with use of SEM, SDD and ICC.

Method	Active/ Passive	Intra rater reliability			Inter rater reliability		
		SEM (degrees)	SDD (degrees)	ICC + 95% C.I.	SEM (degrees)	SDD (degrees)	ICC + 95% C.I.
Goniometer	Active	4.3	11.8	0.55 (0.34 - 0.87)	5.2	14.4	0.31 (-0.18 - 0.77)
Goniometer	Passive	3.5	9.7	0.76 (0.69 - 094)	5.9	16.5	0.37 (-0.42 - 0.79)
Pollexograph-thumb	Active	2.5	7.0	0.71 (0.62 - 093)	2.6	7.1	0.66 (0.53 - 0.91)
Pollexograph-thumb	Passive	2.0	5.5	0.82 (0.78 - 0.96)	3.3	9.0	0.59 (0.42 - 0.89)
Pollexograph-metacarpal	Active	2.3	6.4	0.82 (0.78 - 0.96)	3.7	10.3	0.57 (0.38 - 0.88)
Pollexograph-metacarpal	Passive	2.7	7.5	0.81 (0.76 - 0.95)	3.5	9.7	0.61 (0.45 - 0.89)
		SEM (mm)	SDD (mm)		SEM (mm)	SDD (mm)	
AMA (IP joint)	Active	4.1	11.4	0.72 (0.63 - 0.92)	6.6	18.4	0.24 (-0.40 - 0.73)
AMA (IP joint)	Passive	3.9	10.9	0.65 (0.51 - 0.90)	5.0	13.9	0.52 (0.28 - 0.86)
ASHT (thumb tip)	Active	4.4	12.3	0.78 (0.72 - 0.94)	5.6	15.6	0.55 (0.34 - 0.87)
ASHT (thumb tip)	Passive	4.5	12.6	0.72 (0.63 - 0.93)	6.2	17.2	0.52 (0.29 - 0.86)
IMD	Active	1.2	3.3	0.95 (0.95 - 0.99)	2.2	6.1	0.82 (0.79 - 0.96)
IMD	Passive	1.4	4.1	0.92 (0.90 - 0.98)	2.4	6.5	0.79 (0.78 - 096)

TABLE 3. P-values for intra and inter rater reliability comparing standard errors of measurement for angular and distance methods.

	SEM	SEM	Intra rater reliability	SEM	SEM	Inter rater reliability
			p-value			p-value
Active measurements						
Pollexograph-thumb vs. Goniometer	2.5	4.3	0.016	2.6	5.2	0.002
Pollexograph-metacarpal vs. Goniometer	2.3	4.3	0.004	3.7	5.2	0.085
Pollexograph-thumb vs. Pollexograph-metacarpal	2.5	2.3	0.664	2.6	3.7	0.714
AMA (IP joint) vs. ASHT (thumb tip)	4.1	4.4	0.583	6.6	5.6	0.104
IMD vs. AMA (IP joint)	1.2	4.1	< 0.001	2.2	6.6	< 0.001
IMD vs. ASHT (thumb tip)	1.2	4.4	< 0.001	2.2	5.6	< 0.001
Passive measurements						
Pollexograph-thumb vs. Goniometer	2.0	3.5	0.003	3.3	5.9	0.004
Pollexograph-metacarpal vs. Goniometer	2.7	3.5	0.221	3.5	5.9	0.014
Pollexograph-thumb vs. Pollexograph-metacarpal	2.0	2.7	0.140	3.3	3.5	0.714
AMA (IP joint) vs. ASHT (thumb tip)	3.9	4.5	0.315	5.0	6.2	0.104
IMD vs. AMA (IP joint)	1.4	3.9	<0.001	2.4	5.0	<0.001
IMD vs. ASHT (thumb tip)	1.4	4.5	<0.001	2.4	6.2	<0.001

DISCUSSION

Goal of our study was to compare reliability of the most common measurement methods for palmar thumb abduction. Although conventional goniometry may be most often used in daily clinical practice, it was found to be unreliable. The significant smaller SDD's and SEM's for intra- and inter rater reliability indicated that the Pollexograph-thumb, Pollexograph-metacarpal and the IMD were the most reliable methods for measuring palmar abduction.

There are many definitions of palmar abduction as well as different measurement methods. Tubiana (4), Hartigan (3), and Brand et al. (1) all measured the angle between the first and second metacarpal with a goniometer when the thumb was maximally abducted. Normal values ranged from 40-80 degrees in the study of Tubiana, while Brand et al. reported the normal range of the palmar abduction angle as 40-50°. Harvey et al. (9) found a mean passive palmar abduction angle of 56° (range 53-60°) in a healthy population. In this study, conventional goniometry values ranged from 45° to 70° for active measurements and from 49° to 78° for passive measurements. Thus, these values were most comparable to Tubiana's results.

A limitation of this study is that we have not yet validated Pollexograph measurements and that reliability was tested in a relatively small population of 25 healthy subjects. Future studies are needed to assess reliability in several different patient groups. In addition, the study is limited to subjects with normal anatomy of the hand. Future studies should also indicate the usefulness of these techniques is patients with anatomical deformities, such as contractures in patients with hand spasticity. It should be noted that in our study a retest was only performed by the less experienced examiner and not also by the experienced examiner. We decided to do this, because when good reliability is found with a less experienced examiner, reliability will most probably be higher in an experienced examiner.

Although the Pollexograph-metacarpal measures the orientation of the first metacarpal, similar to conventional goniometry, we found that mean goniometry angles were 5-10 degrees larger than Pollexograph-metacarpal means. The smaller mean angles found for the Pollexograph-metacarpal may be explained by the fact that it measures the angle between palm of the hand and the first metacarpal and not the angle between the first and second metacarpal. In fact, in both Pollexograph methods, it is more correct to say that the orientation of the thumb or first metacarpal is measured relative to the plane of the hand at the palmar

side. Therefore, our Pollexograph means can not be directly compared to conventional goniometry means. Although this may be a limitation to the present method, we believe that it is more important to have a measurement method that is better standardized and therefore more reliable than conventional goniometry. Due to the shape of palm of the hand, the Pollexograph method introduces an offset-angle relative to the second metacarpal that does not influence comparison between subjects or between repeated measurements on the same subject.

Intra- and inter rater reliability of palmar abduction measurements has been reported in several studies. Harvey et al. (9) designed a complex torque-controlled device to measure passive palmar abduction and compared their new device with a caliper that measured the distance between the first and second metacarpal head with the thumb maximally abducted. The intra rater ICC of their new device was 0.78 and the ICC of the caliper method was 0.83. The intra rater ICC of the less-complex Pollexograph in our study was 0.82, comparable to Harvey's device. Murugkar et al. (8) compared the IMD with conventional goniometry and found a good inter rater ICC of 0.84 for passive IMD measurements and a very poor ICC of 0.26 for conventional goniometry. We found ICC's of 0.82 and 0.79 for active and passive inter rater reliability for the IMD and ICC's of 0.31 and 0.37 for conventional goniometry. Thus, both studies showed unacceptable low reliability for conventional goniometry and excellent reliability for the Inter Metacarpal Distance.

While often used, an ICC has the disadvantage of being a ratio of the between subject variation and the overall variation, therefore depending on variation within (healthy) hands. In some cases, it may therefore be more informative to have absolute reliability indices such as SEM's and SDD's. With these indices it is possible to distinguish between measurement errors and real change (17). Since our study is the first to calculate SEM's and SDD's for palmar abduction, these results could not be compared to other studies. In addition to not being dependent on variation between subjects, the SDD has the advantage of being easily interpretable in a clinical setting, since it indicates the value that should be exceeded to conclude the presence of a real (non error) change in an individual patient (19).

CONCLUSIONS

We believe that the IMD is very appropriate for follow-up of individual adults, however it may not be very comparable between subjects due to differences in hand size or for follow-up measurement in children due to the changes in the size of their hands. Alternatively, angular measurements allow comparison within a single subject as well as within different subjects since they are not influenced by hand size. If the Pollexograph-thumb and Pollexograph-metacarpal would prove to be reliable in children, we would recommend using these two methods, since distance measurements are influenced by change in length of a child's hand during follow-up, while angular measurements are not. So, solely based on reliability we would recommend using the IMD, however based on reliability and applicability we would recommend using the Pollexograph.

Since palmar abduction can be diminished in several conditions it is important to have a device that reliably assesses impairment. With a reliable device, clinicians will be able to quantify this impairment and assess intervention efficacy post operatively.

We believe the design of the Pollexograph and marking of the anatomical reference points we chose, contributed to standardization of hand position and therefore resulted in more reliable palmar abduction measurements than the conventional method.

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REFERENCES

1   Brand PW. *Deformity in leprosy*. In Cochrane RG (ed) Leprosy in Theory and practice (ed2). Bristol UK; John Wright & Sons Ltd, 1964:485-496.

2   International Federation of Societies for Surgery of the Hand. Terminology for Hand Surgery. Edinburgh: Harcourt Health Sciences (2001) 200 (5): 53.

3   Hartigan BJ, Stern PJ, Kiefhaber TR. Thumb carpometacarpal osteoarthritis: arthrodesis compared with ligament reconstruction and tendon interposition. *J Bone Joint Surg Am*. 2001: 83-A: 1470-1478.

4   Tubiana R, Thomine JM, Mackin E. *Examination of the Hand and Wrist*. Martin Dunitz Ltd, 1998: 195-196.

5   American Medical Association. *Guides to the Evaluation of Permanent Impairment*. Fourth Edition- June 1993: (3) 28-29.

6   Shrinivasan H. Reconstructive Surgery in treatment of deformities of hand. Dharmendra (ed) *Leprosy*, 1978:567-617.

7   Schwanholt C, Stern PJ. Brief or new: measuring cone for thumb abduction/extension. *Am J Occup Ther*. 1984: 38: 263-264.

8   Murugkar PM, Brandsma J.W., Anderson A.M., Khadka Gurung, Yam Pun. Reliability of Thumb Web Measurements. *J Hand Ther*. 2004: 17(1) 58-63.

9   Harvey L, de Jong I, Goehl G, Armstrong B, Allaous J. A torque-controlled device to measure passive abduction of the thumb carpometacarpal joint. *J Hand Ther*. 2006:19: 403-408.

10   American Society of Hand Therapists. *Clinical Assessment and Recommendations*. (2nd ed) Chicago IL, 1992: 64- 65.

11   Su FC, Kuo LC, Chiu HY, Chen-Sea MJ. Video-computer quantitative evaluation of thumb function using workspace of the thumb. *J Biomech*. 2003: 36:937-942.

12   Chiu HY, Lin SC, Su FC, Wang ST, Hsu HY. The use of the motion analysis system for evaluation of loss of movement in the finger. *J Hand Surg (Br)*. 2000: 25: 195-199.

13   Degeorges R, Parasie J, Mitton D, Imbert N, Goubier JN, Lavaste F. Three-dimensional rotations of human three-joint fingers: an optoelectronic measurement. Preliminary results. *Surg Radiol Anat*. 2005: 27:43-50.

14   Kuo LC, Su FC, Chiu HY, Yu CY. Feasibility of using a video-based motion analysis system for measuring thumb kinematics. *J Biomech*. 2002: 35: 1499-1506.

15   Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet*. 1986: 1:307-310.

16   Rousson V, Gasser T, Seifert B. Assessing intrarater, interrater and test-retest reliability of continuous measurements. Statistics in medicine, 2002: 21:3431-3446.

17   Roebroeck ME, Harlaar J, Lankhorst GJ. The application of generalizability theory to reliability assessment: an illustration using isometric force measurements. *Phys Ther*. 1993: 73:386-395: discussion 396-401.

18   Shavelson RJ, Webb NM, Rowley GL. Generalizability theory. *Am Psych*. 1989: 44:922-932.

19   Roebroeck ME, Harlaar J, Lankhorst GJ. Reliability assessment of isometric knee extension measurements with a computer-assisted hand-held dynamometer. *Arch Phys Med Rehab*. 1998: 79:442-448.

20   Schreuders TA, Roebroeck M, van der Kar TJ, Soeters JN, Hovius SE, Stam HJ. Strength of the intrinsic muscles of the hand measured with a hand-held dynamometer: reliability in patients with ulnar and median nerve paralysis. *J Hand Surg (Br)*. 2000: 25:560-565.

21   Stratford PW, Goldsmith CH. Use of the standard error as a reliability index of interest: an applied example using elbow flexor strength. *Phys Therapy:*1997: 77(7):745-750.

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Chapter 4

Palmar Abduction Measurements:

Reliability and Introduction of Normative Data in Healthy Children

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ABSTRACT

Purpose: Previously, we studied normative and reliability data of palmar thumb abduction measurements (conventional goniometry, the Pollexograph-thumb, the Pollexograph-metacarpal, the Inter Metacarpal Distance, the American Society of Hand Therapists method and the American Medical Association-method) in healthy adults. Since many interventions aimed at improving palmar abduction are performed at an early age, goal of this study was to assess normative and reliability data of the three most reliable measurement methods in children.

Methods: We performed measurements with the Pollexograph-thumb, the Pollexograph-metacarpal and Inter Metacarpal Distance in 100 healthy children to acquire normative data. A retest was performed in 63 children to assess intra observer reliability.

Results: Mean active and passive palmar abduction measured with the Pollexograph-thumb was 62° (range 40-76°). Range of motion of the Pollexograph-metacarpal was smaller (mean 49°, range 32-64). Mean Inter Metacarpal Distance was 50 mm (range 36-70 mm). Intraclass correlation coefficients of the Pollexograph-thumb, the Pollexograph-metacarpal and Inter Metacarpal Distance indicated excellent reliability (ICC's between 0.85 and 0.92).

Conclusions: Normative Pollexograph-thumb and Pollexograph-metacarpal data showed that means measured in children are comparable to values found in healthy adults. Reliability data indicated that the Pollexograph-thumb, the Pollexograph-metacarpal and Inter Metacarpal Distance are also reliable measurement methods in children.

INTRODUCTION

In literature, there is no clear consensus on measurement methods for palmar thumb abduction and the same accounts for definitions for palmar abduction (1-8). An often used definition for palmar abduction is "the angle between metacarpal 1 and 2 with the thumb maximally abducted" (3,9-10). This angle is conventionally measured with a goniometer and has been described, amongst others, by Hartigan et al. (9) Brand et al. (3) and Tubiana (10). Another frequently used definition is "the motion in which the thumb metacarpal moves away from the index metacarpal, perpendicular to the plane of the palm" (8).

Some of the existing measurement methods have disadvantages that cause difficulties in daily clinical use, such as low reliability of conventional goniometry (5) or measurement complexity of 3D-video camera systems (11-14). Therefore, in a previous study (15) we designed the Pollexograph (see Figure 1A) with the aim of creating a reliable and easy tool to perform palmar thumb abduction measurements in daily clinical care.

After development of the Pollexograph we studied reliability in 25 healthy adults (16). Active and passive measurements were performed with a conventional goniometer, the Pollexograph-thumb, the Pollexograph-metacarpal, the Inter Metacarpal Distance (IMD) (5) the American Society of Hand Therapists method (ASHT method) (2) and the method described in "Guides to the Evaluation of Permanent Impairment" of the American Medical Association (AMA method) (1). The high intraclass correlation coefficients (ICCs) and smaller smallest detectable differences (SDDs) and standard error of measurements (SEMs) of the Pollexograph-thumb, the Pollexograph-metacarpal and the IMD indicated these three latter ones were the most reliable methods for measuring palmar abduction.

Goal of this study was to assess reliability and collect normative data of the Pollexograph-thumb, the Pollexograph-metacarpal and the IMD in children, since many interventions aimed at improving palmar abduction are performed at an early age. Therefore, intra observer reliability was assessed in 63 children and normative data were acquired in 100 healthy children.

METHODS

Children

Measurements were performed on the right hand of 100 children between the age of 4 to 12 years, attending a primary school in Rotterdam, The Netherlands. The group consisted of 49

boys and 51 girls with no prior injury to the upper extremity or systemic conditions affecting the muscle or nervous system. Ninety-five children were right handed and the remaining 5 children were left-handed. This study was approved by the Medical Ethics Committee and all parents gave written consent for their child to participate in this study.

Measurements

We performed active and passive palmar abduction measurements with two angular measurement methods (the Pollexograph-thumb, the Pollexograph-metacarpal) and one distance measurement method (IMD). Conventional goniometry, the ASHT method and the AMA method were not assessed, since we found low reliability for these methods in adults.

Measurements were performed by one of the authors (MdK) and after a mean of 26 days (range 7-46 days) a retest was performed in 63 children. These 63 children were equally distributed based on age and gender. To prevent the tester from being influenced by the values of prior tests, retest values were written down on a new form.

For the Pollexograph-thumb measurements, three landmarks were indicated on the hand: 1) the middle, most proximal part of the first metacarpal, indicating the carpometacarpal joint (CMC joint), 2) the thenar crease and 3) the central, distal part of the thumb nail. During measurements, the child was seated at a table with the elbow in 90º flexion. The hand was placed on the Pollexograph with the thenar crease on the edge of the box and the CMC joint marking aligned with the 90º line of the protractor (Figure 1B). The lower arm was positioned parallel to the box with the fingers pointed slightly ulnar. When the hand was placed accurately, the thumb could move without interference of the box surface. During measurements, the other fingers were fixed against the box by the examiner. Maximal palmar abduction of the thumb was read from the nail marking position above the protractor.

With the Pollexograph-thumb, the angle between MC1 and palm of the hand is measured, plus the angle caused by possible laxity in the metacarpophalangeal (MCP) and inter phalangeal (IP) joints. We therefore evaluated an alternative; the Pollexograph-metacarpal application in which a ruler is placed over the first metacarpal to measure the angle between palm of the hand and the first metacarpal. These Pollexograph-metacarpal measurements were performed largely similar to those described for the Pollexograph-thumb measurements. The first 2 skin markings (CMC joint and thenar crease) remained the same; the third marking was placed on the middistal head of the first metacarpal (MC1-marking). During measurements, a ruler was placed over the CMC-marking, the MC1-marking and the protractor (Figure 1C). When the thumb was maximally abducted, the value was read from the ruler position above the protractor, in line with the skin markings.
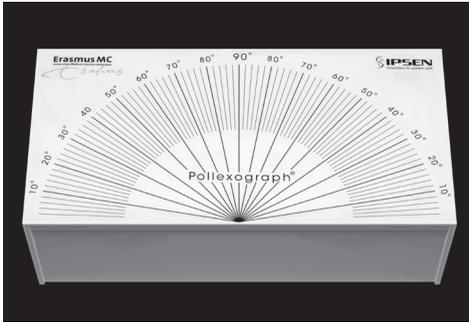
FIGURE 1A. The Pollexograph.
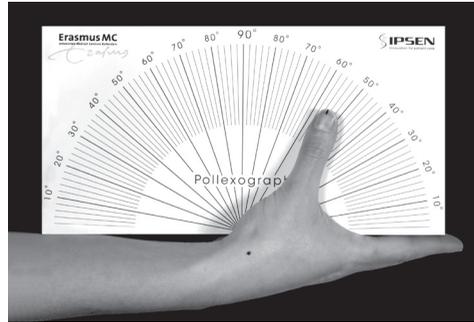
FIGURE 1B. Pollexograph-thumb measurement.
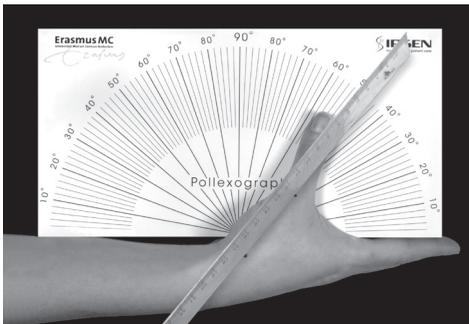
FIGURE 1C. Pollexograph-metacarpal measurement.
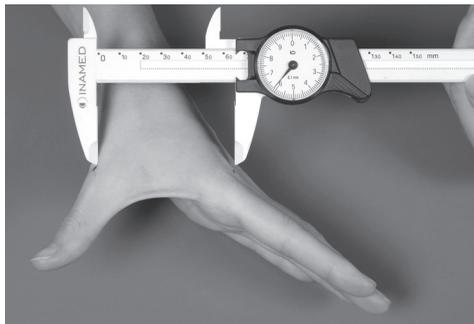
FIGURE 2. Inter Metacarpal Distance measurement.

