Changes In angulation and phalangeal length of fingers and thumbs following surgical treatment for congenital clinodactyly

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Thesis

CHANGES IN ANGULATION AND PHALANGEAL LENGTH OF
FINGERS AND THUMBS FOLLOWING SURGICAL TREATMENT FOR
CONGENITAL CLINODACTYLY

by

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ABSTRACT

Introduction

Congenital clinodactyly is a condition characterized by the deviation of a digit or digits in the coronal plane. Angulation is often due to the presence of a delta phalanx. There is a scarcity of long-term data regarding the results of surgical treatment for clinodactyly, particularly with respect to postoperative phalangeal growth and risk factors for recurrent deformity.

Methods

Our retrospective study involved the analysis of data from medical records of patients who had corrective surgery for congenital clinodactyly. We also measured radiographs to quantify the angle of deviation and the longitudinal lengths of the surgically corrected phalanx and corresponding metacarpal. Clinodactyly was defined as radiographic angulation of 10° or greater in the coronal plane. Recurrence was defined as a final angulation of 10° or greater as well as an increase of at least 10° compared with the immediate postoperative measurement. The primary ratio was defined as the ratio of the length of the primary ossification center of the surgically corrected phalanx to the length of the primary ossification center of the corresponding metacarpal. The secondary
ratio was the ratio of the length of the primary and secondary ossification centers together of the corrected phalanx to those of the metacarpal.

Comparisons were made between preoperative, postoperative, and most-recent follow-up values. Postoperative data was restricted to radiographs taken within three months after surgery. Final follow-up data was initially permitted if radiographs were taken at least one year after surgery. Additional analysis was performed of patients with a minimum of two years clinical and radiographic follow-up.

Results

There was a significant decrease in angulation with surgery and a significant increase in angulation postoperatively (p<0.001; p<0.01). Overall, the mean preoperative and final digital angulation was 40.4° and 17.4°, respectively, when a two-year minimum between the time of surgery and final follow-up measurements was implemented. This resulted in a significant average correction of 23.3° (p<0.001). The postoperative change in angulation was found to be significantly different depending on the surgical technique used. Digits corrected with reverse wedge osteotomies showed little to no change in angulation during the postoperative period. However, digits corrected with closing wedge osteotomies showed a significant increase in angulation between the immediate postoperative and final follow-up measurements (p=0.007). The rate of recurrence was 43.2% (95% CI: 28.7-58.9% with a one year minimum for follow-up; 95% CI: 27.5-60.4% with a two year minimum for follow-up). Postoperative changes in angulation or recurrence were not significantly associated with gender, patient age at the time of
surgery, the type of digit corrected, coexisting congenital syndromes, or the presence of additional hand abnormalities.

The primary ratio decreased significantly with surgery, from 0.35 preoperatively to 0.27 postoperatively (p=0.03). The primary ratio then increased significantly over time to 0.40 when there was a two-year minimum between the time of surgery and final follow-up. There was an insignificant change in primary ratio from immediately after surgery to final follow-up when data as early as one year postoperatively was included. The secondary ratio did not change significantly with surgery or during the postoperative period regardless of whether one or two-year time restrictions were in place. The mean secondary ratio was 0.29 before surgery, 0.25 immediately after surgery, and 0.33 at the time of final follow-up at least two years after surgery.

Conclusions

Surgery to correct clinodactyly effectively decreases angulation of the digit, despite the risk of recurrent deformity over time. Our study did not identify any factors associated with recurrence. However, there was a significant difference in the change in angulation between the immediate postoperative and final follow-up measurements depending on the surgical technique used. Surgery to correct clinodactyly does not hinder postoperative growth of the corrected phalanx.
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INTRODUCTION

It is estimated that 3% of all newborns in the United States are born with some form of congenital difference and that roughly one third of these anomalies affect the musculo-skeletal system (Honein, Paulozzi, Cragan, & Correa, 1999). One population study reported that approximately 0.20% of all children born in Western Australia between 1980 and 1990 were found to have congenital upper limb anomalies (Giele, Giele, Bower, & Allison, 2001). A second population study stated that a congenital upper limb anomaly was present in approximately 0.21% of live births in Stockholm, Sweden, between 1997 and 2007 (Ekblom, Laurell, & Arner, 2010). Upper limb anomalies encompass a wide range of congenital differences, from radial or ulnar deficiencies to the presence of an extra digit or a transverse metacarpal. Clinodactyly is a condition characterized by angulation of a digit or digits in the coronal plane (Berger & Weiss, 2004). The term clinodactyly can be derived from the two Greek words “klenen” and “daktylos,” meaning “to bend” and “finger” (Leung & Kao, 2003).

It has been suggested that anywhere from 1% to 19.5% of children have some degree of clinodactyly in their fingers (Berger & Weiss, 2004; Flatt, 2005). While this seems to contradict the estimate that 0.2% of newborns were found to have congenital upper limb differences, it is important to recognize that there has been debate regarding the magnitude of angulation that constitutes clinodactyly (Berger & Weiss, 2004). In most cases digits are angulated less than ten degrees. Deviation this mild does not usually impair function or range of motion of the digit. In more severe cases, fingers
cross over one another and disrupt normal hand functions. The general consensus is that clinodactyly is truly present when a digit is deviated at least ten degrees from its longitudinal axis in the radioulnar plane (Albright, Xue, Koshy, Orth, & Hollier, 2011). Although digits may be angled towards either the radius or the ulna, clinodactyly typically involves bilateral apex ulnar angulation of the small fingers as a result of a triangular shaped bone known as a delta phalanx (Goldfarb, 2009).

**Growth Plate Involvement**

The cause of clinodactyly can often be traced to an abnormality of the physis, or growth plate. At the time of birth, only one part of the phalanx has ossified. This portion of ossified bone located in the diaphysis is known as the primary ossification center. As the child begins to grow, the secondary ossification center found in the proximal epiphysis also ossifies. Ossification of the secondary ossification center occurs in the proximal phalanges of the hand at around ten to fifteen months of age in girls and between fifteen and twenty-four months of age in boys (Beaty & Kasser, 2010). The secondary ossification centers of the middle and distal phalanges form between ages two and three for girls and ages three and four in boys (Doyle, 2003). Bone that has not yet ossified cannot be seen on radiographs. Longitudinal growth of the phalanges originates at the physis, located between the primary and secondary ossification centers. Eventually the metaphysis and epiphysis of the long bone fuse, thereby closing the growth plate and ending the potential for further longitudinal growth (White & Folkens, 2005).
The growth plate normally lies perpendicular to the longitudinal axis of the phalanx. Congenital clinodactyly is often caused by malalignment of the physis. In some cases, the epiphysis wraps around one side of the diaphysis, joining the proximal and distal ends of the bone. This malformation, known as a longitudinal epiphyseal bracket, restricts normal longitudinal bone growth and forms a triangular bone called a delta phalanx (Figure 1). The terms delta phalanx and longitudinal epiphyseal bracket are often used interchangeably in the scientific literature (Berger & Weiss, 2004). A trapezoidal bone is formed when the bracket is incomplete. The physis wraps partly, but not completely, along the shaft of the bone allowing for a small amount of growth on the shorter side of the phalanx (Figure 2). In the case of both triangular and trapezoidal bones, the articular surfaces on the distal and proximal ends of the phalanx are no longer parallel. The presence of an abnormally shaped phalanx causes deviation at one or both of the interphalangeal joints of the digit (Wolfe, Pederson, Hotchkiss, Kozin, & Cohen, 2010).
Figure 1: Longitudinal Epiphyseal Bracket. This radiograph shows the entirety of the left index finger along with the distal bone of the left thumb. The longitudinal epiphyseal bracket present in the middle phalanx of the index finger clearly wraps around the radial edge of the bone. The delta phalanx causes radial deviation at the distal interphalangeal joint (Courtesy of the Children’s Orthopaedic Surgery Foundation).
Figure 2: Trapezoidal Phalanx. The above radiograph depicts the middle and distal phalanges of the right small finger. The physis of the middle phalanx is not perpendicular to the longitudinal axis of the bone. The abnormal physis results in an affected bone with a trapezoidal shape (Courtesy of the Children’s Orthopaedic Surgery Foundation).