The distance measurement method we performed was the Inter Metacarpal Distance (IMD), introduced by Murugkar et al. (5). For these measurements, the middorsal points of the first and second metacarpal heads were marked and two caliper points were placed on the markings while the thumb was in maximal palmar abduction (Figure 2). The distance was read in millimeters from the scale.

Statistical Methods

Using SPSS 14.0, we calculated descriptive statistics: means, standard deviations (SDs) and ranges of the whole group. Differences in mean values of the different methods indicate systematic differences between measurement techniques.

Intra rater reliability was assessed using intraclass correlation coefficients (ICC) (17-19). Additionally, absolute reliability indices such as standard error of measurement (SEM), and smallest detectable difference (SDD) were calculated. The SEM was calculated with the

estimated variance components; the SEM is the square root of the error variance (20-21). From the SEM, the smallest detectable difference (SDD =1,96 x √2 x SEM) was determined. Specifically, for clinicians, the SDD is valuable since with this index an examiner can distinguish between a measurement error and a real (treatment) change. Only a difference that exceeds the SDD is a real (non error) change (22). For example, a SDD of 5 degrees indicates that a follow-up measurement should differ by at least 5 degrees from a baseline measurement to be sure that there is a real (non-error) change in abduction angle in an individual subject. Correlation between age and angle or distance was assessed using the Pearson's correlation coefficient. A p-value of ≤ 0.05 was considered significant. With use of linear regression analysis, a formula for the relation between Inter Metacarpal Distance and age was calculated. With this formula, it is possible to estimate what the average Inter Metacarpal Distance should be for children of a certain age (between the ages of 4 to 12).

RESULTS

Reliability

Table 1 shows intra rater reliability for each method expressed with use of SEMs, SDDs and ICCs measured in 63 children. ICCs for the Pollexograph-thumb and Pollexograph-metacarpal measurements indicated excellent agreement for active and passive measurements (ICCs 0.85- 0.91). Also IMD measurement ICCs (0.92) showed excellent agreement.

TABLE 1. Intra rater reliability for each method expressed with SEMs, SDDs and ICCs.

Method	Active/ Passive	SEM (degrees)	SDD (degrees)	ICC
Pollexograph-thumb	Active	2.0	5.5	0.91
Pollexograph-thumb	Passive	1.8	5.1	0.89
Pollexograph-metacarpal	Active	2.3	6.4	0.87
Pollexograph-metacarpal	Passive	2.4	6.7	0.85
		SEM (mm)	SDD (mm)	
IMD	Active	1.9	5.3	0.92
IMD	Passive	1.8	5.0	0.92

SEM= standard error of measurement
SDD= smallest detectable difference
ICC= intraclass correlation coefficient

Normative data

Table 2A shows normative data; means, standard deviations and ranges of angular measurement methods for palmar thumb abduction. It can be seen that mean active and passive angles measured with the Pollexograph-thumb were approximately 62° (range 40-76). Angles found with the Pollexograph-metacarpal were smaller; about 49° (range 32-64).

Means, standard deviations and ranges of the distance measurement method are shown in Table 2B. Mean active and passive IMD distances ranged from 36-70 mm with an average of 50 mm. Therefore, in Table 2B we have described normative IMD data separately for each age group, showing an increase of the mean Inter Metacarpal Distance with increasing age.

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TABLE 2A. Normative data; means, standard deviations and ranges of angular measurement methods for palmar thumb abduction.

Method (degrees)		Active/ Passive	Mean	SD	Range
Pollexograph-thumb	Whole group	Active	60.7	7.3	(40- 74)
Pollexograph-thumb	Whole group	Passive	63.6	5.8	(50- 76)
Pollexograph-metacarpal	Whole group	Active	48.8	6.5	(32- 62)
Pollexograph-metacarpal	Whole group	Passive	49.9	6.2	(34- 64)

SD= standard deviation

TABLE 2B. Normative data; means, standard deviations and ranges of distance measurement methods for palmar thumb abduction.

Method		Active/ Passive	Mean (mm)	SD	Range
IMD	**Whole group**	**Active**	**49.8**	**6.5**	**(36- 69)**
	Age 4 years (n=8)		39.8	3.6	(36- 45)
	Age 5 years (n=8)		43.6	2.6	(41- 48)
	Age 6 years (n=13)		44.7	1.8	(41- 47)
	Age 7 years (n=11)		50.4	4.7	(44- 58)
	Age 8 years (n=13)		50.5	4.1	(44- 58)
	Age 9 years (n=14)		51.6	4.7	(44- 60)
	Age 10 years (n=13)		52.6	5.1	(43- 61)
	Age 11 years (n=14)		56.4	5.6	(47- 69)
	Age 12 years (n=6)		57.0	3.8	(50- 61)
IMD	**Whole group**	**Passive**	**51.5**	**6.4**	**(39- 70)**
	Age 4 years (n=8)		42.6	2.9	(39- 46)
	Age 5 years (n=8)		44.8	2.4	(42- 48)
	Age 6 years (n=13)		45.9	2.7	(41- 50)
	Age 7 years (n=11)		51.4	4.4	(45- 58)
	Age 8 years (n=13)		52.9	4.8	(45- 59)
	Age 9 years (n=14)		52.8	4.8	(44- 60)
	Age 10 years(n=13)		54.8	4.9	(46- 63)
	Age 11 years(n=14)		58.3	5.6	(48- 70)
	Age 12 years (n=6)		57.0	4.7	(48- 61)

Figure 3A. shows that the palmar abduction angles of the Pollexograph-thumb range from 40 to 76 degrees and that the angle did not correlate with age (r =0.046, p= 0.65).
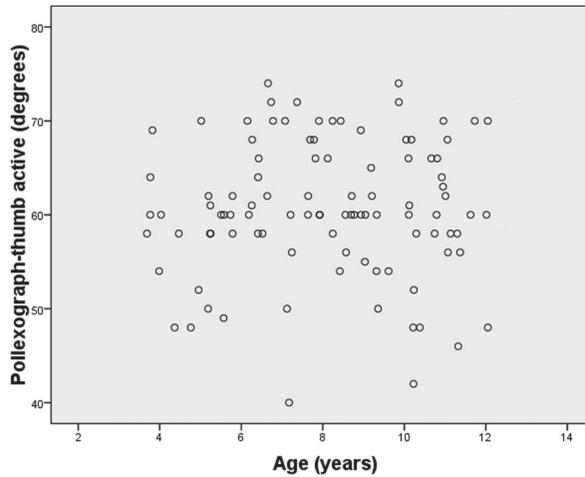
FIGURE 3A. Scatter plot displaying the correlation between age and the Pollexograph-thumb active measurements in 100 children.

Figure 3B shows similar results for the Pollexograph-metacarpal. This palmar abduction angle ranges from 32 and 64 degrees and also did not correlate with age (r =0.064, p=0.53).
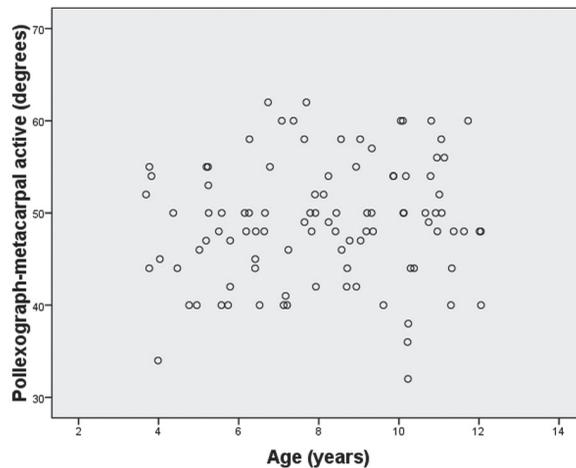
FIGURE 3B. Scatter plot displaying the correlation between age and the Pollexograph-metacarpal active measurements in 100 children.

In contrast to Pollexograph angles, IMD distances (see Figure 3C) did correlate significantly to age (r =0.73, p= 0.001).
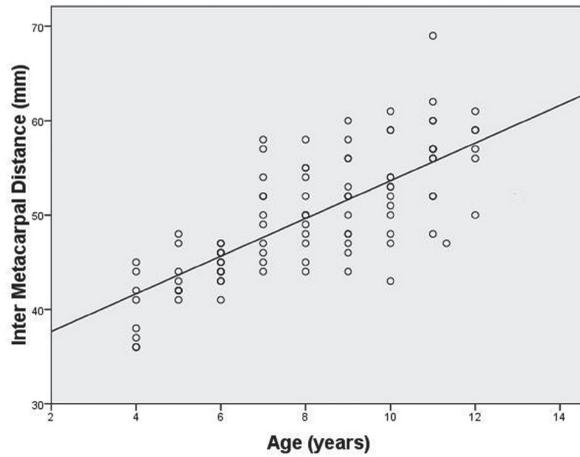
FIGURE 3C. Scatter plot displaying the correlation between age and the IMD active measurements in 100 children. The corresponding regression line for the active IMD is y = 33.66 + 1.99x (where x = age in years and y = IMD distance in mm).

DISCUSSION

The first goal of this study was to assess whether the Pollexograph-thumb, the Pollexograph-metacarpal and IMD, are reliable measurement methods of palmar abduction in children, since many surgical interventions aimed at improving palmar abduction are performed at an early age. We found that the Pollexograph-thumb, the Pollexograph-metacarpal and IMD had excellent intra rater reliability to measure palmar abduction in 63 children aged 4-12 years. Secondly, we obtained normative data for palmar abduction of the thumb in 100 children.

With Pollexograph-metacarpal measurements we found mean palmar abduction to be 48.8°, ranging from 32° to 62° for active measurements. For passive measurements we found a mean value of 49.9° (range 34°-64°). Normative data in this study were most comparable to Tubiana's results (10), who found normal values ranging from 40-80°, while Brand et al. (3) report normal range of the web angle as being 40-50°. Harvey et al. (4) found mean passive palmar abduction to be 56° (range 53-60°) in their healthy adult group. However, it should be noted that these results were reported in healthy adults and to our knowledge; normative data in of palmar abduction angle in children have never been reported. Mean palmar abduction angles measured of the children in this study were similar to the mean values that we recently reported for adults using the same measurement techniques (16). Since children's hands are not yet full-grown, IMD means were not comparable with means found in adults.

CONCLUSIONS

Overall, we found that the Pollexograph-thumb, the Pollexograph-metacarpal and IMD are reliable measurement methods for palmar abduction in healthy children. In addition, we have collected normative palmar thumb abduction data in healthy children between 4 and 12 years. Even though distance-based measurements, like the IMD, may be appropriate for follow-up of individual adults, they may not be very comparable between subjects due to differences in hand size, even more in children where bone length changes with time. We would therefore favor the Pollexograph-thumb and the Pollexograph-metacarpal method for measuring palmar abduction in children.

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REFERENCES

1   American Medical Association. *Guides to the Evaluation of Permanent Impairment*. American Medical Association, 4th Edition 1993:(3) 28-29.

2   American Society of Hand Therapists. *Clinical Assessment and Recommendations*. 2nd ed. Chicago IL: American Society of Hand Therapists 1992: 64-65.

3   Brand P.W. *Deformity in leprosy*. In. Cochrane RG (ed). Leprosy in Theory and Practice. (ed2). Bristol UK; John Wright & Sons Ltd. 1964: 485-496.

4   Harvey L, de Jong I, Goehl G, Armstrong B, Allaous J. A torque-controlled device to measure passive abduction of the thumb carpometacarpal joint. *J Hand Ther* 2006; 19(4): 403-8.

5   Murugkar P.M, Brandsma J.W, Anderson A.M, Gurung K, Pun Y. Reliability of Thumb Web Measurements. *J Hand Ther* 2004; (17): 58-63.

6   Schwanholt C. and Stern P.J. Brief or new: measuring cone for thumb abduction/extension. *Am J Occup Ther* 1984; 38(4): 263-4.

7   Shrinivasan H. Reconstructive Surgery in treatment of deformities of hand. In Dharmendra ed. *Leprosy*. Bombay: Kothari Medical Publishing House, 1978: 567-617.

8   International Federation of Societies for Surgery of the Hand. Terminology for Hand Surgery. Edinburgh, UK: Harcourt Health Sciences 2001:53-54.

9   Hartigan B.J, Stern P.J, and Kiefhaber T.R. Thumb carpometacarpal osteoarthritis: arthrodesis compared with ligament reconstruction and tendon interposition. *J Bone Joint Surg Am* 2001; 83-A (10): 1470-8.

10 Tubiana R., J.M. Thomine, and E. Mackin, *Examination of the Hand and Wrist*. London: Martin Dunitz Ltd. 1998: 195-196.

11 Chiu H.Y, Lin Sc, Su FC, Wang ST, Hsu HY. The use of the motion analysis system for evaluation of loss of movement in the finger. *J Hand Surg [Br]* 2000; 25(2):195-9.

12 Su FC, Kuo LC, Chiu HY, Chen-Sea MJ. Video-computer quantitative evaluation of thumb function using workspace of the thumb. *J Biomech* 2003; 36(7): 937-42.

13 Kuo L.C, Su FC, Chiu HY, Yu CY. A quantitative method to measure maximal workspace of the trapeziometacarpal joint-normal model development. *J Orthop Res* 2004; 22(3): 600-6.

14 Degeorges R, Parasie J, Mitton D, Imbert N, Goubier JN, Lavaste F. Three-dimensional rotations of human three-joint fingers: an optoelectronic measurement. Preliminary results. *Surg Radiol Anat* 2005; 27(1): 43-50.

15 de Kraker M., et al. The Pollexograph®: a new device for palmar abduction measurements of the thumb. *J Hand Ther* 2009; 22 (3): 271-6.

16 de Kraker M., et al. Palmar abduction: reliability of 6 measurement methods in healthy adults. *J Hand Surg (Am)*, 2009; 34(3): 523-30.

17 Bland J.M. and Altman D.G. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986; 1(8476):307-10.

18 Fleiss J.L. The design and analysis of clinical experiments. Wiley series in probability and mathematical statistics. New Jersey: John Wiley and Sons.1986: 1-14.

19 Fleiss J.L, Levin B, and Paik M, Statistical methods for rates and proportions. New Jersey: John Wiley and Sons. 2003: 218.

20 Roebroeck M.E, Harlaar, and Lankhorst G.J. The application of generalizability theory to reliability assessment: an illustration using isometric force measurements. *Phys Ther* 1993; 73(6): 386-95.

21 Shavelson R.J., Webb N.M, and Rowley G.L. Generalizability Theory. *Am Psych* 1989; 44: 922-932.

22 Roebroeck M.E., Harlaar J, and Lankhorst G.J, Reliability assessment of isometric knee extension measurements with a computer-assisted hand-held dynamometer. *Arch Phys Med Rehabil* 1998; 79(4): 442-8.

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Chapter 5

3D Thumb Workspace Assessment in Patients with Thumb Hypoplasia

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ABSTRACT

Purpose: To determine intra rater reliability and clinical usefulness of an electromagnetic motion tracking device for assessing thumb workspace in control subjects and surgically treated hypoplastic thumbs.

Methods: Using a motion tracking device with a sensor placed distally on the first metacarpal in controls and hypoplastic thumb patients, we measured the 3-D thumb workspace. From this, circumference and the surface area of the thumb's workspace were calculated.

Results: Good to excellent intra rater reliability was found with ICC's ranging from 0.76 to 0.90. A large number of patients showed an aberrant workspace in comparison to controls; some of the workspaces were increased, others decreased. No significant correlation was found between patient's 3-D workspace and Kapandji scores.

Conclusions: Three dimensional thumb workspace analysis is a reliable tool that can detect significant differences in thumb workspace between control subjects and patients with a thumb condition, in contrast to the frequently used Kapandji score.

INTRODUCTION

The thumb's wide range of motion (ROM) enables grip and pinch, allowing us to grasp and manipulate objects. Due to its saddle-shape (1,2), the carpometacarpal joint of the thumb (CMC1) contributes substantially to the ROM of the thumb and in particular positioning of the thumb opposite to the fingers. As a consequence, conditions that affect the thumb cause significant impairment in many daily life activities. Many of these conditions require surgical interventions to relieve pain and to improve thumb function. To assess the results of these interventions, a reliable and easily applicable measurement method to determine CMC1 range of motion is highly desirable.

Several methods are available to quantitatively measure 2-D thumb ROM. In clinical practice, goniometry (3) and the Inter Metacarpal Distance (IMD) (4) are most commonly used to measure palmar and radial abduction. Since goniometry has poor intraobserver reliability (5, 6) and since the IMD measurements are influenced by differences in hand size, we have recently introduced the Pollexograph to measure palmar abduction more reliably (5-6). Another frequently used method in clinical practice, is the Kapandji score (7) in which patients have to move the tip of their thumb to ten anatomic landmarks located on the four fingers and the palmar crease of the hand. Even though the Kapandji method is easy to perform, its clinical relevance and reliability remain questionable, because a pseudo-opposition of the thumb can be performed flexion in the interphalangeal joint and adduction of the thumb.

While the abovementioned tools measure the range of motion of the CMC1 joint, they measure a 2-D angle or distance instead of the full 3-D range of motion. Therefore, other methods have been developed to assess the whole workspace of the thumb. For example, 3-D motion analysis using camera systems have been used by several authors, while others have used electromagnetic motion tracking (8-13). Most of these studies analyze the workspace while fixating the hand and wrist and asking the subjects to perform thumb movements. Alternatively, motion sensors or markers are placed not only on the thumb but also on the hand and wrist. Generally, outcome measures obtained from these recordings are range of motion in separate directions or quantification of the total work space.

Although a number of studies have quantified 3-D motion patterns of the thumb, so far, these studies have mainly focused on technique development (9,14), on description of the normal workspace in healthy subjects, or on validity and reliability of the measurements in healthy patients (12,13,15,16). To our knowledge, 3-D thumb motion and workspace have not been

extensively described in specific patient groups. The aim of this study was to determine the intraobserver reliabilty in healthy subjects for measuring the ROM of CMC1. The obtained data were used as a baseline comparing it to 3-D CMC1 movement in patients with an operated hypoplastic thumb. The group consisted of patients with a hypoplastic thumb who underwent a flexor digitorum superficialis IV tendon transfer (FDS IV) or a pollicisation. Additionally, as the Kapandji score is a frequently used denominator for thumb function, we wanted to assess its correlation with the measured circumduction circumference.

MATERIAL AND METHODS

Control subjects

Measurements were performed on the right hands of 17 healthy subjects recruited at our medical center. The group consisted of 11 males and 6 females with a mean age of 29 years (range 21-47 years). Subjects had no prior injury to the upper extremity or systemic conditions affecting the muscular or nervous system.

Hypoplastic thumb patients

In total, we included twelve patients with 13 hypoplastic thumbs. The group consisted of 7 males and 5 females with a mean age of 13 years (range 5-30 years). Of these patients, 5 patients (six thumbs) had a Type II hypoplastic thumb with an unstable metacarpophalangeal (MCP) joint, a narrow webspace and thenar hypoplasia. Two other patients (2 thumbs) had a Type IIIA hypoplastic thumb, indicating the same deformities as the Type II thumbs but with additional extrinsic hypoplasia. All eight thumbs sustained a flexor digitorum superficialis (FDS IV) tendon transfer to restore thumb stability and opposition.

In addition, we included 5 patients (5 thumbs) with a Type IIIB-IV hypoplastic thumb, which sustained a pollicisation of the index finger to create a new thumb. Two out of these patients with a pollicisation also sustained an additional abductor digiti quinti tendon (ADQ) transfer to improve opposition.

Measurements

Thumb range of motion was measured using an electromagnetic tracking device, the miniBIRD™ 500 (Ascension Tech. Corp., Burlington, VT). The system consists of an electromagnetic transmitter, a 5mm sensor, an electronic unit for calculation of 3-D sensor displacement and orientation.

During measurements, subjects were fixed in a measurement set-up consisting of non-magnetic materials. The subject's elbow was placed in 90 degrees flexion with the forearm in a neutral position (between pronation and supination) and the fingers in full extension. A splint was used to immobilize the wrist and fingers while the thumb could move free. Tape was applied to the thumb to reduce sensor movement caused by skin and tendon gliding (9). First, to measure the location of the CMC1 joint, the sensor was placed at the base of the first metacarpal at the so-called "anatomical snuffbox" and its position was recorded. Thereafter, the sensor, placed in a non-magnetic block of 1.5 by 1.5 cm to facilitate sensor stability, was placed mid-dorsally on the first metacarpal, approximately 0.5cm proximal of the metacarpophalangeal (MCP) joint. We chose to place the sensor at the first metacarpal and not at the tip of the thumb, since this enabled us to assess the ROM of the CMC1 joint in more detail. For other purposes, for example when it is of more interest to assess the workspace of the complete thumb, the sensor could be placed at the tip of the thumb.

After sensor fixation, a standardized reference position was measured in which the fully extended thumb was aligned with the second metacarpal (MC2). Then, subjects were asked to execute four repetitions of three movements: palmar abduction (abduction perpendicular to the palm), radial abduction (abduction parallel to the palm) and circumduction. For all movements, subjects were instructed to move with a maximum excursion. For circumduction measurements, patients were instructed to start at the reference position or as close as possible, and to move the thumb to maximal radial abduction, from there sideways toward palmar abduction, then towards the fifth digit, and finally over the palm of the hand back to the reference position.

For comparison, in addition to the 3-D motion analysis, the 3-D opposition was scored for all subjects using the Kapandji score (7). To determine intraobserver reliability of the experimental set-up, retest measurements were performed on the same day for all control subjects. After the first measurement, all measurement material, including skin markings and tape, were removed and applied again to repeat the measurements.

Data analysis

The collected data were stored as ASCII files on a personal computer. We developed custom-made MATLAB software for data analysis. As a first step, based on a visual inspection of the 3-D position traces, we manually selected the three largest movements from the four repetitions in each file. In the large majority, this resulted in the selection of the last three repetitions. To obtain maximum palmar and radial abduction angles, maximum angles of the three repetitions were computed by calculating the maximum difference from the reference

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position. Since only a few patients were not able to independently move to the reference position, we did not separately study the radial and palmar range of motion, but only focused on the maximal angles.

In addition, total thumb workspace was calculated using two parameters: the mean circumference of the circumduction movement and the surface area across the three repetitions of the complete circumduction movement. The surface area was estimated by fitting a 'maximally' smooth 3-D-surface through all position data for each circumduction movement. This procedure generated a large number of grid points. The grid points falling within the boundary of the circumduction movement were used to define a large number of triangles. The thumb workspace was calculated by summing the surface of these triangles. The circumference was expressed in millimeters and the surface area in square millimeters. Then, the circumference and surface were normalized by the mean distance between the sensor location during the measurements and the sensor location of the "anatomical snuffbox" to adjust for differences in thumb length and sensor placement. This distance and surface area are referred to as the "normalized circumference" and "normalized surface" respectively.

Statistical analysis

Using SPSS 22.0, we calculated descriptive statistics: means, standard deviations (SD) and ranges. Intraobserver reliability was assessed using intra-class correlation coefficients (ICC). Additionally, absolute reliability indices such as standard error of measurement (SEM), and smallest detectable difference (SDD) were calculated. The SEM was calculated using estimated variance components with the SEM defined as the square root of the error variance (17). From the SEM, the smallest detectable difference (SDD =1,96 x √2 x SEM) was determined.

To compare patients and controls, we calculated mean and standard deviation of the workspace variables. In addition, we used a one-way analysis of variance (ANOVA) to compare the means. Finally, we used the Spearman correlation coefficient to evaluate the relation between Kapandji score and circumference data. For all tests, a p-value of ≤ 0.05 was considered significant.

RESULTS

Reliability and normative data

Figure 1 shows a typical example of the motion patterns during the three movements of a control subject, showing a relatively regular trajectory. The circumduction pattern first follows the path upwards in the direction of radial abduction, moves towards the position of maximum palmar abduction and then moves from opposition back to the reference position.
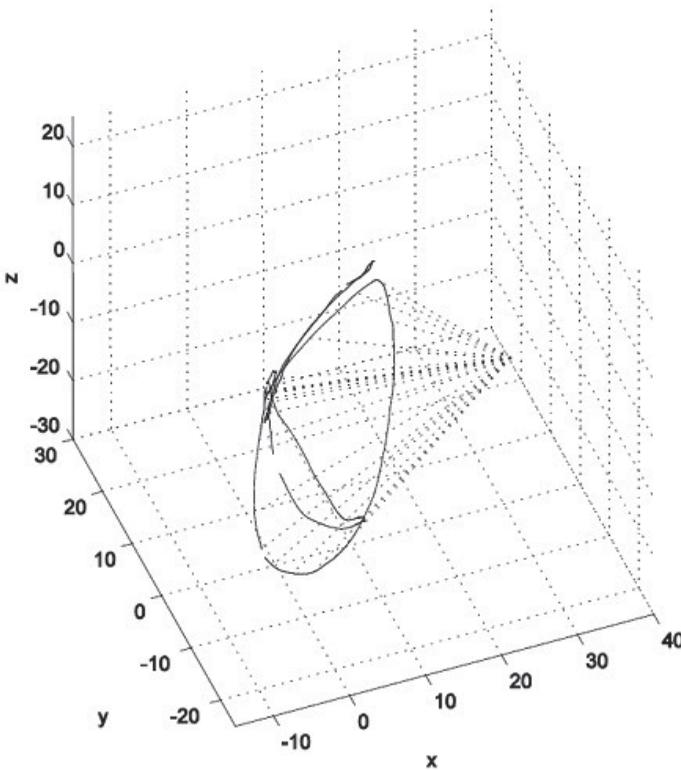
FIGURE 1. Typical example of the motion patterns of the sensor during movements from the reference position to palmar abduction, radial abduction and during a complete circumduction movement.

The means, standard deviations and ranges of the palmar and radial abduction as well as the circumduction parameters of the control subjects are shown in Table 1. In addition, the results from the intraobserver reliability analysis are shown, with the ICC's ranging between 0.74 and 0.88.

TABLE 1. Normative values for the different parameters derived from the motion analysis. Indicated are the mean, standard deviation and range of the first measurements of the control subjects. In addition, the intraobserver reliability results are shown, expressed as the standard error of measurement (SEM), the smallest detectable difference (SDD,) and the intra-class correlation coefficient (ICC).

Motion	Mean (SD)	[range]	SEM	SDD	ICC
Radial abduction (degrees)	33.1 (5.9)	(23- 45)	2.6	7.3	0.81
Palmar abduction (degrees)	36.9 (5.1)	(26- 46)	1.8	4.9	0.88
Circumference (mm)	91.0 (14.3)	(67- 117)	7.1	19.5	0.74
Normalized circumference	2.18 (0.30)	(1.67- 2.85)	0.15	0.41	0.71
Surface area (mm)	400.2 (111.0)	(196- 610)	59.1	163.7	0.70

Thumb workspace in patients

Pollicisation: Figure 2A shows the circumduction of a 9-year-old girl with a Type IV hypoplastic right thumb who underwent a pollicisation. In this subject, the total thumb workspace was increased compared to the control subject.
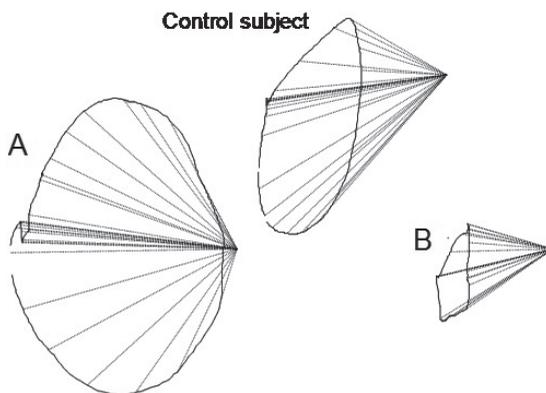
FIGURE 2. Examples of the 3-D workspace of patients in the two different patient groups. In the center, the control subject from Figure 1 is shown again. In Figures A-B, examples are illustrated from patients with a pollicisation (A), and (B) a hypoplastic thumb with an FDS IV tendon transfer for opposition. All plots were created from the same 'camera position' and have the same scales of the axes.

FDS IV: Figure 2B shows an example of a 5-year-old boy with a Type II hypoplastic right thumb, which underwent a FDS IV tendon transfer. The thumb workspace was smaller than the workspace of the control subject. We found a significant difference on a group level; the majority of patients had scores outside of the range of values measured in the control subjects. In most patients, the workspace was reduced. However, in one or two patients, depending on the specific parameter, the workspace was increased.

Table 2 indicates that in most patients range of motion was reduced, whereas in one patient it was enlarged. It averaged out for the group for almost all measurements analysis, indicating that most patient thumb measurements differ from a normal pattern.

TABLE 2. Active range of motion of control subjects and both patient groups, expresses as means, standard deviations (SD's). Additonally, significance in differences between means and standard deviations are shown.

Measurement	Controls (n=17)	Pollicisation (n=5)	Significance Mean*	Significance SD*	FDS IV (n=8)	Significance Mean**	Significance SD**
	Mean (SD)	Mean (SD)			Mean (SD)		
Radial abduction (degrees)	32.8 (5.8)	26.2 (18.5)	0.43	0.03	22.7 (13.6)	0.06	0.04
Palmar abduction (degrees)	37.1 (4.9)	28.7 (19.2)	0.34	0.02	27.9 (17.2)	0.15	0.001
Circumference (mm)	80.8 (14.7)	68.7 (36.9)	0.47	0.05	66.7 (37.8)	0.31	0.001
Normalized circumference	1.9 (0.31)	2.1 (0.81)	0.75	0.06	1.9 (0.92)	0.87	0.001
Surface area (mm^2)	217.5 (151.8)	286.7 (375.0)	0.68	0.06	212.7 (291.0)	0.96	0.05
Normalized surface area	0.12 (0.7)	0.23 (0.22)	0.29	0.002	0.13 (0.17)	0.85	0.03

*= Significance for mean/ SD comparing controls and pollicisations, **= Significance for mean/ SD comparing controls and FDS IV tendon transfer.

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Correlation with Kapandji

Mean Kapandji score was 8,8 in the pollicisation group and 6,6 in the group that underwent a tendon transfer using the FDS IV. Since the Kapandji score is often used in clinical studies to quantify opposition, we related the Kapandji score with the normalized circumference. The scatter plot of this relation (Figure 3) suggests that the Kapandji score may be able to detect strongly reduced thumb workspace. The Kapandji, however, cannot detect smaller differences in the workspace, as indicated by the low and non-significant correlation coefficient of 0.44 (p=0.17).
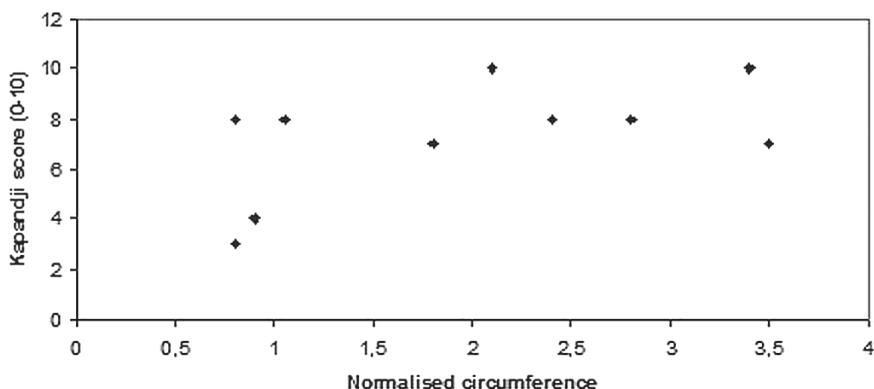
FIGURE 3. Scatter plot of the relation between normalized circumference and Kapandji scores measured in 10 out of 13 patients. Both were not significantly correlated (Spearman correlation coefficient 0.44, p=0.17).

DISCUSSION

To evaluate thumb function in patients with a thumb condition, a measurement method is required that is reliable and able to measure the total 3-D workspace of the thumb. An electromagnetic motion tracking device such as the miniBIRD[tm] 500 is able to track real-time 3-D motions. We found that the 3-D motion analysis had good intraobserver reliability for measurements in healthy subjects. Furthermore, 3-D measurements of healthy subjects and the patient group showed that the individual thumb workspace of patients significantly differed from the controls. In addition, no correlation between Kapandji scores and normalized circumference measurements was found. Subjects with poor CMC1 function, thus achieving

poor thumb circumduction, attained high or even maximal Kapandji scores suggesting that the Kapandji score is highly influenced by the metacarpophalangeal and interphalangeal movements. This suggests that Kapandji takes CMC1 function only marginally into account and tends to overestimate the subject's thumb/ CMC1 function.

Few studies have been published about the reliability and clinical use of a 3-D motion analysis to assess thumb function. Kuo et al. (12) found that their experiment set-up using an electromagnetic device had an excellent intraobserver reliability for measuring the thumb's workspace surface area, attaining an ICC of 0.97. We found an ICC value of 0.74 for the thumb's circumference. In this study, we additionally corrected the surface area for thumb length since larger thumbs misleadingly attain larger ROMs (12). The normalized circumference calculations had an ICC of 0.71. As the ICC depends on the variation within subjects, the lower ICC value in our study compared to Kuo may be explained by a smaller within-subject variation. Furthermore, we added measurements of palmar and radial abduction because surface area is a coarse measure which doesn't indicate the direction of impaired thumb function. The study of Forget et al. (18) were the first to use an electromagnetic device in a clinical setting. They compared active ROM of de Quervain's disease patients with control subjects. However, thumb ROM was displayed graphically and only quantitatively determined by calculating a linear displacement of the thumb, therefore providing little information about the actual total thumb ROM.

Drawbacks of 3-D ROM measurements are that these measurements are more time-consuming and it requires more expensive material than conventional methods such as goniometry. Therefore, it is less suitable for a swift daily assessment of an individual's total thumb function.

A limiting aspect of our study was the heterogeneity within the patient group as both parameters might be a considerable factor in movement performances. This is reflected in the great variability of the measured thumb functions. Yet, this technique enabled us to detect individual differences in CMC1 movement between patients and controls. In addition, we believe that a tool such as this one should not be used independently, but should be part of a larger set of measurements that describes all relevant aspects of a patients thumb function. As part of such a set of measurements, the present measurement allows for a more detailed description of the range of motion of the thumb than standard measurements such as palmar abduction goniometry or the Kapandji score.

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CONCLUSIONS

In summary, we found that the present protocol provides reliable data on a subject's total thumb workspace determined by CMC1 movement and that it may demonstrate significant differences in thumb range of motion between healthy subjects and patients with a thumb condition. On average most differences were statistically significant using a comparison on a group level. Patients had a thumb workspace that was either smaller or larger compared to the control subjects than that would be expected based on random variation. In addition, the Kapandji scores, although frequently used, isn't capable of demonstrating these differences in range of motion and tends to overestimate patient's thumb range of motion.

REFERENCES

1   Zancolli, EA, Zaidenberg C, Zancolli E Jr. Biomechanics of the trapeziometacarpal joint. *Clin Orthop Relat Res* 1987; (220): 14-26.

2   Kauer JM. Functional anatomy of the carpometacarpal joint of the thumb. *Clin Orthop Relat Res* 1987; (220): 7-13.

3   Hartigan, BJ, Stern PJ, Kiefhaber TR. Thumb carpometacarpal osteoarthritis: arthrodesis compared with ligament reconstruction and tendon interposition. *J Bone Joint Surg Am* 2001; 83-A (10): 1470-8.

4   Murugkar PM, Brandsma JW, Anderson AM, Gurung K, Pun Y. Reliability of thumb web measurements. *J Hand The*r 2004; 17(1): 58-63.

5   de Kraker M, Selles RW, Schreuders TA, Hovius SE, Stam HJ. The Pollexograph: a new device for palmar abduction measurements of the thumb. *J Hand Ther 2009*; 22 (3): 271-6.

6   de Kraker M, Selles RW, Schreuders TA, Stam HJ, Hovius SE. Palmar abduction: reliability of 6 measurement methods in healthy adults. *J Hand Surg Am* 2009; 34(3): 523-30.

7   Kapandji, A. Clinical test of apposition and counter-apposition of the thumb. *Ann Chir Main* 1986; 5(1): 67-73.

8   Coert JH, van Dijke HG, Hovius SE, Snijders CJ, Meek MF. Quantifying thumb rotation during circumduction utilizing a video technique. *J Orthop Res* 2003; 21(6): 1151-5.

9   Kuo LC, Cooney WP 3rd, Oyama M, Kaufman KR, Su FC, An KN. Feasibility of using surface markers for assessing motion of the thumb trapeziometacarpal joint. *Clin Biomech* 2003; 18(6): 558-63.

10 Su FC, Kuo LC, Chiu HY, Chen-Sea MJ. Video-computer quantitative evaluation of thumb function using workspace of the thumb. *J Biomech* 2003; 36(7): 937-42.

11 Chiu, HY, FC Su. The motion analysis system and the maximal area of fingertip motion. A preliminary report. *J Hand Surg (Br)* 1996; 21(5): 604-8.

12 Kuo LC, Cooney WP 3rd, Kaufman KR, Chen QS, Su FC, An KN. A quantitative method to measure maximal workspace of the trapeziometacarpal joint--normal model development. *J Orthop Res* 2004; 22(3): 600-6.

13 Kuo LC, Chiu HY, Chang CW, Hsu HY, Sun YN. Functional workspace for precision manipulation between thumb and fingers in normal hands. *J Electromyogr Kinesiol* 2009; 19(5): 829-39.

14 Kuo LC, Cooney WP, Chen QS, Kaufman KR, Su FC, An KN. A kinematic method to calculate the workspace of the trapeziometacarpal joint. *Proc Inst Mech Eng H* 2004; 218(2): 143-9.