Etiology of Clinodactyly

Clinodactyly can occur by itself, in association with congenital syndromes, or as a result of a traumatic event. Studies examining families with a high prevalence of isolated clinodactyly have suggested that the trait may be inherited in an autosomal dominant fashion with variable penetrance (Albright et al., 2011; Flatt, 2005; Watts & Hooper, 2006). The presence of other congenital hand differences in addition to clinodactyly increases the complexity of the affected hand (Figure 3). Clinodactyly has also been associated with a number of congenital syndromes including Rubinstein-Taybi syndrome,
Down syndrome, Apert syndrome, and Poland syndrome. Children who are born with triphalangeal thumbs commonly have a middle delta phalanx that causes deviation despite the presence of normal articular surfaces of the proximal and distal phalanges (Figure 4) (Berger & Weiss, 2004).

Figure 3: Polysyndactyly and Clinodactyly. Polysyndactyly is a congenital condition that involves the fusion of digits as well as the presence of extra digits. The above radiograph is an example of a left hand with extra phalanges present between fused middle and ring fingers as well as clinodactyly of the index finger (Courtesy of the Children’s Orthopaedic Surgery Foundation).
Figure 4: Triphalangeal Thumb. The radiograph above depicts the lateral view of a right hand with an anteroposterior view of a triphalangeal thumb. The triangular middle phalanx is the source of the digit’s ulnar deviation (Courtesy of the Children’s Orthopaedic Surgery Foundation).

Congenital clinodactyly can usually be attributed to the presence of a delta phalanx. However, an abnormally shaped phalanx with a normal physis can cause clinodactyly as well. A child may develop crooked fingers later in life due to an alteration of the structure of the phalanx or as a result of damage to the growth plate (Ali, Jackson, & Rayan, 2009). A phalanx with an abnormal distal edge can cause clinodactyly despite the presence of a normal growth plate. Angulation can be caused by a bony tumor like an osteochondroma growing on the distal articular surface. An
improperly healed fracture or frostbite may also result in a phalanx with an articular surface that it is no longer perpendicular to the longitudinal axis of the phalanx (Wolfe et al., 2010).

Correcting Clinodactyly with Wedge Osteotomies

Minor angulation typically does not interfere with a digit’s function or range of motion. Due to the fact that most cases of clinodactyly are mild, the majority of patients do not require any corrective surgeries (Berger & Weiss, 2004). Clinically, the degree to which a digit is deviated is measured by physical examination with a goniometer (Jain, Rehman, & Smith, 2010). The angle of deviation can also be determined using radiographs. If the middle phalanx is abnormal, two lines can be drawn through the longitudinal axes of the adjacent proximal and distal phalanges. The angle formed by these two intersecting lines indicates the degree of deviation (Figure 5) (Ali et al., 2009). Surgical treatment is indicated for patients in whom the digital angulation is severe enough to impart functional limitations, such as the inability to pinch or digital overlap compromising grasp (Wolfe et al., 2010).
Clinodactyly does not resolve spontaneously, nor does it respond to nonoperative treatments like splinting (Jones, 1964). The main surgical options for deformity correction are either corrective osteotomy or physiolysis. In a closing wedge osteotomy, a wedge of bone is removed from the longer, convex side of the phalanx (Figure 6). This operation is the most simple and straightforward type of wedge osteotomy. However, by removing a section of bone, the digit is shortened. This is not ideal when trying to preserve digital length (Wolfe et al., 2010).
Figure 6: Closing Wedge Osteotomy. The left picture shows the wedge that will be removed from the convex side of the abnormal bone in a closing wedge osteotomy. The right picture shows how the bone is realigned after the procedure and stabilized with pins while it heals (Figure from Flatt, 2005).

Reverse and opening wedge osteotomies help preserve the length of a digit. A reverse wedge osteotomy involves removing a wedge of bone from one side of the abnormal phalanx, rotating the wedge 180 degrees in the coronal plane, and inserting it into the other side of the phalanx (Figure 7). This technique corrects the angular deformity by both shortening the longer side and lengthening the shorter side. A reverse wedge osteotomy is more technically challenging than a closing wedge osteotomy and can be especially difficult in young children with small bones (Wolfe et al., 2010). An opening wedge osteotomy requires that a cut be made into the shorter side of the bone so that a wedge of bone can be inserted, lengthening the short side of the phalanx without any shortening of the long side (Figure 8). An opening wedge osteotomy is more challenging than a closing wedge, but has the advantage of creating a barrier between the distal and proximal ends of the epiphyseal bracket. While this sort of lengthening is ideal
in a child with an extremely short phalanx, a source for a bone graft is not always readily available (Berger & Weiss, 2004).