15 Kuo LC, Cooney WP 3rd, An KN, Lai KY, Wang SM, Su FC. Effects of age and gender on the movement workspace of the trapeziometacarpal joint. *Proc Inst Mech Eng* 2009; 223(2): 133-42.

16 Tang J, Zhang X, Li ZM. Operational and maximal workspace of the thumb. *Ergonomics* 2008; 51(7):1109-18.

17 Stratford PW, Goldsmith CH. Use of the standard error as a reliability index of interest: an applied example using elbow flexor strength data. *Phys Ther* 1997; 77(7): 745-50.

18 Forget N, Piotte F, Arsenault J, Harris P, Bourbonnais D. Bilateral thumb's active range of motion and strength in de Quervain's disease: comparison with a normal sample. *J Hand Ther* 2008; 21(3): 276-84; quiz 285.

5

PART II

Outcome in Thumb Hypoplasia

Chapter 6

Outcome of Flexor Digitorum Superficialis Opponensplasty for Type II and IIIA Thumb Hypoplasia

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ABSTRACT

Purpose: This study reports on outcomes of the flexor digitorum superficialis tendon transfer from the ring finger in Type II and IIIA hypoplastic thumbs.

Methods: We included 22 patients with 27 involved hands: 16 Type II thumbs and five Type IIIA treated by transfer and six non-operated Type II thumbs. The outcomes were assessed by range of motion, strength, sensibility, joint stability and patient/parent satisfaction.

Results: Compared with normative data, the range of motion was diminished in all patient groups. Opposition strength in operated Type II thumbs was significantly better than in non-operated thumbs. Grip strength, pinch strength, tripod strength and key pinch strength were approximately 50% of normal in Type II thumbs and 35% in Type IIIA thumbs. Metacarpophalangeal joint stability was restored in all operated Type II thumbs and in 40% of Type IIIA thumbs.

Conclusions: We conclude that the FDS tendon transfer of the fourth finger is a good functioning opponensplasty in both Type II and IIIA thumbs. The transfer provides excellent stability of the metacarpophalangeal joint in Type II thumbs.

INTRODUCTION

In Type II and IIIA thumb hypoplasia, thenar hypoplasia, a narrow first web and an unstable metacarpophalangeal (MP) joint are common. To restore some thumb function, stabilization of the MP joint and a web correction are needed, in addition to a tendon transfer to enhance opposition. Several tendons are available for transfer. The most often used transfer in thumb hypoplasia is the abductor digiti minimi muscle (ADM) (1-9). Alternative tendons to restore thumb opposition are the flexor digitorum superficialis (FDS) of the ring finger (10) and the extensor indices (EI) (11).

Use of the ADM in thumb hypoplasia was first described by Huber (1) and subsequently others have reported on their own series (3,6). The ADM is considered a suitable opponensplasty because donor site morbidity is acceptable, a thenar eminence is recreated and satisfactory opposition is achieved. However, a marked limitation of the ADM and EI is that both tendons are too short to simultaneously stabilize the MP joint (11,12). For stabilization, an additional capsular reefing is needed. This may loosen over time, resulting in either the need for a further tightening or an MP joint arthrodesis in the long term (9,11). An additional limitation of the EI is that it is often aberrant, since it is in close proximity to the underdeveloped thumb (11).

In contrast to the ADM and EI, the FDS tendon does not seem to have these disadvantages since it is almost always present and is sufficiently long. One FDS tendon slip can be used to stabilize the MP joint by reconstructing the ulnar collateral ligament, while the other slip can be used to restore thumb opposition. For this reason, in our centre, we have used the FDS tendon.

There are few quantitative reports on the effectiveness of FDS tendon transfers in thumb hypoplasia. The goal of this study was to establish the outcomes in Type II and IIIA hypoplastic thumbs after an FDS tendon transfer. Outcome was compared with normative data. In addition, the outcomes in operated Type II thumbs were compared with non-operated Type II thumbs.

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METHODS

Patients

From 1980 until 2006, 38 patients with a Type II hypoplastic thumb and eight patients with a Type IIIA hypoplastic thumb (according to Blauth's classification, modified by Manske and McCarroll (1978)) (4) were treated by FDS tendon transfer. Type II thumbs have a narrow first web and an unstable MP joint in combination with thenar hypoplasia. The Type IIIA thumbs have the same abnormalities as Type II thumbs with additional hypoplasia of the extrinsic muscles and hypoplasia of the carpometacarpal joint of the thumb. For assessment, we included patients from the age of 4 years, since these children are generally able to cooperate with measurements and reliable hand strength recordings can be obtained. For comparison normative data were collected in 100 healthy children (13). Patients were excluded when they had additional conditions affecting the muscular or nervous systems or when the tendon transfer had been done less than 1 year before assessment. Patients with pollex abductus were excluded from this study.

Four patients were unavailable for follow-up evaluation consequent to immigration, while 12 patients were not able or willing to participate in the study. Patients who did not participate in the study were comparable in base line characteristics to the investigated group.

We included 22 patients with 27 affected hands: 16 Type II thumbs and five Type IIIA thumbs with an FDS transfer and six non-operated Type II thumbs. Five patients were affected bilaterally. Of the bilaterally affected patients, one patient had an FDS tendon transfer for a Type II hypoplastic thumb on both sides. Two patients had bilateral Type II thumb; in both patients only one thumb was treated by an FDS tendon transfer and the other side was not operated on. The two remaining bilateral affected patients had a Type II thumb on one side and a Type IIIA on the other side; all four thumbs were treated by FDS tendon transfer. There were various reasons why several thumbs were not treated such as parents not wanting their child to undergo any more surgery, to being "satisfied with one good thumb". The parents made the final decision, even though the surgeon found that a good indication for surgery was present.

The remaining 17 patients (17 hands) were unilaterally affected; ten Type II thumbs and three Type IIIA thumbs were treated by an FDS tendon transfer and four Type II thumbs were not operated on. Longitudinal radial deficiency Type I (14) was present in two patients. One patient had a Type II thumb and the other a Type IIIA thumb.

The group consisted of 14 male and eight female patients. The mean age at assessment was 18 (range 5-32) years. We chose this time since some patients had operations on each hand at

different ages. The median time between surgery and evaluation was 6.4 (range 2- 19) years. All patients or parents provided written consent for participation.

Technique

The first web deepening consisted of freeing the fascial connection between the first and second metacarpal, followed by a 5-flap Z-plasty (15) or transposition flap from the radiodorsal side of the index finger. At the radial side of the MP joint, tendinous structures of the remnant of the thenar musculature were identified together with the extensor apparatus at the proximal phalanx. In all the reported cases the tendons of the extensor pollicis longus, the flexor pollicis longus and the abductor pollicis longus were present and normal. Often thin attachments of extensor and flexor tendons can be detected, however these were not consistently recorded. The FDS was cut at the proximal part of the proximal phalanx of the ring finger and either pulled through a separate incision just distal to the flexor retinaculum or (in one patient) placed around the flexor carpi ulnaris (FCU) tendon. The FDS was split in two halves, and one slip was passed through a bone tunnel in the distal metacarpal, in a radiopalmar to ulnodorsal direction. The ulnar slip was passed underneath the capsule of the MP joint, attached to the ulnar proximal part of the proximal phalanx and folded back superficial to the capsule to be attached to itself just distal to the bone tunnel. In this way the ulnar collateral ligament was reconstructed. The radial slip was attached to the radial side of the proximal phalanx and extensor apparatus (11,16). No K-wires were used and immobilization for 6 weeks was followed by a removable splint which was gradually discarded over the next 4-6 weeks.

Twenty-two of the 27 hands were operated by the senior author (S.E.R.H.); the other five thumbs were operated by two board certified plastic surgeons instructed by the senior author.

METHODS AND MEASUREMENTS

All measurements were performed by an independent researcher, the first author (MdK).

Joint stability

Stability of the interphalangeal (IP) joint, metacarpophalangeal (MP) joint and carpometacarpal (CMC) joints were manually tested in the neutral position (10) and in 30° flexion (7). IP joints were classified as unstable when laxity was greater than 5°. Since there is no consensus on the threshold of MP joint stability, we defined the joint as unstable when the deviation was greater than 30°. CMC joints were classified as unstable when the dorsal shift test was positive.

Strength

Hand strength was measured with an electronic dynamometer for grip, pinch, key pinch and tripod pinch strength (18). Strength of individual fingers and the thumb was measured using the Rotterdam Intrinsic Hand Myometer (RIHM) (19). RIHM measurements were performed for thumb opposition strength, palmar abduction strength of the thumb, radial abduction strength of the index finger, and abduction of the little finger. The mean of three repeated measurements was calculated for each. The RIHM has proven to be a reliable instrument for strength measurements in healthy children between the age of 4 and 12 years (13). Strength was expressed in newtons (N).

Range of motion

Range of motion of flexion, extension, radial abduction, palmar abduction and opposition of the thumbs were measured actively and passively. Radial abduction, flexion and extension were measured with a conventional goniometer and expressed in degrees. Palmar abduction was measured with the Pollexograph-thumb and –metacarpal (20,21) and expressed in degrees. Retroposition was measured as the distance in centimetres from table to tip of the thumb (22). Opposition was scored using the method of Kapandji (23), ranging from 0 (thumb tip on lateral aspect of proximal phalanx of index finger) to 10 (thumb tip reaches distal palmar crease at base of little finger).

Sensibility

Sensibility was tested in adults (age ≥ 18 years) using Semmes-Weinstein monofilaments (24) and in children using the Sensibility Texture Index (STI) (25). In all patients, 2-point discrimination (2-PD) was tested.

Self-evaluation of function and appearance

All patients were asked to score function and thumb appearance using a visual analogue score (VAS) ranging from 0 (very poor/ugly) to 10 (very good/ beautiful). Parents were also asked to score their child's thumbs.

Statistics

We calculated the following descriptive statistics: means, means expressed as a percentage of normative data, which were collected in 100 healthy children (19), standard deviations (SDs) and ranges. The independent sample *t*-test was used to compare means between groups. A *p*-value of ≤ 0.05 was considered significant.

RESULTS

Joint stability

When MP joint instability was classified as joint laxity more than 30°, all Type II thumbs treated by an FDS tendon transfer had a stable MP joint. One Type II thumb that had been treated by an FDS tendon transfer had instability (20° laxity- not corrected) of the IP joint and one thumb had an unstable CMC joint based on the dorsal shift test.

Three of the five Type IIIA thumbs with an FDS tendon transfer had MP instability, with a mean instability of 33° (range 31-34°). All non-operated Type II thumbs had an unstable MP joint, with a mean instability of 37° (range 34-40°).

Strength measurements

Strength measurements for pinch, tripod, key and grip showed similar patterns in all three groups (Table 1). For operated Type II hypoplastic thumbs, strength measurements were approximately 50% (46-51%) of normal. There was a significant difference in opposition strength (p= 0.01) between operated (72% of normal) and non-operated Type II thumbs (33% of normal). All other strength measurements were not significantly different between operated and non-operated Type II thumbs. In Type II thumbs treated by an FDS tendon transfer, pinch strength (p=0.002) and key pinch strength (p= 0.01) were significantly greater than in operated Type IIIA thumbs.

Range of motion

Table 2 demonstrates all active range of motion measurements for all three patient groups. In operated Type II thumbs, retroposition, and IP and MP flexion and extension were most markedly reduced (14-52% of normal), whereas radial abduction, palmar abduction and the Kapandji score were closer to normal (68-77% of normal). Figure 1 shows good opposition in a Type II thumb treated by an FDS tendon transfer. Only retroposition was significantly higher (p= 0.004) in non-operated Type II thumbs than in Type II thumbs treated by tendon transfer.

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TABLE 1. Means expressed as a percentage of normal, standard deviations and ranges for all strength measurements per patient group.

	Type II without FDS IV (n=6) (% of normal)			Type II with FDS IV (n=16) (% of normal)			Type IIIA with FDS IV (n=5) (% of normal)		
	Mean Force	SD	Range	Mean Force	SD	Range	Mean Force	SD	Range
Grip strength	60	30	(7-95)	48	16	(26 - 84)	39	10	(27 -53)
Pinch strength	61	30	(10-89)	51*	19	(27 – 86)	31*	4	(27 –36)
Tripod pinch strength	45	22	(13- 67)	46	19	(23 – 94)	30	22	(14 –69)
Key pinch strength	49	33	(4-87)	49**	20	(22 – 99)	30**	8	(19 –38)
Abduction of index finger	126	29	(92-162)	105	23	(67 – 165)	82	19	(62 – 108)
Abduction of little finger	91	28	(49-121)	107	33	(66 – 197)	88	18	(64 – 106)
Palmar thumb abduction	69	42	(20 -144)	68	39	(10 – 157)	48	19	(22 – 72)
Thumb opposition	33***	25	(6-62)	72***	23	(14 – 135)	47	22	(16 – 70)

*/**/*** p< 0.05

TABLE 2. Means, standard deviations, ranges and percentages of normative means for all active range of motion measurement.

Range of Motion (degrees)	Normative means	Type II without FDS IV (n=6)	SD	range	% of normal	Type II with FDS IV (n=16)	SD	range	% of normal	Type IIIA with FDS IV (n=5)	SD	range	% of normal
Radial abduction	50	47	8	(40-60)	94	38	15	(0-62)	76	41	12	(30-60)	82
Palmar abduction thumb	62	45	8	(38-58)	73	42	10	(21-56)	68	45	17	(22-70)	73
Palmar abduction metacarpal	48	38	12	(25-60)	79	32	9	(16-44)	67	35	12	(23-52)	73
Flexion IP	80	23	20	(0-50)	28	11	17	(0-50)	14	6	13	(0-30)	8
Flexion MP	60	33	21	(8-60)	55	31	22	(2-70)	52	17	33	(0-76)	28
Extension IP	30	11	13	(0-30)	37	5	10	(0-40)	17	2	4	(0-10)	7
Extension MP	40	32	21	(10-70)	80	13	15	(0-42)	33	18	17	(0-38)	45
Retroposition (cm)	>3	2.5	1	(1.5- 3.5)	83*	1,1	1	(0-4)	37*	1.0	1	(0-3)	33
Kapandji score (0-10)	10	8.3	1	(7-10)	83	7.7	2	(3-10)	77	6.8	2	(4-9)	68

* p< 0.05

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FIGURE 1. A Type II thumb treated by an FDS tendon transfer, showing good opposition.

Sensibility

Sensibility measured in children (16 thumbs) using the STI and 2-PD showed normal values in all patients. The Semmes-Weinstein measurements in adults showed "normal sensibility" in eight thumbs (73%) and "diminished light touch" in three thumbs (27%). Overall, in both children and adults, sensibility was normal in 89% of the thumbs.

Self-evaluation of function and appearance

Table 3 shows patients' and parents' evaluation of function and appearance. Function and appearance were rated higher by non-operated patients and their parents than by operated Type II patients. With regard to function we found a significant (p= 0.008) mean difference of 2.5 and a non-significant (p= 0.44) mean difference of 1.0 for appearance. Between parents and their children there were no significant differences in satisfaction, except for aesthetics in Type IIIA patients with an FDS tendon transfer. Parents rated appearance significantly higher (p=0.03) than their children.

TABLE 3. Evaluation of function and appearance rated by the patients and their parents using a Visual Analogue Score scored from 0 to 10.

Function/ Aesthetics	Type II without FDS IV (n=6)	SD	Range	Type II with FDS IV (n=16)	SD	Range	Type IIIA with FDS IV (n=5)	SD	Range
	Mean Visual Analogue Score			Mean Visual Analogue Score			Mean Visual Analogue Score		
Function of affected hand (rated by patient)	9.1*	1.2	(7.4-10)	6.6*	2.9	(1-10)	7.1	2.5	(4.5-10)
Function of affected hand (rated by parent)	8.8	1.3	(7.4-9.8)	6.9	2.8	(1.3-9.4)	6.2	5.4	(2.3-10)
Aesthetics of affected hand (rated by patient)	7.9	2.7	(2.8-10)	6.9	2.7	(0.2-10)	7.3	2.8	(3.5-10)
Aesthetics of affected hand (rated by parent)	8.4	2.1	(6.0-9.8)	7.6**	2.3	(3.8-9.8)	9.8**	0.4	(9.5-10)

*/** p< 0.05

Complications

In one patient, a suture at the level of the MP joint caused irritation and wound healing problems, resulting in a re-operation. In another Type II patient a re-operation was done to regain sufficient tension in the FDS tendon transfer. Simultaneously, the carpometacarpal joint was stabilized, as it had become unstable.

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DISCUSSION

We are well aware that there is a debate about classification of hypoplastic thumbs (26) relating to the extrinsic anomalies in Type II or III thumbs. We have chosen the classification by Blauth, modified by Manske and McCarroll (4) as this is the most used currently. We are therefore not able to rule out the influence of any extrinsic anomalies on the final outcomes in this study. Furthermore, pollex abductus was excluded as it is considered a different entity in the spectrum of hypoplastic thumbs with a number of extrinsic anomalies.

Although there are many reports on the outcome of abductor digiti minimi transfers in thumb hypoplasia many studies have used qualitative assessments (4,6,7) making comparison with our data difficult. Available quantitative results on ADM transfers regarding key pinch strength,

MP joint stability and opposition were comparable with our results. For example, Upton and Taghinia (9) reported that key pinch strength was 40% of normal in six patients with a Type II or IIIA hypoplastic thumbs that had an ADM transfer. This is comparable to the mean key pinch strength of 49% and 30% in our Type II and Type IIIA thumbs, respectively.

We found that grip strength was lower in Type II thumbs with an FDS transfer (48% of normal) than in Type II thumbs without an FDS tendon transfer (60% of normal). Although this difference was not significant, it suggests that the donor FDS digit influences total grip strength.

Surprisingly, there was increased abduction strength of the little finger in Type II thumbs with an FDS IV transfer (107% of normal). We believe that this may be due to compensated use of this digit in grasping and opposition. Therefore, perhaps we should be extra careful not to weaken this digit, which might occur when using an ADM transfer.

Manske and McCarroll (4) reported that MP joint stability was obtained in eight out of 10 (80%) Type II thumbs treated by ADM transfer. Ogino et al. (6) found a stable MP joint in six out of nine patients (67%) after an ADM transfer. Takayama et al. (12) reported satisfactory stability in five patients with a Type II or IIIA hypoplastic thumb treated by an ADM transfer. In our study, we found that MP joint stability was obtained in all operated Type II thumbs and in 40% of the Type IIIA thumbs. Perhaps in the future a primary chondrodesis should be done in Type IIIA thumbs with multidirectional instability of the MP joint, instead of trying to correct the instability with a tendon transfer.

The range of motion in treated and untreated patients was reduced compared with normative data. In this analysis we also included MP joint mobility as an outcome of surgery. In the treated patients, the range of motion in the operated Type II thumbs was less than in non-operated Type II thumbs. We believe this is caused by the stabilizing effect of the tendon transfer used to reconstruct the ulnar collateral ligament, thereby reducing motion in other directions, which was one of the objectives of the operation.

With regard to opposition, many other authors have reported that satisfactory opposition was obtained after an ADM transfer. We also found good opposition with mean Kapandji scores of 6.8 and 7.7 in operated Type II and Type IIIA thumbs, respectively.

We found rather similar outcomes for patient and parent satisfaction in all operated patients. We added the unoperated thumbs Type II thumbs as a comparison to see whether there was a difference in function between both groups. The decision was made by the parents and not the hand surgeon not to operate. The surgeon may have been willing to operate on all unoperated thumbs, whereas parents chose against their child having an operation for various reasons. We could not find a specific explanation for the higher scores for functional

and aesthetic outcome in the non-operated Type II thumbs. However, one patient and the parents were very dissatisfied with the outcome, thereby severely reducing the mean outcome score in the operated Type II patients. The independent researcher, assessed the outcome as good and could not correlate the dissatisfaction to poor functional outcomes.

In contrast to what we expected, diminished touch was observed in three thumbs of two patients. In one patient both the operated Type II thumb on one side and the non-operated Type II thumb on the other side showed diminished light touch. The third thumb was also a Type II thumb which had been treated by an FDS tendon transfer. Medical records did not report any complications during surgery that could explain the observed diminished light touch.

Complications and re-operation rates were low in the patients treated by FDS tendon transfer. One of the 27 thumbs needed a re-operation after 13 years. In this patient the tendon transfer slip had lost its tension and had to be reinserted to stabilize the MP joint. One patient needed to be re-operated due to a perforating suture near the MP joint.

CONCLUSIONS

Overall, we conclude the FDS tendon transfer from the ring finger is a good functioning opponensplasty in both Type II and IIIA thumbs. The transfer provides excellent MP joint stability in the Type II thumbs.

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REFERENCES

1   Huber E. Hilfsoperation bei Medianuslähmung. Dtsch Z Chir. 1921, 126: 271–5.

2   Royle ND. An operation for paralysis of the intrinsic muscles of the thumb. *J Am Med Assn*. 1938, 111; 612-13.

3   Littler JW, Cooley SGE. Opposition of the thumb and its restoration by abductor digiti quinti transfer. *J Bone Joint Surg Am*. 1963, 45: 1389–96.

4   Manske PR, McCarroll HR, Jr. Abductor digiti minimi opponensplasty in congenital radial dysplasia. *J Hand Surg*. 1978, 3: 552-9.

5   Oberlin C, Gilbert A. Transfer of the abductor digiti minimi (quinti) in radial deformities of the hand in children. *Ann Chir Main*. 1984, 3: 215-20.

6   Ogino T, Minami A, Fukuda K. Abductor digiti minimi opponensplasty in hypoplastic thumb. *J Hand Surg Br*. 1986, 11: 372-7.

7   Latimer J, Shah M, Kay S. Abductor digiti minimi transfer for the restoration of opposition in children. *J Hand Surg*. 1994, 19: 653-8.

8   Cawrse NH, Sammut D. A modification in technique of abductor digiti minimi (Huber) opponensplasty. *J Hand Surg Br*. 2003, 28: 233-7.

9   Upton J, Taghinia A. Abductor digiti minimi myocutaneous flap for opponensplasty in congenital hypoplastic thumbs. *Plast Reconstr Surg*. 2008, 122: 1807-11.

10 Kozin SH, Ezaki M. Flexor digitorum superficialis opponensplasty with ulnar collateral ligament reconstruction for thumb deficiency. *Tech Hand Up Extrem Surg*. 2010, 14: 46-50.

11 Hovius SE, Versnel SL, Zuidam JM. Tendon transfers in reconstructive hand surgery. In: Tendon transfer in the congenital hand. London, Informa Healthcare, 2005: 121-132, Chapter 9.

12 Takayama S, Nakao Y, Ikegami H, Nakamura T. Modified abductor digiti minimi opponensplasty in congenital hypoplastic thumb with laxity of metacarpophalangeal joint. *Tech Hand Up Extrem Surg*. 2002, 6: 166-70.

13 Molenaar HM, Zuidam JM, Selles RW, Stam HJ, Hovius SE. Age-specific reliability of two grip-strength dynamometers when used by children. *J Bone Joint Surg Am*. 2008b, 90: 1053-9.

14 Bayne LG, Klug MS. Long-term review of the surgical treatment of radial deficiencies. *J Hand Surg Am*. 1987,12: 169-79.

15 Fraulin FO, Thomson HG. First webspace deepening: comparing the four-flap and five-flap Z-plasty. Which gives the most gain? *Plast Reconstr Surg*. 1999, 104: 120-8.

16 Bunnell S. Opposition of the thumb. J Bone Joint Surg. 1938, 20: 269-84.

17 Catalano LW 3rd, Cardon L, Patenaude N, Barron OA, Glickel SZ. Results of surgical treatment of acute and chronic grade III (corrected) tears of the radial collateral ligament of the thumb metacarpophalangeal joint. *J Hand Surg Am*. 2006, 31: 68-75.

18 American Society of Hand Therapists. *Clinical Assessment and Recommendations*. 2 nd Edn. Chicago IL, 1992: 64-65.

19 Molenaar HM, Selles RW, Schreuders TA, Hovius SE, Stam HJ. Reliability of hand strength measurements using the Rotterdam Intrinsic Hand Myometer in children. *J Hand Surg Am*. 2008a, 33: 1796-801.

20 de Kraker M, Selles RW, Molenaar TM, Schreuders TA, Hovius SE, Stam HJ. Palmar abduction measurements: reliability and introduction of normative data in healthy children. *J Hand Surg Am*. 2009a, 34: 1704-8.

21 de Kraker M, Selles RW, Schreuders TA, Hovius SE, Stam HJ. The Pollexograph: a new device for palmar abduction measurements of the thumb. *J Hand Ther*. 2009b, 22: 271-6.

22 Lemmen MH, Schreuders TA, Stam HJ, Hovius SE. Evaluation of restoration of extensor pollicis function by transfer of the extensor indicis. *J Hand Surg Br*. 1999, 24: 46-9.

23 Kapandji A. Rotation of the thumb on its longitudinal axis during opposition. Geometric and mechanical study of the trapezo-metacarpal joint (mechanical model of the hand). Revue de chirurgie orthopedique et reparatrice de l'appareil moteur. 1972, 58:273-89.

24 Weinstein S. Fifty years of somatosensory research: from the Semmes-Weinstein monofilaments to the Weinstein Enhanced Sensory Test. *J Hand Ther*. 1993, 6: 11-22; discussion 50.

25 Jerosch-Herold C. Assessment of sensibility after nerve injury and repair: a systematic review of evidence for validity, reliability and responsiveness of tests. *J Hand Surg Br*. 2005, 30: 252-64.

26 Tonkin MA. On the classification of congenital thumb hypoplasia. *J Hand Surg Br*. 2014, 39: 948-5.

6

Chapter 7

Outcome after Pollicisation:

Comparison of Patients with Mild and

Severe Longitudinal Radial Deficiency

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ABSTRACT

Purpose: Pollicisation of the index finger is a well-established treatment in Type IIIB-V hypoplastic thumbs. However, reports in literature assessing postoperative success have been diverse. There is a lack of quantative outcome studies and little is known about the outcome differences between patients with mild and severe longitudinal radial deficiencies. Therefore, the aim of this study was to quantitatively assess and compare outcome after pollicisation in mild and severe longitudinal radial deficiency and compare outcome to healthy controls.

Methods: In total, we included 24 patients with 30 affected hands. The group consisted of 16 males and 8 females with a mean age of 14 years. Median time between pollicisation and evaluation was 9.4 years. Active and passive range of motion, extrinsic and intrinsic strength, sensibility, and patient and parent satisfaction was measured in patients with mild and severe longitudinal radial deficiency. Means are expressed as percentage of normative data, standard deviations and ranges were calculated. The independent sample T-test was used to compare means between groups.

Results: In the overall pollicisation group with associated longitudinal radial deficiency range of motion and strength were significantly diminished compared to normative data. In severe longitudinal radial deficiency all strength measurements were significantly more affected than in mild longitudinal radial deficiency.

Conclusions: Overall, range of motion and strength of pollicisations were diminished compared to normative data. In severe LRD this is even more pronounced. Despite this outcome, patients and their parents were very satisfied with function and appearance of the new thumb.

INTRODUCTION

Pollicisation of the index finger is a well-established treatment in patients with a Type IIIB-V hypoplastic thumb. However, reports in literature assessing the postoperative success have been diverse, ranging from highly positive to very disappointing (1-4). A factor that may have caused the diversity in outcome is the wide variety between patients; some articles only reported on their "best cases", leaving out patients with severe longitudinal radial deficiency (LRD) (3-5), while others combined results of patients with and without LRD (4,6,7). However, despite diversity in results, nearly all authors have proposed modifications for pollicisation procedures, trying to improve outcome (1,2,8,9).

Most articles on pollicisations address surgical techniques (1,2,10) flap design (1,11-14) or qualitative outcome, while quantitative outcome reports are scarce (3,6,15,16). The lack of quantitative outcome studies may be caused by difficulty of quantitative assessment of these often young patients (3,17). Manske et al. and Staines et al. (3,15) previously noted that it would be better to compare patient values to normative data instead of the apparently non-affected opposite hand. However, normative data on, for example, intrinsic hand strength in children under the age of 12 years, were until recently not available (18).

Despite the lack of quantitative results, it is generally assumed that pollicisation is a rewarding procedure in congenital hypoplasia and aplasia of the thumb. This is in contrast to patients with associated LRD, since in these patients the associated musculo-skeletal defects often compromise functional outcome (6,16,19-21). However, at present, little is known about how much more compromised outcome truly is in patients with LRD compared to patients that do not have this deficiency. Furthermore, we believe it is important to inform parents prior to surgery what outcome can be expected in relation to the condition of the operated hand. Therefore, the aim of this study was to quantitatively assess and compare outcome after pollicisation in mild and severe LRD and compare outcome in both groups to healthy controls.

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METHODS

Subjects

From 1980 until 2006, 40 patients with a Type IIIB-V thumb hypoplasia sustained a pollicisation at our centre. For the present evaluation, we included patients from the age of 4 years, the age from which children are generally able to sufficiently cooperate and from which reliably hand strength recordings can be obtained (18). Patients were excluded when they had additional systemic conditions affecting the muscle or nervous system. Also they were excluded if the pollicisation or additional tendon transfer was performed less than one year before evaluation or if pollicisations were performed for other reasons like for example in triphalangeal thumb patients. Four patients were lost to follow-up and 12 patients were not able or willing to participate. The patients who were not willing to participate were both patients who were satisfied as well as less satisfied with thumb function. Their parents reported that they didn't want to burden their child with any more tests. All patients or their parents provided written consent for participation and this study was approved (MEC-2006-141) by the Medical Ethics Committee.

In total, we included 24 patients with 30 affected hands. The group consisted of 16 males and 8 females. The mean age was 14 years, ranging from 5 to 25 years. Mean age at which pollicisation was performed was 3.6 years, median age was 3 years, ranging from 1.5 to 15 years. Median time between pollicisation and evaluation was 9.4 years (range 2.8- 17.7 years). Of the 24 patients, six patients were affected bilateral (12 hands) and 18 patients (18 hands) were affected unilateral. Thumb hypoplasia was classified according to the Blauth's classification modified by Manske and McCarroll (22). The group consisted of 8 Type IIIB thumbs, 15 Type IV thumbs and 7 Type V thumbs. LRD was classified according to James (23). The group consisted of 7 Type 0 LRD; 7 Type I LRD; 3 Type II LRD; 2 Type III LRD; and 11 Type IV LRD. LRD was associated with a syndrome in 16 patients (67%). Holt-Oram was present in 5 of these patients, VACTERL in 6 patients, Townes-Brocks and Klein-Felter in 2 patients and Poland syndrome in 1 patient. One patient had an unknown syndrome.

Eight of the 13 pollicisations with associated severe LRD received an additional abductor digiti quinti tendon transfer (ADQ), compared to 6 out of 17 pollicisations with mild LRD. Of the 13 pollicisations with severe LRD, 7 arms sustained soft tissue distraction followed by dynamic positioning of wrist on the distal end of the ulna. In the other six arms no prior soft tissue distraction was performed. Furthermore, distraction-lengthening of the ulna was performed in 8 cases after pollicisation.

Technique and post operative management

The incisions as proposed by Buck-Gramcko (1) were used in the early pollicisations. In the last 4 years the Carter-Ezaki technique (20) is used for the incisions. Concerning the preparation of the neurovascular bundles, intrinsic muscles and extrinsic tendons, dorsal veins and metacarpal bone, the technique according to Buck-Gramcko is used. The head of the metacarpal is turned and fixed in the remnant of the proximal metacarpal of the second ray with an anchor (resorbable micro Mitek* anchor) to prevent a hyperextension deformity. Stabilisation with the intrinsics and the extrinsics is again as described by Buck-Gramcko. If only one extensor tendon is present it is used as the new 'EPL'. The skin is then rearranged to provide an adequate first web. No K-wires are used. Post operative management consisted of a sticky tape bandage in ball form for 6 weeks in which the fingers can be moved inside the bandage. After 6 weeks free movement is allowed. The senior author has performed nearly all pollicisations.

The abductor digiti quinti transfer (Huber transfer) was performed in cases where opposition needed to be strengthened. The muscle and insertion was freed via an ulnar incision at the watershed of dorsal to palmar skin. The origin was left intact as well as the neurovascular bundle proximally. A subcutaneous tunnel was created to the radial side of the 'thumb' at the new 'metacarpophalangeal' joint. The tendineous part was subsequently inserted to the proximal phalanx on the radial side.

Postoperative management consisted of a sticky tape bandage in ball form for 6 weeks in which the fingers can be moved inside the bandage. After 6 weeks free movement is allowed.

MEASUREMENTS

Range of motion

We measured flexion, extension, radial abduction, palmar abduction and opposition of the thumbs, both actively and passively. Radial abduction, flexion and extension were measured with a conventional goniometer and expressed in degrees. Palmar abduction was measured with the Pollexograph-thumb and Pollexograph-metacarpal (24-26) and expressed in degrees. We measured retroposition as the distance in centimeters from table to tip of the thumb, with the hand flat on the table and the thumb lifted maximally (27). For assessing opposition, we used Kapandji's method with scores ranging from 0 (thumb tip on lateral aspect of proximal phalanx of index finger) to 10 (thumb tip reaches distal palmar crease at base of little finger).

Strength

Hand strength was examined using JAMAR dynamometers for grip strength, pinch strength, key pinch strength and tripod pinch strength, using the protocol described by the American Society of Hand Therapists (28). We used the Rotterdam Intrinsic Hand Myometer (29) to measure strength of individual fingers and thumb in different directions. The RIHM allows measurement of more detailed aspects of hand function than with grip strength and pinch strength dynamometers and, in some specific situations, allows measurement of isolated intrinsic hand muscle strength (18). Using the RIHM we measured 1) thumb opposition 2) palmar abduction and 3) abduction of the little finger. The RIHM has proven to be a reliable instrument for strength measurements in adult patients with peripheral nerve injuries (30), in Charcot Marie Tooth (31) and in healthy children between the age of 4 and 12 years (18,32). For all strength measurements, means of three repeated measurements were calculated and strength was expressed in Newton (N).

Sensibility

In adults (≥ 18 yrs), sensibility was tested using Semmes-Weinstein monofilaments (33) and in children sensibility was tested using the Sensibility Texture Index (34). In all subjects, 2-point discrimination (2-PD) was tested.

Self evaluation of function and appearance

All subjects were asked to score their own function and thumb appearance using a visual analog score (VAS score) ranging from 0 (very poor/ugly) to 10 (very good/ beautiful). Scores were measured for both thumbs separately. Parents were also asked to score their child's thumbs.

Statistics

For comparison between mild and severe LRD, the patients were sub-divided in 2 groups. Type 0-I-II LRD was classified as "mild LRD" and Type III-IV LRD was classified as "severe LRD". Using SPSS 19.0, we calculated descriptive statistics: means, means expressed as percentage of normative data, standard deviations (SDs) and ranges. The independent sample T-test was used to compare means between groups. A p-value of ≤ 0.05 was considered significant.

RESULTS

Range of motion

Table 1 shows all range of motion measurements. Compared to normative data, all range of motion measurements except for radial abduction (p=0.48) were significantly lower in LRD (p= 0.001-0.003).

Radial abduction, palmar abduction-thumb and palmar abduction-metacarpal were closest to normal, ranging from 61 to 95% of reference values. The lowest scores were found for interphalangeal / metacarpophalangeal (MP) extension and IP flexion, which were only 22-27% of normal values.

When comparing mild and severe LRD we found no significant difference in range of motion measurements except for opposition (p= 0.01) and MP flexion (p= 0.02).

TABLE 1. Mean percentages of normative means for pollicisations range of motion for the whole group and separate for mild and severe LRD. In addition, standard deviations and p-values are displayed.

Range of Motion	Normative mean	Group Mean (±SD)	% of normal	p value	Mild LRD Mean (±SD)	Severe LRD Mean (±SD)	p-value
Radial abduction	50	48 (18.6)	95	0.48	49 (13.9)	46 (23.6)	0.66
Palmar abduction thumb	62	38 (19.0)	61	*<0.001*	39 (14.5)	37 (24.0)	0.77
Palmar abduction metacarpal	48	37 (16.9)	76	*0.003*	37 (16.0)	36 (19.3)	0.89
Flexion IP	80	19 (17.5)	24	*<0.001*	18 (19.7)	20 (15.2)	0.85
Flexion MP	60	40 (25.4)	65	*<0.001*	49 (25.3)	28 (20.9)	*0.02*
Extension IP	30	7 (7.9)	22	*<0.001*	7 (6.1)	6 (9.8)	0.91
Extension MP	40	11 (12.8)	27	*<0.001*	11 (12.8)	11 (13.2)	0.95
Retroposition (cm)	>3	1.4 (1.3)	47	*<0.001*	1.2 (1.3)	1.7 (1.3)	0.31
Kapandji score (0-10)	10	7.4 (2.4)	74	*<0.001*	8.4 (1.6)	6.2 (2.7)	*0.01*

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Strength

Table 2 shows strength measurements for mild and severe LRD. It shows that strength of the thumb after pollicisation ranges from 13 to 77% of normative thumb strength. In severe LRD, all strength measurements were significantly weaker than in mild LRD.

TABLE 2. Means expressed as a percentage of normal, standard deviations and ranges for all strength measurements for mild and severe LRD.

	Mild LRD (n=17)			Severe LRD (n=13)			
	Mean Force (N) (% of normal)	± SD	Range	Mean Force (N) (% of normal)	± SD	Range	p-value
Grip strength	45	24.3	(23-123)	17	15.6	(0-47)	0.003
Pinch strength	54	22.5	(29-113)	19	23.2	(0-64)	0.001
Tripod pinch strength	46	25.8	(13-107)	15	22.5	(0-68)	0.003
Key pinch strength	35	15.6	(17-67)	13	13.9	(0-49)	0.001
Abduction of little finger	114	64.1	(25-260)	63	46.9	(8-154)	0.04
Palmar thumb abduction	77	25.2	(30-112)	29	17.3	(8-69)	< 0.001
Thumb opposition	47	31.1	(6-112)	17	13.6	(0-48)	0.007

Sensibility

Sensibility measured in children using the STI and 2-PD showed normal values in all patients. Two-point discrimination was normal in all adult thumbs. Sensibility measured in adults using the Semmes-Weinstein monofilaments showed normal sensibility in all but one patient. The diminished light touch that was observed in one of the patients could be explained by the presence of an underdeveloped neurovascular bundle on the radial side that was observed during surgery.