**Figure 7: Reverse Wedge Osteotomy.** The left picture depicts a middle phalanx with a complete longitudinal epiphyseal bracket. The middle and right pictures show how a wedge is removed, rotated, and reinserted back into the phalanx in order to achieve proper alignment of the digit (Figure from Flatt, 2005).
Figure 8: Opening Wedge Osteotomy. The right figure (A) shows a trapezoidal phalanx prior to correction. The horizontal dotted line drawn through the bone represents where the cut will be made. The left picture (B) depicts the phalanx with the newly added wedge of bone and two pins holding it in place (Figure from Wolfe et al., 2010).

Correcting Clinodactyly with the Physiolysis Procedure

The physiolysis procedure is an alternative to wedge osteotomies. Instead of cutting into the diaphysis of the bone, the portion of the aberrant epiphysis and physis along the longitudinal axis is resected so that the diaphysis is no longer completely bracketed. A fat graft is inserted in place of the removed bone in order to maintain this separation and avoid recurrent bony consolidation (Berger & Weiss, 2004) (Figure 9). The goal of the physiolysis procedure is to divide the bracket and thus release the tether so that the previously restricted, shorter side of the phalanx may grow and catch up in length with the rest of the bone. This procedure must be performed at an early age in
order to allow sufficient time for longitudinal growth of the digit to occur naturally (Al-Qattan, 2007).

Figure 9: Physiolysis. A longitudinal epiphyseal bracket is clearly visible around the phalanx depicted on the left. A physiolysis procedure involves the resection of the middle portion of the bracket, which is replaced by a fat graft, seen on the right (Figure from Berger & Weiss, 2004).

One of the challenges of physiolysis is that the patient must present with clinodactyly at an early enough age for this to be a feasible option. A retrospective study conducted by Caouette-Laberge et al. (2002) showed greater correction of deviation when a phalanx underwent a physiolysis procedure before age six. Berger and Weiss (2004) stated that a physiolysis procedure should be performed by the age of four in order to ensure adequate time for growth. Ali et al. (2009) goes as far as to suggest that the physiolysis procedure should be executed at the age of three. While this surgical
technique is most effective in young children, one must keep in mind that it is difficult to operate on patients younger than four years of age because their phalanges are still very small.

**Correcting Clinodactyly with Other Surgical Techniques**

Two other corrective techniques used less frequently are the removal of the entire delta phalanx and the fusion of two bones at an interphalangeal joint. The excision of a delta phalanx is common among patients who have triphalangeal thumbs. An extra middle bone adds unnecessary length to the thumb and can be removed as long as the articular surfaces of the proximal and distal bones align correctly. Fusion of the delta phalanx with an adjacent phalanx is a viable option if this will help improve the stability of the digit (Wolfe et al., 2010).

**Age of Corrective Surgery**

The recommended age to operate on a patient with clinodactyly depends on the type of procedure being performed and which digit is undergoing correction. When performing a wedge osteotomy on a digit other than the thumb, it is best to delay the surgery so that the phalanx can reach an acceptable length and size (Wolfe et al., 2010). As stated before, the physiolysis technique is optimally performed when a child is younger than the age of six (Caouette-Laberge et al., 2002).

Clinodactyly present in thumbs is usually severe enough that it cannot be corrected with a physiolysis procedure and instead requires an osteotomy (Berger &
Weiss, 2004). When operating on patients with Rubinstein-Taybi syndrome, Wood and Rubinstein (1987) recommended that surgery to correct thumb clinodactyly be performed before a child is four years old, preferably before age two. This way, the thumb is relatively straight and “functional during the initial development of hand-eye coordination” (p. 166), thereby allowing the child to develop fine motor skills at an appropriate rate (Wood & Rubinstein, 1987). Jain et al. (2010) proposes waiting until after three and a half years of age to operate so that the bones of the thumb are larger, making a wedge osteotomy easier to perform.

**Choosing Between Operative Techniques**

When choosing between different treatments, it is important to consider the patient’s age along with the eventual function, length, and appearance of the digit. If a relatively older patient were to undergo corrective surgery, a wedge osteotomy would be preferable to the physiolysis technique (Al-Qattan, 2007). A wedge osteotomy may also be a better choice if immediate correction of the digit is necessary. If time is not an issue and the patient is young enough, a physiolysis procedure would allow the phalanx to continue growing and achieve a longer final length (Berger & Weiss, 2004). A triphalangeal thumb with clinodactyly due to a middle delta phalanx could theoretically be corrected with a wedge osteotomy. However, choosing to excise the entire delta phalanx would help correct the digit’s deviation and abnormal length simultaneously (Berger & Weiss, 2004; Wolfe et al., 2010).
The presence of other abnormalities or syndromes should also be taken into account when choosing a surgical technique. Children with Rubinstein-Taybi syndrome have abnormally short, broad thumbs that are considerably deviated towards the radius (Wood & Rubinstein, 1987). Ideally, these thumbs would be corrected with either an opening or reverse wedge osteotomy in order to realign the digits while maintaining their length. Preservation of the length of a thumb is important in order to allow for optimal hand function in the future. It is not very common, but there are cases that report that closing wedge osteotomies were performed to correct deviation of thumbs in patients with Rubinstein-Taybi syndrome. While there is some loss of digital length with this surgical technique, a closing wedge osteotomy is less complicated than other wedge osteotomies. Patients with Rubinstein-Taybi syndrome often have trouble with anesthesia due to the cranio-facial and cardiac abnormalities that accompany this syndrome (Twigg & Cook, 2002). A closing wedge osteotomy is simple, effective, and minimizes the amount of time that patients with Rubinstein-Taybi syndrome are under anesthesia (Jain et al., 2010). Angulation in fingers is often corrected with closing wedge osteotomies because the preservation of finger length is not as critical as the conservation of thumb length in order to maintain allow function.

**Measuring Bone Lengths**

A few studies in the late 1960s and 1970s attempted to establish ratios of the bones in the hand by measuring their longitudinal lengths. Poznanski et al. measured the lengths of metacarpals and phalanges in patients who had congenital syndromes that were
known to also cause distinct malformations of the hand. The researchers hoped to be able to confirm the presence of certain congenital syndromes by comparing the relative lengths of particular bones in the hand (Poznanski, Garn, Nagy, & Gall, 1972). In addition, Garn et al. measured the longitudinal length of the bones in the hand of healthy subjects on anteroposterior views of radiographs (Table 1). Their study specifically mentioned that the epiphysis was included whenever visible on radiographs (Garn, Hertzog, Poznanski, & Nagy, 1972). Furthermore, Parish (1966) measured longitudinal bone lengths by drawing a straight line between the midpoints of the distal and proximal epiphyses. This line did not always run through the middle of the diaphysis (Figure 10). Despite the absence of a standardized method to measure longitudinal bone length, the techniques proposed by Garn et al. and Parish provide guidelines for the measurement of the full length of curved or abnormally shaped bones as well as straight bones.

<table>
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Figure 10: Measuring Longitudinal Bone Length. The longitudinal axis drawn through the fifth metacarpal is used to measure its length. This line connects the midpoints of each end of the bone (Figure from Parish, 1966).

Complications of Corrective Surgeries

While major complications are uncommon following corrective surgery for clinodactyly, a few minor complications have been reported in the published literature. Wedge osteotomies have been noted to result in joint stiffness (Wolfe et al., 2010). A newly corrected phalanx that heals in an incorrect position may also lead to malrotation of the digit (Chang & Neligan, 2012). Another potential complication of wedge osteotomies is overcorrection of the initial deformity. This is more common in young children whose bones are still quite small (Wolfe et al., 2010). In a study of 13 thumbs corrected for clinodactyly in Rubinstein-Taybi syndrome, Jain et al. did not report a single case of infection or malunion. The only immediate complication noted was the
formation of a cyst where a pin was holding the bones in their corrected position (Jain et al., 2010).