Self evaluation of function and appearance

Table 3 shows patients' and parents' evaluation of thumb function and appearance using a Visual Analog Score. Since we found no significant difference in self evaluation between mild and severe LRD (Figure 1 and Figure 2), results are shown for the whole group. Function was rated similarly by the patients and their parents with a mean score of 7.5. Appearance had a mean rate of 7.2 scored by the patients, compared to a mean of 8.1 rated by the parents.

TABLE 3. Evaluation of function and appearance in LRD rated by the patients and their parents using a Visual Analog Score.

Function/ Aesthetics Pollicisation	Mean Score	SD	Range
Function of affected hand (rated by patient)	7.5	2.9	(0.4-10)
Function of affected hand (rated by parent)	7.5	2.4	(2.4-10)
Aesthetics of affected hand (rated by patient)	7.2	2.6	(0.6-10)
Aesthetics of affected hand (rated by parent)	8.1	2.1	(2.8-10)

FIGURE 1. Result of a pollicisation with mild LRD showing good opposition.

FIGURE 2. Result of a pollicisation in a (severe) Type IV LRD.

Complications

There were no complications observed that were related to pollicisation surgery except one suture granuloma which was removed surgically.

Complications influencing thumb function were to our mind relapse of the wrist position to radial deviation. Four patients sustained a relapse of their wrist position of which two of them were re-operated. Measurements of the pollicised thumb were performed after the re-operations on the wrist. Another factor possibly influencing thumb function could have been ulna distraction. This was performed in eight patients in this study. Distraction lengthening was performed in an attempt to achieve as much length as possible, up to 12 cm. Complications relating to ulna distraction were pin track infections and one case of non-union requiring osteosynthesis.

All thumb measurements in these 8 patients were performed after completion of the distraction.

DISCUSSION

Pollicisation is recognized as a rewarding procedure in congenital hypoplasia and aplasia of the thumb without associated LRD (6,16,19-21). Congenital hand surgeons are fully aware that pollicisation outcome in patients with LRD is far less optimal than without this deficiency. However, not many reports are available comparing outcome between these two patient groups. Quantative and qualitative information should be available when outcome of pollicisation is discussed in relation to the severity of the congenital difference. In this study, we found that range of motion and strength of pollicisations with associated LRD was significantly diminished compared to healthy subjects. Furthermore, in severe LRD, MP flexion and opposition range of motion and all strength measurements were significantly more decreased than in mild LRD. Resulting from this study more detailed information can be provided to the parents prior to surgery.

Patients with a pollicisation have a range of motion which is significantly lower than the range of motion of a thumb in healthy subjects. Mean range of motion values found in our study were similar to results reported by Kozin et al. (35) and Roper et al. (17). Manske et al. (36) also reported that total range of motion was 40-75% of the range of motion of a normal thumb, depending whether associated conditions were present. When comparing range of motion of the pollicisations in our group, between severe and mild LRD, only MP flexion and opposition were significantly lower in severe LRD.

In regard to strength, we found that strength of the pollicised thumb was significantly more affected in severe LRD than in mild LRD. Eight of the 13 thumbs (62%) with severe LRD and 6 of 17 thumbs (35%) with mild LRD received an additional ADQ opponensplasty to improve opposition range of motion and opposition strength. Despite the higher percentage of additional ADQ opponensplasties in the severely affected group, we found significantly lower opposition range of motion and opposition strength in this group. However, it is not known how much more affected opposition strength would have been if the ADQ tendon transfer had not been performed in this group. Foucher et al. (2) found no need to perform an additional ADQ opponensplasty to further improve opposition in their "best pollicisations". However, Manske et al. (15) found it necessary to perform an additional ADQ opponensplasty in 8 out of 28 pollicisations (29%), and Oberlin and Gilbert et al. (37) performed an additional opponensplasty in 5 of their 14 (36%) pollicisations. The indication to perform an opponensplasty is highly dependent on the surgeon's opinion and not on exact data. In patients with severe LRD who have a strong scissor grip between the fourth and fifth digit, a pollicisation is hardly ever performed in our unit. In these patients the little finger is important and we believe that it should not be impaired by for instance an opponensplasty using the Huber technique (8,22,37-42).

In other quantitative reports on pollicisations, hand strength is diminished compared to the other unaffected other side. Only two other reports compare their results to normative data (4,16). Foucher et al. (5) reported on their best pollicisation cases and found that grip strength and pinch strength were 55% and 42% of the other unaffected hand. Comparable results were reported by Roper et al. (17), who found a mean grip strength of 63% and a mean pinch strength of 56%. Similarly, Clark et al. (4) assessed thumb strength with use of the Percival score (43) and established that thumb strength was approximately 50% of normal. The highest strength scores were reported by Vekris et al. (16). They found average grip strength ranging from 63-75% in patients with and without LRD. Their mean pinch strength ranged from 56 to 65% of the unaffected other side. Comparable good results were reported by Kozin et al. (6) with a mean grip strength of 67%, pinch strength of 60% and tripod strength of 39%. Manske et al. (15) and Staines et al. (3) reported lower strength measurements, ranging from 21-36% of the other apparently unaffected hand. Most likely, the variation within the results reported in these studies is caused by variation in the number of LRD cases included (2,5). In mild LRD grip strength, pinch strength, tripod strength, and key pinch strength were 36-52% of normal in our study. As could be expected, strength was significantly lower in patients with severe LRD, ranging from only 13-19% of normal. Our findings in mild LRD are difficult to compare, but seem to be rather similar with the results reported by other authors.

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Even though range of motion and strength measurements were diminished compared to normal, patient and their parents were satisfied with function and appearance of the pollicised index finger. In contrast to what might be expected, satisfaction was not affected by the severity of the LRD (see Figure 1).

Mildly affected patients were not more satisfied, than more severely affected patients (see Figure 2).

Foucher et al. (5) found excellent satisfaction with appearance in 23 of the 27 patients. Clark et al. (4) operated on 15 patients, of which 7 scored satisfaction as "excellent", 6 as "good", and 2 as "poor". Goldfarb et al. (44) found that when rating appearance, there was no significant difference between caregivers, surgeons and hand therapists. In our study we also found no significant difference in ratings between patients and their parents.

In our study, as in most studies that assess outcome in patients with these deformities, the small number of patients that could be included was a marked limitation. However, despite the small number of patients, significant outcome differences could be detected in these patients. Due to the small number of patients a Bonferroni correction was not performed.

The only complication in this study truly correlated to the performed pollicisations, was the occurrence of one suture granuloma. The other reported complications were related to treatment and correction of the LRD and not to the pollicisation itself. Four patients experienced a relapse of wrist position, of which two sustained a re-operation. It is possible that this may have affected thumb function in these two patients. Furthermore, pin track infections and 1 case of non-union occurred in eight patients following ulna distraction. All thumb measurements were performed after completion of treatment therefore these complications do not influence the outcome of this particular study.

CONCLUSIONS

Overall, range of motion and intrinsic and extrinsic strength of pollicisations were diminished compared to normal thumbs. In severe LRD this is even more pronounced. Despite this outcome, patients and their parents were very satisfied with function and appearance of the new thumb. If the more ulnarly functioning hands are excluded, pollicisation is a rewarding procedure, even in patients with more severe LRD.

REFERENCES

1   Buck-Gramcko D. Pollicization of the index finger. Method and results in aplasia and hypoplasia of the thumb. *J Bone Joint Surg Am.* 1971;53: 1605-1617.

2   Foucher G, Medina J, Lorea P, Pivato G. Principalization of pollicization of the index finger in congenital absence of the thumb. *Tech Hand Up Extrem Surg.* 2005;9: 96-104.

3   Staines KG, Majzoub R, Thornby J, Netscher DT. Functional outcome for children with thumb aplasia undergoing pollicization. *Plast Reconstr Surg.* 2005;116: 1314-1323; discussion 1324-1315.

4   Clark DI, Chell J, Davis TR. Pollicisation of the index finger. A 27-year follow-up study. *J Bone Joint Surg Br.* 1998;80: 631-635.

5   Foucher G, Medina J, Lorea P, Pivato G, Szabo Z. Pollicization in congenital differences. *Handchir Mikrochir Plast Chir.* 2004;36: 146-151.

6   Kozin SH, Weiss AA, Webber JB, Betz RR, Clancy M, Steel HH. Index finger pollicization for congenital aplasia or hypoplasia of the thumb. *J Hand Surg Am.* 1992;17: 880-884.

7   Sykes PJ, Chandraprakasam T, Percival NJ. Pollicisation of the index finger in congenital anomalies. A retrospective analysis. *J Hand Surg Br.* 1991; 16:144-147.

8   Littler JW. Architectural principles of reconstructive hand surgery. *Surg Clin North Am.* 1950;31: 463-476.

9   Foucher G, Lorea P, Pivato G, Medina J, Szabo Z. Technical note: ulnar "pseudo-pollicisation" in congenital hand differences. *Chir Main.* 2004;23: 289-293.

10   Littler JW. On making a thumb: one hundred years of surgical effort. *J Hand Surg Am.* 1976; 1:3 5-51.

11   Egloff DV, Verdan C. Pollicization of the index finger for reconstruction of the congenitally hypoplastic or absent thumb. *J Hand Surg Am.* 1983;8: 839-848.

12   Blauth W. Indication and technics of the index-finger thumb in aplasia of the thumb. *Handchirurgie.* 1969;1: 28-33.

13   Lister G. Reconstruction of the hypoplastic thumb. *Clin Orthop Relat Res.* 1985:52-65.

14   Zancolli E. Transplantation of the index finger in congenital absence of the thumb. *J Bone Joint Surg Am.* 1960;42-A:658-660.

15   Manske PR, Rotman MB, Dailey LA. Long-term functional results after pollicization for the congenitally deficient thumb. *J Hand Surg Am.* 1992;17: 1064-1072.

16   Vekris MD, Beris AE, Lykissas MG, Soucacos PN. Index finger pollicization in the treatment of congenitally deficient thumb. *Ann Plast Surg.*66:137-142.

17   Roper BA, Turnbull TJ. Functional assessment after pollicisation. *J Hand Surg Br.* 1986;11: 399-403.

18   Molenaar HM, Zuidam JM, Selles RW, Stam HJ, Hovius SE. Age-specific reliability of two grip-strength dynamometers when used by children. *J Bone Joint Surg Am.* 2008;90: 1053-1059.

19   Gilbert A. Congenital absence of the thumb and digits. *J Hand Surg Br.* 1989;14: 6-17.

20   Kozin SH. Pollicization: the concept, technical details, and outcome. *Clin Orthop Surg.*4:18-35.

21   Manske PR, McCaroll HR, Jr. Index finger pollicization for a congenitally absent or nonfunctioning thumb. *J Hand Surg Am.* 1985;10: 606-613.

22   Manske PR, McCarroll HR, Jr. Abductor digiti minimi opponensplasty in congenital radial dysplasia. *J Hand Surg Am.* 1978;3: 552-559.

23   James MA, Green HD, McCarroll HR, Jr., Manske PR. The association of radial deficiency with thumb hypoplasia. *J Bone Joint Surg.* 2004;86-A:2196-2205.

24   de Kraker M, Selles RW, Molenaar TM, Schreuders TA, Hovius SE, Stam HJ. Palmar abduction measurements: reliability and introduction of normative data in healthy children. *J Hand Surg Am.* 2009;34: 1704-1708.

25   de Kraker M, Selles RW, Schreuders TA, Hovius SE, Stam HJ. The Pollexograph: a new device for palmar abduction measurements of the thumb. *J Hand Ther.* 2009;22: 271-276; quiz 277.

26   de Kraker M, Selles RW, Schreuders TA, Stam HJ, Hovius SE. Palmar abduction: reliability of 6 measurement methods in healthy adults. *J Hand Surg Am.* 2009;34: 523-530.

27   Lemmen MH, Schreuders TA, Stam HJ, Hovius SE. Evaluation of restoration of extensor pollicis function by transfer of the extensor indicis. *J Hand Surg Br.* 1999;24: 46-49.

7

28   ASHT. Clinical Assessment and Recommendations. *American Society of Hand Therapists*. Chicago IL1992:64-65.

29   Schreuders TA, Roebroeck M, van der Kar TJ, Soeters JN, Hovius SE, Stam HJ. Strength of the intrinsic muscles of the hand measured with a hand-held dynamometer: reliability in patients with ulnar and median nerve paralysis. *J Hand Surg Br*. 2000;25: 560-565.

30   Schreuders TA, Roebroeck ME, Jaquet JB, Hovius SE, Stam HJ. Measuring the strength of the intrinsic muscles of the hand in patients with ulnar and median nerve injuries: reliability of the Rotterdam Intrinsic Hand Myometer (RIHM). *J Hand Surg Am*. 2004;29: 318-324.

31   Selles RW, van Ginneken BT, Schreuders TA, Janssen WG, Stam HJ. Dynamometry of intrinsic hand muscles in patients with Charcot-Marie-Tooth disease. *Neurology*. 2006;67: 2022-2027.

32   Molenaar HM, Selles RW, Willemsen SP, Hovius SE, Stam HJ. Growth Diagrams for Individual Finger Strength in Children Measured with the RIHM. *Clin Orthop Relat Res*.469:868-876.

33   Weinstein S. Fifty years of somatosensory research: from the Semmes-Weinstein monofilaments to the Weinstein Enhanced Sensory Test. *J Hand Ther*. 1993; 6:11-22; discussion 50.

34   Jerosch-Herold C. Assessment of sensibility after nerve injury and repair: a systematic review of evidence for validity, reliability and responsiveness of tests. *J Hand Surg Br*. 2005; 30:252-264.

35   Kozin SH. Upper-extremity congenital anomalies. *J Bone Joint Surg Am*. 2003;85-A:1564-1576.

36   Manske PR, McCarroll HR, Jr. Reconstruction of the congenitally deficient thumb. *Hand Clin*. 1992;8: 177-196.

37.   Oberlin C, Gilbert A. Transfer of the abductor digiti minimi (quinti) in radial deformities of the hand in children. *Ann Chir Main*. 1984;3: 215-220.

38   Upton J, Taghinia A. Abductor digiti minimi myocutaneous flap for opponensplasty in congenital hypoplastic thumbs. *Plastic Reconstructive Surgery*. 2008;122: 1807-1811.

39   Huber E. Hilfsoperation bei Medianuslähmung. *Deutsche Zeitschrift für Chirurgie*. 1921:271–275.

40   Latimer J, Shah M, Kay S. Abductor digiti minimi transfer for the restoration of opposition in children. *J Hand Surg Br*. 1994; 19:653-658.

41   Ogino T, Minami A, Fukuda K. Abductor digiti minimi opponensplasty in hypoplastic thumb. *J Hand Surg Br*. 1986; 11:372-377.

42   Cawrse NH, Sammut D. A modification in technique of abductor digiti minimi (Huber) opponensplasty. *J Hand Surg Br*. 2003; 28:233-237.

43   Percival NJ, Sykes PJ, Chandraprakasam T. A method of assessment of pollicisation. *J Hand Surg Br]*. 1991; 16:141-143.

44   Goldfarb CA, Deardorff V, Chia B, Meander A, Manske PR. Objective features and aesthetic outcome of pollicized digits compared with normal thumbs. *J Hand Surg Am*. 2007; 32:1031-1036.

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Chapter 8

General discussion

GENERAL DISCUSSION

Interventions aimed at restoring thumb function in thumb hypoplasia can be divided into conservative and surgical. Due to the complexity of anomalies displayed in hypoplastic thumbs, surgical interventions are often necessary to achieve sufficient functional and aesthetic results. For evaluation of outcome after these surgical interventions, reliable and valid measurement methods are mandatory.

Goal of this thesis was to assess reliability of several measurement methods and with these methods assessing thumb function in patients with thumb hypoplasia after a reconstruction with the intention of improving outcome.

MAIN FINDINGS, LIMITATIONS AND POSSIBLE EXPLANATIONS

PART I: MEASUREMENT METHODS

In congenital malformations of the upper limb and hand in recent years more emphasis is placed on measuring the different aspects of impairment and outcome after treatment. Besides conventional methods (e.g. goniometry) we focused on reliably measuring palmar abduction. As discussed in **Chapter 2**, we therefore developed the Pollexograph (1) to measure a more reliable angle between index finger and thumb when the thumb is in palmar abduction. The Pollexograph design was based on the concept that hand position should be standardized to obtain repetitive and reliable measurements. We obtained intra rater reliability for conventional goniometry and the Pollexograph in 21 patients with a hypoplastic thumb, showing excellent reliability for the Pollexograph.

With the Pollexograph, hand therapists found it easier to measure both active and passive palmar abduction and were more confident that they performed the measurement correctly. Even though these promising primary results, it was only a small group in which reliability was assessed. The high inter correlation coefficients (ICC's) could perhaps be explained by the retest being performed on the same day. Another explanation for the high ICC's, could be found in the fact that the range within measured angles is quite large, resulting in higher ICC's. So therefore, there was a need for a more comprehensive study, measuring Pollexopgraph reliability in adults (and children) and comparing it to existing measurement methods. We therefore conducted the study *"Palmar abduction: reliability of 6 measurement methods in healthy adults* which is addressed in **Chapter 3.** We compared reliability of the 1)

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Pollexograph-"thumb" (which measures the angle between the thumb and the index metacarpal, perpendicular to the plane of the palm, which includes the angle produced by possible laxity in the metacarpophalangeal (MCP) and interphalangeal (IP) joints) (2), 2) the "Pollexograph-metacarpal" (in which a ruler is placed over the first metacarpal to better resemble conventional goniometry measurements by leaving out laxity in these two joints) (2), 3) conventional goniometry (3-5), 4) the Inter Metacarpal Distance (IMD) (6), 5) the American Society of Hand Therapists method (ASHT method) (7), 6) and the method described in "Guides to the Evaluation of Permanent Impairment" of the American Medical Association (AMA method) (8). ICC's for conventional goniometry, the American Society of Hand Therapists method and the American Medical Association method showed only moderate reliability (ICC's 0.55-0.72). The significant smaller smallest detectable differences (SDD's) and standard error of the mean (SEM's) for intra- and inter rater reliability indicated that the Pollexograph-thumb, Pollexograph-metacarpal and the Inter Metacarpal Distance (IMD) were the most reliable methods for measuring palmar abduction. Comparable intra- and inter rater reliability of palmar abduction measurements have been reported in several other studies (6,8). Harvey et al. (9) and Murugkar et al. (6) assessed reliability of conventional goniometry, the IMD and a complex torque-controlled device (9). Both studies showed comparable unacceptable low reliability for conventional goniometry and excellent reliability for the Inter Metacarpal Distance and their torque controlled device. A limitation of this study was that measurements were performed in 25 healthy subjects and these measurements should also be performed in several patient groups with affected thumb function. A limitation of the IMD is that it may be very appropriate for follow-up of individual adults, however it may not be very comparable between subjects due to differences in hand size or for follow-up measurement in children due to the changes in the size of their hands.

Since we had not yet validated Pollexograph measurements and its reliability in children, we therefore performed the study described in **Chapter 4** *"Palmar abduction measurements: reliability and introduction of normative data in healthy children".* The first goal of this study was to assess whether the Pollexograph-thumb, the Pollexograph-metacarpal and IMD, were also reliable measurement methods for palmar abduction in children, since many surgical interventions aimed at improving palmar abduction/ opposition are performed at an early age. In children between 4 and 12 years of age, we found that the Pollexograph-thumb, the Pollexograph-metacarpal and IMD had excellent intra rater reliability. Secondly, normative data were obtained in 100 children. These data were needed to allow comparison between healthy children and children with a thumb deformity. With Pollexograph-metacarpal measurements we found mean palmar abduction to be

approximately 50°. Normative data in this study were comparable to results from other studies (3,4,9). Mean palmar abduction angles measured in the children in this study were similar to the mean values we found for adults using the same measurement techniques. Since children's hands are not yet full-grown, IMD means were not comparable with means found in adults. Even though distance-based measurements, like the IMD, may be appropriate for follow-up of individual adults, they may not be very comparable between subjects due to differences in hand size, even more in children where bone length changes with time.