Recurrence of deformity is a well-documented—though less immediate—complication of surgery for clinodactyly. Ali et al. (2009) defined recurrence as a degree of angulation “greater than initially corrected deformity” (p. 917). Skin that is stretched too tightly as a result of an opening wedge osteotomy can potentially cause a recurrence of deviation. If the degree of angulation increases and causes functional limitations or aesthetic problems, a second operation may be performed to again try to realign the digit (Chang & Neligan, 2012).

What Remains to Be Studied

While the orthopedic hand surgery literature contains many reports describing surgical techniques for clinodactyly correction, there is still a paucity of longer-term clinical data and a number of questions that remain unanswered. Many studies chose to focus on only one type of digit and exclude either thumbs or fingers (Al-Qattan, 2007; Ali et al., 2009). It would be beneficial to have a direct comparison between the correction and recurrence of deviation of different types of digits. Other studies have limited their inclusion criteria to patients with isolated clinodactyly, excluding any patients with an associated syndrome present (Caouette-Laberge et al., 2002). Differential analysis would allow similarities and differences in expected surgical results to be compared. Finally, while many studies report the presence of recurrence, little is known about factors that are associated with recurrent deformity.
There is no scientific literature providing quantitative data regarding the lengths of phalanges before and after surgical correction of clinodactyly. As stated before, the preservation of length in thumbs is especially important so that a child may develop proper hand function. It would be useful to have information pertaining to the change in digital length that occurs immediately with surgery as well as postoperatively as the child continues to grow. Our study aims to explore factors associated with recurrence as well as changes in phalangeal length. With more information about the change in angulation and digital length postoperatively, physicians will also be able to better inform patients and their families regarding the anticipated results of surgical treatment.

Specific Aims

The objective of this study is to assess the change in angulation with corrective surgery as well as the rate of recurrent deformity in digits following clinodactyly surgery. This study will also examine the change in phalangeal length that occurs immediately after surgery and postoperatively as the patient grows. Specifically,

1. Patients in the Boston Children’s Hospital database that had surgical correction of clinodactyly in either fingers or thumbs between January 1st, 1990, and December 1st, 2013, will be selected for analysis.

2. Angulation of a digit will be measured using radiographs taken preoperatively, postoperatively, and at the final follow-up visit. The length of both the abnormal phalanx and the corresponding metacarpal will be measured using these same radiographs.
3. We will conduct a sub-analysis in order to determine whether preexisting syndromes, the presence of additional hand abnormalities, the type of digit affected, or the patient’s age at the time of surgery are significantly associated with postoperative changes in bone length and angulation.

Our hypotheses are that:

1. Surgery to correct clinodactyly is safe, effective, and rarely results in complications such as infection and nonunion
2. Thumbs are operated on at an earlier age compared with fingers
3. The rate of recurrence will be higher in patients with a genetic syndrome or another hand abnormality in addition to clinodactyly
4. Longitudinal growth is preserved in the majority of digits after surgical correction of clinodactyly. Patients who have a congenital syndrome will have digits that grow less than patients who do not have a congenital syndrome.

This study will help us understand the factors affecting long-term results of postoperative growth and angulation in digits with surgically corrected clinodactyly.
METHODS

Our retrospective study utilized data found in patient medical records at Boston Children’s Hospital. Electronic medical records were searched to identify patients who had operative reports between January 1st, 1990, and December 1st, 2013, that included key words suggesting that surgical correction of clinodactyly had taken place. We searched for the phrases “delta phalanx,” “clinodactyly,” and “longitudinal epiphyseal bracket” each paired with either the word “hand” or “finger.” Although our search identified 101 patients, only 62 of these patients met all of our inclusion criteria and thus were included in our analysis.

Our study focused solely on patients who had surgery with the purpose of correcting clinodactyly in either fingers or thumbs. For this reason, some of the patients identified by our search could not be included. Digits with clinodactyly were excluded if they did not undergo any surgical correction. In addition, the surgery performed must have had the intention of correcting clinodactyly. Realignment of a digit can occasionally occur as a secondary result of a different operation. For example, deviation of a digit that is fused with an adjacent digit by soft tissue could potentially be corrected with syndactyly release. However, the goal of the surgery was to separate the two digits, not to fix the deviation of the affected digit. Therefore, digits like the one in this example were excluded.

As stated earlier, clinodactyly may either be present from birth or occur as a result of trauma. Our study was interested in congenital clinodactyly. Patients who presented
with clinodactyly of a digit that had been previously fractured were excluded because it was not possible to determine whether the deviation was due to improper healing of the fracture or if the angulation was present prior to the injury. We similarly excluded digits that were affected by a transverse bone or those in which the clinodactyly was secondary to osteochondroma or other neoplastic conditions. Again, these digits were excluded because we could not say whether or not the deviation would have occurred if these other abnormalities had not been present.

Clinodactyly was defined in our study as radiographic deviation of 10° or greater in the coronal plane. If the preoperative angle of deviation measured on radiographs was less than 10°, the digit was excluded. Furthermore, the presence of a delta phalanx alone was not enough to meet our inclusion criteria. A digit containing a delta phalanx also needed to have at least 10° of deviation in order to be included in the study. Recurrence was defined as a final angulation greater than 10° as well as an increase of 10° or more from the immediate postoperative measure of deviation. Digits were excluded if the deviation visible in the coronal plane was clearly due to the camptodactyly. Camptodactyly is a condition in which digits are permanently fixed in a flexed position. Three digits affected by both camptodactyly and clinodactyly were included in this study because their deviation in the coronal plane did not seem to be a result of their flexion deformity.
Collection of Qualitative Data

General patient information was collected from medical records. This included gender, date of birth, and ethnicity. The date of initial examination, whether or not the affected bone was a delta phalanx, the presence of any congenital syndromes or associations, and the presence of other congenital hand abnormalities were also recorded. A patient was said to have an additional hand anomaly regardless of whether or not the digit with clinodactyly was involved. We also reported if there was a positive or negative family history of clinodactyly. Many patients had multiple congenital hand differences. When describing the patient’s family history, medical records rarely distinguished between different hand abnormalities. For this reason, patients with multiple congenital hand differences were only noted to have a positive family history of clinodactyly if clinical notes specifically identified or described the condition.

Additional data was collected from operative reports, including which hand was affected, which digit was operated on, and the segment of the digit that was surgically corrected. The type of digit that was operated on was almost always easily identified. The only exception was one patient who had complex syndactyly of the thumb and index finger. Since this digit was eventually reconstructed to form a thumb, it was grouped with other thumbs for our analysis. The date of the surgery, the type of surgery performed, and the dates of postoperative follow-up visits were also recorded.
Collection of Quantitative Data

The main goal of our study was to analyze the changes in angulation and bone length both immediately after surgery and at longer-term follow-up. Length and angle measurements were taken from the first available radiograph, the last preoperative radiograph, the first postoperative radiograph, and the final postoperative radiograph available (Figure 1). In order to ensure that we were accurately measuring the initial postoperative values, only radiographs taken within three months of surgery were used for “first postoperative” measurements. Additionally, radiographs that were taken less than one year after surgery were excluded in order to allow time for postoperative change to occur. A sub-group analysis was performed of patients with a minimum of two years between the time of surgery and final follow-up. If a digit was operated on a second time to correct clinodactyly, then the postoperative follow-up period was considered to be the time between the two surgeries. This means that the last available radiograph before the second surgery took place was considered to be the final postoperative radiograph from the first procedure.
Figure 11: Flow Chart of Measurements Taken for Each Digit. There are four different time periods at which measurements are taken, shown chronologically on the left from top to bottom. At each of the four time periods, radiographic measurements are taken. These three sets of measurements are shown on the right.

Patients who did not have any radiographs available were excluded entirely from our study. Digits with either one radiograph or only two preoperative radiographs were included in all qualitative analyses, but could not be included in the quantitative analyses of changes in bone length and angulation. The reason for this exclusion is that there were no postoperative values to compare with the preoperative data available. Changes in angulation and bone length could be analyzed in digits with two or more radiographs as long as there was at least one postoperative radiograph.
Two digits were each corrected by the fusion of two phalanges. One digit that was corrected with joint fusion could be included in our analysis of the change in bone length. The other digit corrected in this manner was excluded from our bone length analysis because the patient’s growth plates had already closed at the time of surgery, thus eliminating the potential for postoperative growth. However, this digit could still be included in the analysis of changes in angulation. Digits corrected with bone excision were also excluded from the analysis of changes in bone length, but included in the analysis of changes in angulation.