Even though we found excellent reliability for these three measurement methods, they are static measurement methods. Preferably, researchers want to assess the total 3-D workspace of the thumb in a dynamic matter. A few dynamic measurement systems had been developed in the past (10-14). When performing measurements with these systems several limitations such as system complexity and costs are drawbacks of these systems.

After assessing the different systems available, we chose the miniBIRD™ 500 (an electromagnetic motion tracking device) which is able to track real-time 3-D thumb motions. For the Minibord-500 motion analysis, we found good intra observer reliability for measuring palmar and radial abduction and for calculating the circumference and surface area of the thumb's workspace in healthy subjects (**Chapter 5**). Furthermore, 3-D measurements of healthy subjects and patients with hypoplastic thumbs showed that the individual thumb workspace of the patients differed from the controls. The few studies (10,11,15) published earlier about reliability and clinical use of 3-D motion analysis systems show comparable good reliability.

Drawbacks of 3-D ROM measurements are that these measurements are much more time-consuming and they require more expensive material than conventional static methods. Therefore, it is less suitable for a swift daily assessment of an individual's thumb range of motion. Since active ROM is measured, measurements require adequate cooperation of the subjects and movements should be demonstrated to them well before the actual measurement in order to attain reliable results.

We believe that a tool such as this one should not be used independently, but should be part of a larger set of measurements, such as range of motion of all relevant joints, strength, joint stability, sensibility, pain, and function during daily life.

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PART II: OUTCOME IN THUMB HYPOPLASIA

With the normative data obtained in the first part of this thesis, we were able to compare patient data to data measured in healthy subjects.

A known limitation of studies performed in patients with congenital hand deformities is the small number of patients available. This makes it impossible to perform prospective studies and therefore we were limited to performing retrospective studies.

In **Chapter 6**, we retrospectively assessed outcome in patients with a Type II and IIIA hypoplastic thumb that underwent an FDS IV opponensplasty. We found that overall range of motion and strength was diminished compared to normal. Range of motion was 17-77% of normal in Type II and Type IIIa hypoplasia. Only retroposition of the thumb was significantly reduced compared to normal, probably due increased stiffness which was partly intended with the stabilisation of the thumb.

Grip strength, pinch strength, tripod strength, and key pinch strength were approximately 50% of normal in Type II thumbs and 35% in Type IIIA thumbs. However, the MP joint was stable in 100% of the Type II thumbs and in 40% of the Type IIIA thumbs. Furthermore, opposition strength was significantly higher in Type II thumbs that underwent an FDS tendon transfer.

In contrast to reports on FDS IV opponensplasties, there are many reports on the outcome of abductor digiti minimi transfers in thumb hypoplasia. However, most studies have used qualitative assessments (16-18) making comparison with our data difficult. Available quantitative results on ADM transfers regarding key pinch strength, MP joint stability and opposition were comparable with our results. For example, Upton and Taghinia (19) reported that key pinch strength was 40% of normal in six patients with a Type II or IIIA hypoplastic thumb in which an ADM transfer was performed. This is comparable to the mean key pinch strength of 49% and 30% in our Type II and Type IIIA thumbs, respectively. Opposition strength was significantly higher in the operated Type II thumbs, compared to the unoperated Type II thumbs.

Manske and McCarroll (17) reported that MP joint stability was obtained in eight out of 10 (80%) Type II thumbs treated by ADM transfer. Ogino et al. (18) found a stable MP joint in six out of nine patients (67%) after an ADM transfer. Takayama et al. (20) reported satisfactory stability in five patients with a Type II or IIIA hypoplastic thumb treated by an ADM transfer. In our study, we found that MP joint stability was obtained in all operated Type II thumbs and in 40% of the Type IIIA thumbs. Perhaps in the future a primary chondrodesis should be done in Type IIIA thumbs with multidirectional instability of the MP joint, instead of trying to correct the instability with a tendon transfer.

With regard to opposition, many other authors have reported that satisfactory opposition was obtained after an ADM transfer. We also found good opposition with mean Kapandji scores of 6.8 and 7.7 in operated Type II and Type IIIA thumbs, respectively.

We found rather similar outcomes for patient and parent satisfaction in all operated patients. In contrast to what we expected, satisfaction was higher for unoperated patients and their parents. We could not find a specific explanation for the higher scores for functional and aesthetic outcome in the non-operated Type II thumbs. However, one patient and his parents were very dissatisfied with outcome, thereby severely reducing the overall mean outcome score in the operated Type II patients.

Overall, the FDS tendon transfer from the ring finger is a good functioning opponensplasty in both Type II and IIIA thumbs. The transfer provides excellent MP joint stability in the Type II thumbs.

The second patient group (**Chapter 7**) in which we wanted to assess thumb function, were patients that underwent a pollicisation for the more severe types of thumb hypoplasia (Types IIIb-V).

Pollicisation is recognized as a rewarding procedure in congenital hypoplasia and aplasia of the thumb without associated longitudinal radial dysplasia (LRD) (21-27). Congenital hand surgeons are fully aware that pollicisation outcome is far less optimal in patients with LRD than without this deficiency. However, it was not known how much more compromised outcome truly is.

In this study, we found that range of motion and strength of pollicisations with associated LRD were significantly diminished compared to healthy subjects. Furthermore, in severe LRD (Type III-IV), MP flexion, opposition range of motion and all strength measurements were significantly more decreased than in mild LRD (Type 0-II).

Patients with a pollicisation have a range of motion which is significantly lower than range of motion of a thumb in healthy subjects. Mean range of motion values found in our study were similar to results reported by Kozin et al. (25) and Roper et al. (28). Manske et al. (29) also reported that total range of motion was 40-75% of the range of motion of a normal thumb, depending whether associated conditions were present. When comparing range of motion of the pollicisations in our group, between severe and mild LRD, only MP flexion and opposition were significantly lower in severe LRD.

In other quantitative reports on pollicisations, hand strength is diminished compared to the other unaffected other side. Only two other reports compare their results to normative data. Foucher et al. (24) reported on their best pollicisation cases and found that grip strength and pinch strength were 55% and 42% of the other unaffected hand. Comparable results were

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reported by Roper et al, Clark et al, Vekris et al, Kozin et al, Manske et al, and Staines et al. (22,23,25,28-31). They report comparable outcome for strength measurements. Most likely, the existing variation within the results reported in these studies is caused by variation in the number of LRD cases included (29,31). In mild LRD grip strength, pinch strength, tripod strength, and key pinch strength were 36-52% of normal in our study. As could be expected, strength was significantly lower in patients with severe LRD, ranging from only 13-19% of normal.

When looking at complications that occurred in this patient group, they were associated with interventions correcting the radial dysplasia and not related to the performed pollicisation. Complications that occurred were a relapse of wrist position in four patients, of which in two a re-operation was performed. Furthermore, pin track infections and in one case a non-union occurred of eight patients following ulna distraction.

Even though range of motion and strength measurements were diminished compared to normal, patients and their parents were satisfied with function and appearance of the pollicised index finger. In contrast to what might be expected, satisfaction was not affected by the severity of the LRD. Mildly affected patients were not more satisfied, than more severely affected patients. We believe that, if the more ulnarly functioning hands are excluded, pollicisation is a rewarding procedure, even in patients with more severe LRD.

Future research suggestions

In the future, it would be interesting to study Quality of Life in patient with congenital upper extremity deformities. Several studies have shown that quality of life did not always correlate with disease severity (32-34).

In our patient group, we expect that quality of life also doesn't correlate with severity of the congenital deformity, since satisfaction also did not seem to correlate with severity. Quality of life is also not significantly correlated to severity in other patient groups with (corrected) congenital deformities (35,37). However, we need to study this in more detail for this specific patient group.

One of the other studies, we hope to conduct in the future is, comparing outcome in patients with a Type II thumb hypoplasia that underwent an ADQ tendon transfer and patients with an FDS IV tendon transfer. Especially, differences in opposition strength and 3-D range of motion are of interest. However, the difficulty lies within the small number of patients available and classifying patients pre-operatively. Several classification systems for thumb hypoplasia are present, and there is still (mild) variation between the systems used. Also the classification might change based on findings during surgery. The question remains how much influence

do small differences in anatomy have on final outcome, when comparing patients. And also the influence of growth and the ability to cooperate in such a study may influence outcome. Therefore, it would be interesting to perform two assessments in the same patients with several years in between, to see whether growth and age influence the measured outcomes. Purely based on our experiences during this study, it seems that the attitude of the parents plays a crucial role in the way the children perceive their "disability". We would prefer to expand our treatment team with a psychologist that purely focusses on supporting patients and their parents in the whole process. Unfortunately, due to lack of financial means this is currently not possible.

Perhaps in the future we will be able to develop a standardized program for parents to support their child during the whole (surgical) process, creating the best coping mechanism possible.

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REFERENCES

1   de Kraker M, Selles RW, Schreuders TA, Hovius SE, Stam HJ. The Pollexograph: a new device for palmar abduction measurements of the thumb. *J Hand Ther.* 2009, 22: 271-6.

2   de Kraker M, Selles RW, Schreuders TA, Stam HJ, Hovius SE. Palmar abduction: reliability of 6 measurement methods in healthy adults. *J Hand Surg Am* 2009; 34(3): 523-30.

3   Brand PW. *Deformity in leprosy*. In Cochrane RG (ed) Leprosy in Theory and practice (ed2) Bristol UK; John Wright & Sons Ltd, 1964:485-496.

4   Tubiana R, Thomine JM, Mackin E. *Examination of the Hand and Wrist*: Martin Dunitz Ltd, 1998.

5   Hartigan BJ, Stern PJ, Kiefhaber TR. Thumb carpometacarpal osteoarthritis: arthrodesis compared with ligament reconstruction and tendon interposition. *J Bone Joint Surg Am*. 2001; 83-A:1470-1478.

6   Murugkar PM, Brandsma J.W., Anderson A.M., Khadka Gurung, Yam Pun. Reliability of Thumb Web Measurements. *J Hand Ther*. 2004:58-63.

7   American Society for Therapy of the Hand. *Clinical Assessment and Recommendations*. 2nd ed, 1992.

8   American Medical Association. *Guides to the Evaluation of Permanent Impairment*. American Medical Association, 4th Edition 1993:(3) 28-29.

9   Harvey L, de Jong I, Goehl G, Armstrong B, Allaous J. A torque-controlled device to measure passive abduction of the thumb carpometacarpal joint. *J Hand Ther*. 2006; 19:403-408; quiz 409.

10   Coert JH, van Dijke HG, Hovius SE, Snijders CJ, Meek MF. Quantifying thumb rotation during circumduction utilizing a video technique. *J Orthop Res* 2003; 21(6): 1151-5.

11   Kuo LC, Chiu HY, Chang CW, Hsu HY, Sun YN. Functional workspace for precision manipulation between thumb and fingers in normal hands. *J Electromyogr Kinesiol 2009*; 19(5): 829-39.

12   Kuo LC, Cooney WP 3rd, Oyama M, Kaufman KR, Su FC, An KN**.** Feasibility of using surface markers for assessing motion of the thumb trapeziometacarpal joint. *Clin Biomech* 2003; 18(6): 558-63.

13   Su FC, Kuo LC, Chiu HY, Chen-Sea MJ**.** Video-computer quantitative evaluation of thumb function using workspace of the thumb. *J Biomech* 2003; 36(7): 937-42.

14   Kuo LC, Cooney WP, Chen QS, Kaufman KR, Su FC, An KN**.** A kinematic method to calculate the workspace of the trapeziometacarpal joint. *Proc Inst Mech Eng H* 2004; 218(2): 143-9.

15   Kuo LC, Su FC, Chiu HY, Yu CY. Feasibility of using a video-based motion analysis system for measuring thumb kinematics. *J Biomech*. 2002; 35:1499-1506.

16   Latimer J, Shah M, Kay S. Abductor digiti minimi transfer for the restoration of opposition in children. *J Hand Surg Br*. 1994; 19:653-658.

17   Manske PR, McCarroll HR, Jr. Abductor digiti minimi opponensplasty in congenital radial dysplasia. *J Hand Surg*. 1978, 3: 552-9.

18   Ogino T, Minami A, Fukuda K. Abductor digiti minimi opponensplasty in hypoplastic thumb. *J Hand Surg Br*. 1986, 11: 372-7.

19   Upton J, Taghinia A. Abductor digiti minimi myocutaneous flap for opponensplasty in congenital hypoplastic thumbs. *Plast Reconstr Surg*. 2008;122: 1807-1811.

20   Takayama S, Nakao Y, Ikegami H, Nakamura T. Modified abductor digiti minimi opponensplasty in congenital hypoplastic thumb with laxity of metacarpophalangeal joint. *Tech Hand Up Extrem Surg*. 2002, 6: 166-70.

21   Buck-Gramcko D. Pollicization of the index finger. Method and results in aplasia and hypoplasia of the thumb. *J Bone Joint Surg Am*. 1971;53: 1605-1617.

22   Staines KG, Majzoub R, Thornby J, Netscher DT. Functional outcome for children with thumb aplasia undergoing pollicization. *Plast Reconstr Surg*. 2005;116: 1314-1323; discussion 1324-1315.

23   Clark DI, Chell J, Davis TR. Pollicisation of the index finger. A 27-year follow-up study. *J Bone Joint Surg Br*. 1998;80: 631-635.

24   Foucher G, Lorea P, Pivato G, Medina J, Szabo Z. Technical note: ulnar "pseudo-pollicisation" in congenital hand differences. *Chir Main*. 2004;23: 289-293.

25 Kozin SH, Ezaki M. Flexor digitorum superficialis opponensplasty with ulnar collateral ligament reconstruction for thumb deficiency. *Tech Hand Up Extrem Surg.* 2010 Mar;14(1): 46-50.

26 Sykes PJ, Chandraprakasam T, Percival NJ. Pollicisation of the index finger in congenital anomalies. A retrospective analysis. *J Hand Surg Br.* 1991; 16:144-147.

27 Littler JW, Cooley SGE. Opposition of the thumb and its restoration by abductor digiti quinti transfer. *J Bone Joint Surg Am.* 1963, 45: 1389–96.

28 Roper BA, Turnbull TJ. Functional assessment after pollicisation. *J Hand Surg Br.* 1986;11: 399-403.

29 Manske PR, McCarroll HR, Jr. Reconstruction of the congenitally deficient thumb. *Hand Clin.* 1992;8: 177-196.

30 Vekris MD, Beris AE, Lykissas MG, Soucacos PN. Index finger pollicization in the treatment of congenitally deficient thumb. *Ann Plast Surg.* 66:137-142.

31 De Kraker M, Selles RW, van Vooren J, Stam HJ, Hovius SER. Outcome after pollicization: comparison of patients with mild and severe longitudinal radial deficiency. *Plast Reconstr Surg. 2013 Apr;131(4):544-51.*

32 Versnel SL, Plomp RG, Passchier J, Duivenvoorden HJ, Mathijssen IM. Long-term psychological functioning of adults with severe congenital facial disfigurement. *Plast Reconstr Surg.* 2012 Jan;129(1):110-7.

33 Jackson JL, Hassen L, Gerardo GM, Vannatta K, Daniels CJ. Medical factors that predict quality of life for young adults with congenital heart disease: What matters most? *Int J Cardiol* 2016 Jan 1; 202:804-9.

34 Versteegh HP, van den Hondel D, IJsselstijn H, Wijnen RM, Sloots CE, de Blaauw I. Cloacal malformation patients report similar quality of life as female patients with less complex anorectal malformations. *J Pediatr Surg* 2015 Aug.

35 Widerberg A, Sommerstein K, Dahlin LB, Rosberg HE. Long-term results of syndactyly correction by the trilobed flap technique focusing on hand function and quality of life. *J Hand Surg Eur* Vol 2015. Nov 5.

36 Jardine J, Glinianaia SV, McConachie H, Embleton ND, Rankin J. Self-reported quality of life of young children with conditions from early infancy: a systematic review. *Pediatrics.* 2014 Oct;134(4): 1129-48.

37 Ardon MS, Janssen WG, Hovius SE, Stam HJ, Selles RW. Low impact of congenital hand differences on health-related quality of life. *Arch Phys Med Rehabil.*2012. Feb; 93(2): 351-7.

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Chapter 9

Summary

SUMMARY

Several surgical interventions aimed at restoring thumb function in thumb hypoplasia are available. For outcome evaluation after these surgical interventions, reliable and valid measurement methods are mandatory.

Goal of this thesis was to assess reliability of several measurement methods and with these methods assessing thumb function in patients with thumb hypoplasia after they sustained a reconstruction with the intention of improving outcome.

PART I: MEASUREMENT METHODS

In **Chapter 2**, we describe the design and development of the Pollexograph to measure active and passive palmar abduction. The tool was designed in such a way that it is simple, affordable, applicable to left and right hands of varying sizes and most importantly, valid and reliable. As a first test to determine applicability and inter rater reliability, 14 occupational and physical therapists performed measurements on the same subject with a conventional goniometer and with the Pollexograph to assess inter rater reliability. Additionally, Pollexograph intra rater reliability was assessed in 21 patients with a hypoplastic thumb (Blauth Type II-IV) that had undergone surgical treatment in our medical center. The preliminary results suggested that the Pollexograph was more reliable than a conventional goniometer for measuring palmar thumb abduction.

In **Chapter 3**, we assessed means and reliability in adults of 4 known palmar thumb abduction measurement methods: conventional goniometry, the Inter Metacarpal Distance (IMD), the method described by the American Medical Association (AMA), the method described by the American Society of Hand Therapists (ASHT) and two new methods: the Pollexograph-thumb and the Pollexograph-metacarpal. The Pollexograph-thumb measures the angle between the thumb and the index metacarpal, perpendicular to the plane of the palm, which includes the angle produced by possible laxity in the metacarpophalangeal (MCP) and interphalangeal (IP) joints. The "Pollexograph-metacarpal" leaves out laxity in these two joints since a ruler is placed over the first metacarpal to better resemble conventional goniometry measurements.

Mean active and passive angles measured with goniometry resembled values measured with the Pollexograph-thumb (approximately 60 degrees). Mean angles found with the Pollexograph-metacarpal were approximately 48 degrees. Mean active and passive intermetacarpal distances were 64 mm. Mean distances found with the American Society of

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Hand Therapists method were 97-101 mm and means of the American Medical Association method were 67-70 mm for active and passive measurements.

ICC's of the Pollexograph-thumb, Pollexograph-metacarpal and the Inter Metacarpal Distance indicated good and significantly higher intra rater reliabilty (ICC's 0.71-0.95) for active and passive measurements than ICC's of conventional goniometry, the American Society of Hand Therapists method and the American Medical Association method showing only moderate reliability (ICC's 0.55-0.72). For inter rater reliability, the same measurement methods were found to be most reliable: the Pollexograph-thumb, Pollexograph-metacarpal and the Inter Metacarpal Distance.

Since many interventions aimed at improving palmar abduction are performed at an early age, we assessed normative and reliability data of these three reliable measurement methods in children. We therefore performed measurements **(Chapter 4)** with the Pollexograph-thumb, the Pollexograph-metacarpal and Inter Metacarpal Distance. In 100 healthy children normative data were acquired and intra rater reliability was measured in 63 children. We found that normative Pollexograph-thumb and Pollexograph-metacarpal means measured in children were comparable to values found in healthy adults and reliability data indicated that the Pollexograph-thumb, the Pollexograph-metacarpal and Inter Metacarpal Distance were also reliable measurement methods in children.

After having assessed reliability of several static palmar abduction measurement devices we wanted to determine intra rater reliability and clinical usefulness of an electromagnetic motion tracking device (Minibird-500) for assessing 3-D thumb workspace **(Chapter 5)**. For this assessment we performed measurements in control subjects and patients with surgically-treated hypoplastic thumbs.

We found good to excellent intra rater reliability with ICC's ranging from 0.70 to 0.88. A large number of patients showed an aberrant workspace in comparison to controls; some of the workspaces were increased, others decreased. In contrast to what we expected, no significant correlation was found between patient's 3-D workspace and Kapandji scores for opposition.

PART II: OUTCOME IN THUMB HYPOPLASIA

After sustaining several reliable measurement methods, we studied thumb function in patients with Type II and IIIA thumb hypoplasia **(Chapter 6)** that received a Flexor Digitorum Superficialis (FDS IV) Opponensplasty. For comparison, we also included several unoperated Type II thumbs.

Outcome was assessed by range of motion, strength, sensibility, joint stability and patient/parent satisfaction. We found that compared to normative data, range of motion was diminished in all three patient groups. Grip strength, pinch strength, tripod strength, and key pinch strength were approximately 50% of normal in Type II thumbs and 35% in Type IIIA thumbs. However, opposition strength in operated Type II thumbs was significantly better than in non-operated thumbs. MP joint stability was restored in all operated Type II thumbs and in 40% of Type IIIA thumbs.

So overall, we believe that the FDS tendon transfer from the ring finger is a good functioning opponensplasty in both Type II and IIIA thumbs. The transfer provides excellent MP joint stability in the Type II thumbs.

In Type IIIB-V thumb hypoplasia, pollicisation of the index finger is a well-established treatment. However, reports in literature assessing postoperative success had been diverse. There was a lack of quantative outcome studies and little was known about the outcome differences between patients with mild and severe longitudinal radial deficiencies (LRD). Therefore, in **Chapter 7** the quantitative assessment and outcome after pollicisation in mild and severe longitudinal radial deficiency was reported and compared to outcome in healthy controls. In twenty-four patients (30 affected hands) with mild and severe longitudinal radial deficiency active and passive range of motion, extrinsic and intrinsic strength, sensibility, and patient and parent satisfaction was measured.

In the overall pollicisation group with associated longitudinal radial deficiency range of motion and strength were significantly diminished compared to normative data. Moreover, in severe longitudinal radial deficiency all strength measurements were significantly more affected than in mild longitudinal radial deficiency. However, patients and parents were very satisfied with function and appearance of the newly created thumb, non-dependent of the severity of the longitudinal radial deficiency.

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NEDERLANDSE SAMENVATTING

Er bestaan verschillende chirurgische interventies met als doel het herstellen van duimfunctie. Om het resultaat van deze interventies te evalueren, zijn betrouwbare en valide meetmethoden onmisbaar.

Het doel van dit proefschrift was het in kaart brengen van de betrouwbaarheid van verschillende meetmethoden. Middels deze meetmethoden wilden we vervolgens duimfunctie meten bij patienten met een hypoplastsiche duim, die een chirugische interventie hadden ondergaan, met als doel de functie te herstellen.

DEEL I: MEETMETHODEN

In **Hoofdstuk 2**, beschrijven we het ontwerp en de ontwikkeling van een nieuw meetinstrument, de Pollexograph, om actieve en passieve palmair abductie te kunnen meten. De Pollexograph is zo ontworpen dat het simpel is, betaalbaar, toepasbaar op linker en rechter handen van verschillende groottes en bovenal valide en betrouwbaar.

Tijdens een eerste test om de toepasbaarheid en de inter rater betrouwbaarheid te onderzoeken hebben 14 hand- en fysiotherapeuten metingen verricht op eenzelfde proefpersoon. De metingen werden verricht met een conventionele goniometer en met de Pollexograph.

Aanvullend is de intra rater betrouwbaarheid van de Pollexograph onderzocht in 21 patiënten met een Type II-IV hypoplastische duim die een reconstructie hadden ondergaan in het Erasmus MC. Voorlopige resultaten lieten zien dat de Pollexograph betrouwbaarder was in het meten van palmair abductie, dan een conventionele goniometer.

In **Hoofdstuk 3**, hebben we in volwassenen, gemiddelden en betrouwbaarheid onderzocht van 4 bekende palmair abductie meetmethoden: conventionele goniometrie, de Inter Metacarpal Distance (IMD), de methode beschreven door de American Medical Association (AMA), de method beschreven door de American Society of Hand Therapists (ASHT) en 2 nieuwe methoden: de Pollexograph-thumb en de Pollexograph-metacarpal.

De Pollexograph-thumb meet de hoek tussen de duim en de metacarpaal van de wijsvinger in een vlak perpendiculair aan het vlak van de handpalm, waarbij een hoek wordt meegenomen die wordt gecreëerd door eventuele laxiteit in het metacarpophalangeale (MCP) en interphalangeale (IP) gewricht.

Bij de Pollexograph-metacarpal wordt deze extra hoek niet meegenomen in de meting,

omdat er een liniaal wordt geplaatst over de eerste metacarpaal, waarbij de gemeten hoek meer overeen zou moeten komen met de hoek gemeten met conventionele goniometrie.

Gemiddelde actieve en passieve hoeken gemeten met een goniometer kwamen overeen met metingen van de Pollexograph-thumb (ongeveer 60 graden). Gemiddelde hoeken gemeten met de Pollexograph-metacarpal waren ongeveer 48 graden. De gemiddelde actieve en passieve Inter Metacarpal Distances waren 64 mm. Gemiddelde afstanden voor de American Society of Hand Therapists methode waren 97-101 mm en gemiddelden voor de American Medical Association methode waren 67-70 mm voor actieve en passieve metingen.

Intraclass correlation coefficients (ICC's) voor de Pollexograph-thumb, Pollexograph-metacarpal en de Inter Metacarpal Distance lieten goede en significant hogere intra rater betrouwbaarheid zien (ICC's 0.71-0.95) voor actieve en passieve metingen, dan voor conventionele goniometrie, de American Society of Hand Therapists methode en de American Medical Association method, welke matige betrouwbaarheid toonden (ICC's 0.55-0.72).

Wanneer we keken naar de inter rater betrouwbaarheid, bleken dezelfde methoden betrouwbaar te zijn; de Pollexograph-thumb, de Pollexograph-metacarpal en de Inter Metacarpal Distance.

Veel interventies met als doel het verbeteren van de palmair abductie van de duim worden op jonge leeftijd uitgevoerd. Om deze reden hebben we in kinderen tussen de 4 en 12 jaar, normaalwaarden onderzocht en de betrouwbaarheid van deze 3 meest betrouwbare meetmethoden.

In **Hoofdstuk 4** beschrijven we de resultaten van de metingen die zijn verricht met de Pollexograph-thumb, de Pollexograph-metacarpal en de Inter Metacarpal Distance.

In 100 gezonde kinderen hebben we normaalwaarden verkregen en hebben we de intra rater betrouwbaarheid vastgesteld in 63 kinderen.

We vonden dat gemiddelde normaalwaarden voor de Pollexograph-thumb en Pollexograph-metacarpal gemeten in kinderen vergelijkbaar waren met de gemiddelden gemeten bij volwassenen. Uit de metingen bleek dat ook voor kinderen de Pollexograph-thumb, de Pollexograph-metacarpal en de Inter Metacarpal Distance betrouwbare meetmethoden zijn.

Na vaststellen van de betrouwbaarheid van een aantal statische meetmethoden voor palmair abductie, was ons doel om de intra rater betrouwbaarheid en klinische toepasbaarheid van een elektromagnetisch bewegingssysteem (Minibird-500) vast te stellen. Middels een elektromagnetisch bewegingssysteem systeem kan de 3-D workspace van de duim in kaart worden gebracht **(Hoofdstuk 5)**.

Voor deze studie hebben we metingen verricht in een controle groep en in een groep patiënten met een hypoplastsiche duim die een reconstructie hadden ondergaan. We vonden goede tot zeer goede intra rater betrouwbaarheid met ICC's van 0.70 tot 0.88. Een groot aantal patiënten liet een afwijkende workspace zien vergeleken met de controle groep: sommigen waren groter en anderen kleiner. In tegenstelling tot onze verwachtingen, was er geen siginificante correlatie tussen 3-D workspace en Kapandji scores voor oppositie van patiënten.

DEEL II: RESULTATEN IN DUIMHYPOPLASIE

Nadat enkele betrouwbare meetmethoden voor het meten van een deel van duimfunctie waren vastgesteld, hebben we de duimfunctie onderzocht in patiënten met een Type II en IIIA duimhypoplasie, die een Flexor Digitorum Superficialis (FDS IV) oppositieplastiek hadden ondergaan **(Hoofdstuk 6)**. Ter vergelijking hebben we ook enkele ongeopereerde Type II duimen onderzocht.

We hebben de duimfunctie in kaart gebracht door te kijken naar range of motion, kracht, sensibiliteit, stabiliteit en de patiënt/ouder tevredenheid. Range of motion bleek lager te zijn in alle 3 de patiëntengroepen, vergeleken met de normaalwaarden. Grijpkracht, pinch kracht, tripod knijpkracht en sleutelgrip- kracht waren ongeveer 50% van normaal in Type II duimhypoplasie en ongeveer 35% in Type IIIA duimhypoplasie. Echter, oppositiekracht was significant hoger in Type II duimen die een FDS IV oppositieplastiek hadden ondergaan.

Stabiliteit van het MCP gewricht was hersteld in alle Type II duimen en in 40% van de Type IIIA duimen.

Overall, vonden we dat de FDS IV oppositieplastiek een goede oppositieplastiek is, voor zowel Type II als Type IIIA duimhypoplasie. In Type II duimhypoplasie geeft de oppositieplastiek zeer goede stabiliteit van het MCP gewricht.

Pollicisatie van de wijsvinger is voor Type IIIB-V duim hypoplasia een erkende behandeling. Echter, in de literatuur zijn de post-operatieve successen zeer divers. Er was een gebrek aan kwantitaieve uitkomst studies en er was weinig bekend over hoe verschillend de resultaten zijn tussen patienten met milde en ernstige radius dysplasie.

In **Hoofdstuk 7** onderzochten we de kwantitatieve duimfunctie na een pollicisatie bij patienten met milde en ernstige radius dysplasie. Hierna werd de functie vergeleken met normaalwaarden.

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In 24 patienten (30 handen) met milde en ernstige radius dysplasie werd range of motion, extrinsieke en intrinsieke kracht, sensibiliteit en patiënt/ouder tevredenheid gemeten.

In de gehele pollicisatie groep met radius dysplasie bleek range of motion en kracht significant verminderd vergeleken met normaalwaarden. Bovendien, bleek dat alle krachtmetingen van patiënten met ernstige radius dysplasie significant zwakker waren dan van patienten met milde radius dysplasie.

Echter, patiënten en ouders waren zeer tevreden met de functie en het uiterlijk van de nieuwe duim, onafhankelijk van de ernst van de radius dysplasie.

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Appendices

List of publications

Curriculum Vitae

PhD portfolio

Dankwoord

LIST OF PUBLICATIONS

Abstract
- **De Kraker M**, Kluin J, Renken N, Maat A.P.W.M, Bogers, A.J.J.C.
  CT and Myasthenia Gravis: correlation between mediastinal imaging and histopathological findings.
  Netherland Heart Journal, volume 12, supplement 3, dec. 2004

Articles
- **De Kraker M**, Kluin J, Renken N, Maat A.P.W.M, Bogers, A.J.J.C.
  CT and Myasthenia Gravis: correlation between mediastinal imaging and histopathological findings.
  Interactive Cardiovascular and Thoracic Surgery (ICVTS) 2005; 4(3):267-271

- **De Kraker M**, Selles RW, Schreuders TA, Hovius SER, Stam HJ.
  The Pollexograph®: a new device for palmar abduction measurements of the thumb.
  J Hand Ther. 2009 Jul-Sep;22(3):271-6.

- **De Kraker M**, Selles RW, Schreuders TA, Stam HJ, Hovius SER.
  Palmar Abduction: reliability of 6 measurement methods in healthy adults.
  J Hand Surg Am. 2009 Mar;34(3):523-30.

- **De Kraker M**, Selles RW, Molenaar TM, Schreuders TA, Hovius SER, Stam HJ.
  Palmar abduction measurements: reliability and introduction of normative data in healthy children.
  J Hand Surg Am. 2009 Nov;34(9):1704-8.

- **De Kraker M**, De Paepe KNA, Slijper HJ, Stam HJ, Hovius SER, Coert JH, Selles RW.
  3D- thumb workspace assessment in patients with thumb hypoplasia.
  Submitted for publication.

- **De Kraker M**, Selles RW, Zuidam JM, Molenaar HM, Stam HJ, Hovius SER.
  Outcome of flexor digitorum superficialis opponensplasty for Type II and IIIA thumb hypoplasia.
  J Hand Surg Eur. 2015 Aug 28.

- **De Kraker M**, Selles RW, van Vooren J, Stam HJ, Hovius SER.
  Outcome after pollicisation: comparison of patients with mild and severe longitudinal radial deficiency.
  Plast Reconstr Surg. 2013 Apr;131(4):544-51.

- Zuidam JM, **De Kraker M**, Selles RW, Hovius SE.
  Evaluation of function and appearance of adults with untreated triphalangeal thumbs.
  J Hand Surg Am. 2010 Jul;35(7):1146-52.

- Molenaar HM, **De Kraker M**, Zuidam JM, Hovius SE, Stam HJ, Selles RW.
  Visual feedback and weight reduction of a grip strength dynamometer do not increase reliability in healthy children.
  J Hand Ther. 2010 Jul-Sep;23(3):272-9; quiz 280.

- Zuidam JM, Selles RW, **de Kraker M**, Hovius SE
  Outcome of two types of surgical correction of the extra phalanx in triphalangeal thumb: is there a difference?
  J Hand Surg Eur Vol. 2015 Mar 20. [Epub ahead of print]

- Molenaar HM, Selles RW, **de Kraker M**, Stam HJ, Hovius SE.
  The added value of measuring thumb and finger strength when comparing strength measurements in hypoplastic thumb patients.
  Clin Biomech. 2013 Oct;28(8):879-85. Epub 2013 Jul 27.

CURRICULUM VITAE

Marjolein de Kraker, was born on April 15th 1981 in Roosendaal, the Netherlands. After graduating from the Gertrudis College in Roosendaal in 1999, she started medical school at the Erasmus University of Rotterdam. During her study she worked as a student member on the medical ward of de department of Neurology and Gynaecology. During her MD training she found a great interest in Plastic and Reconstructive Surgery and during her final months, she was offered the chance to work on this thesis by Prof.dr. S.E.R. Hovius. Together with support from Prof. dr. H.J. Stam of the Department of Rehabilitation, it was made possible to conduct this thesis. After working on her PhD thesis for 3 years, in 2009, she started her residency in Plastic and Reconstructive Surgery, which she finished in March 2016. On May 1st she will start working as a stafmember at the *Erasmus Medical Center* and *Franciscus Gasthuis en Vlietland* specializing in post bariatric reconstructions and breast reconstructions.

PHD PORTFOLIO

PhD training	Year	Workload (hours)
Biomedical English writing	2010	20 hrs
Medical Statistics course	2009	20 hrs

Specific courses		
Microsurgery: Mw. JM Hekking		
Skillslab Plastic and Reconstructive Surgery	2006-2009	150 hrs

Oral presentations		
Dutch Society for Thoracic Surgery, (NvVT), Utrecht, the Netherlands Thymectomy for Myasthenia Gravis: Determinants of outcome.	2003	20 hrs
Third joint Meeting EACTS/ESTS, Leipzig CT and Myasthenia Gravis: correlation between mediastinal imaging and histopathological findings	2004	20 hrs
Dutch Society for Thoracic Surgery, (NvVT), Utrecht, the Netherlands CT and Myasthenia Gravis: correlation between mediastinal imaging and histopathological findings	2004	20 hrs
Dutch Society for Hand Surgery (NVvH), Amsterdam, the Netherlands Palmar abduction: Introduction of a new tool and reliability comparison with conventional goniometry	2007	20 hrs
Dutch Society for Hand Surgery (NVvH), Amsterdam, the Netherlands Palmar abduction: reliability data of 6 measurement methods	2008	20 hrs
FESSH/ FESHT joint meeting Lausanne, Switserland Palmar abduction: introduction of a new tool and reliability data of measurement methods in healthy adults	2008	20 hrs

FESSH/ FESHT joint meeting, Lausanne, Switserland Palmar abduction: reliability data of measurement methods in 100 healthy children.	2008	20 hrs
FESSH/ FESHT, Hamburg, Germany Outcome of Flexor Digitorum Superficialis Opponensplasty for Type II and IIIA Thumb Hypoplasia.	2009	20 hrs
FESSH, Milan, Italy Thumb hypoplasia: long term outcome after treatment.	2015	20 hrs

Others		
Wrist Surgery – 2nd International Dissection Course, Dr Tulp Utrecht, the Netherlands	2007	30 hrs
Organization CHASG meting 2009, Rotterdam, the Netherlands	2009	80 hrs
Organization World Congenital Hand Symposium, Rotterdam, the Netherlands	2015	100 hrs

Teaching		
Coach microsurgery course	2007-9	80 hrs
Anatomy of the arm and hand course (2-4rd year medical students)	2007-10	40 hrs
Hand examination course (2-4rd year medical students)	2007-11	40 hrs

Grants		
Nuts Ohra Foundation	€ 50.000	
"Young Investigator Award" at Third Joint Meeting EACTS/ESTS, Leipzig.	€ 3.000	

Total		**860 hrs= 30 ECTS**

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Bedankt dat u me 9 jaar geleden de kans heeft gegeven om dit traject in te gaan en bedankt voor de fantastische begeleiding tijdens dit onderzoek. Het heeft "iets" langer geduurd dan we hadden gepland, maar het is nu dan toch echt een mooi boekje geworden. Dank je wel voor het bijna onvoorwaardelijke vertrouwen in mij gedurende de afgelopen jaren, ook toen ik het moeilijk had. Ik hoop dat u met trots terugkijkt op al het verrichte (klinische) werk ten aanzien van "uw kindjes"…

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Graag wil ik de overige leden van de commissie, **Prof.dr. C.M.A.M van der Horst, Prof.dr. J.H. Coert, Prof.dr. J.A.N. Verhaar, Prof.dr. R.M.H. Wijnen, Prof.dr. C.K. van der Sluis,** bedanken voor het beoordelen van mijn proefschrift en het plaatsnemen in de commissie op de dag van de verdediging. Ik ben u erg erkentelijk.

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DE-koffiemanager, Baja Beach club, pijltje naar links, heb geen pijltje naar rechts, de Beurs, Salsa dansen, de "gate-keeper", stranddag, handencongresjes etc etc.
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