When possible, measurements were made from digital anteroposterior radiographs of the hand using Synapse, medical imaging software manufactured by Fujifilm Medical Systems U.S.A., Inc. (Hanover Park, IL). For patients whose radiographs were taken prior to the institution’s transition to a computerized radiology system, radiographs were requested from storage and subsequently digitized. Once digitized, the angle of deviation could be measured on these radiographs electronically. However, the length of bones from older radiographs had to be measured by hand.

**Radiographic Measurements of Length**

The radiographic visibility of each particular portion of a phalanx depends on the age of the patient. The secondary ossification center is not visible in very young patients, and the border between the primary and secondary ossification centers cannot always be distinguished after the growth plate has closed. For this reason, two sets of measurements were taken: one to measure the length of the primary ossification center
alone and one to measure the length of both the primary and secondary ossification centers together. The length of the primary ossification center was measured by drawing a line through the midpoints of each end of that portion of the bone (Figure 11). A similar line connecting the midpoints of each articular surface of the phalanx was used to measure the bone’s entire length (Figure 12).

**Figure 12: Measuring the Length of the Primary Ossification Center.** The above radiograph shows the anteroposterior view of the proximal phalanx of a left thumb. The radial deviation through the interphalangeal joint is partly visible. A line is drawn to connect the midpoints of the distal and proximal ends of the primary ossification center in order to make the first measurement of bone length (Courtesy of the Children’s Orthopaedic Surgery Foundation).
**Figure 13: Measuring the Length of the Primary and Secondary Ossification Centers.** A second line is drawn to measure the full length of the same proximal phalanx. This line connects the midpoints of each articular surface (Courtesy of the Children’s Orthopaedic Surgery Foundation).

This is consistent with the technique used by Parish (1966) to measure the full length of normal bones in the hand. However, determining the longitudinal axis of abnormally shaped bones is not as simple. The line used to measure the abnormal bone’s length was drawn so that it ran through the midpoints of the two articular surfaces of the delta phalanx. We then calculated two longitudinal length ratios. The ratio of the length of the primary ossification center of the surgically corrected phalanx to the length of the primary ossification center of the metacarpal was defined as the primary ratio. The secondary ratio included the values measuring the primary and secondary ossification centers together of the abnormal phalanx and the corresponding metacarpal. By creating
two ratios, we hoped to eliminate differences between bone lengths due to age and changing skeletal maturity.

**Radiographic Measurements of Angles**

The angle of deviation in the coronal plane was constructed using the same longitudinal lines that measured the full length of a phalanx. A line was drawn longitudinally through each of the bones adjacent to the abnormal bone. For example, the angulation of a digit with an abnormal middle phalanx was defined as the angle between the longitudinal axes of the proximal and distal phalanges (Figure 13). Angulation in digits with an abnormal distal phalanx was measured in a similar manner since these patients often had a somewhat irregular middle phalanx as well. Caouette-Laberge et al. used this same technique in order to measure angulation (2002).
Figure 14: Measuring the Angle of Deviation. A line is drawn through the longitudinal axes of the two bones adjacent to the abnormal middle phalanx. A digit without any angulation would form an angle of 180° on a radiograph. Since the angle formed is 154°, the digit is angled 26° in the coronal plane (Courtesy of the Children’s Orthopaedic Surgery Foundation).

The angle formed between the longitudinal axes of the proximal and distal phalanges measured the total angulation present in the digit. The total angulation of the digit included deviation within the proximal and distal interphalangeal joints along with deviation present within the bones themselves. The angle of deviation for a digit with an abnormal proximal phalanx was measured in one of two ways. If the longitudinal axis was easily identified, then the angle was measured between the proximal phalanx and the...
phalanx distal to it. In cases in which the normal longitudinal axis of the proximal phalanx was not easily identified, the angle of deviation was defined by the angle formed between the longitudinal axes of the corresponding metacarpal and phalanx distal to the proximal phalanx.

**Statistical Methods**

Our study measured angulation and bone length ratios of digits surgically corrected for clinodactyly immediately before surgery, within three months after surgery, and at least one year postoperatively. We then calculated the immediate change in these values with surgery and the change from the immediate postoperative values to those measured at the time of the patient’s final follow-up. The data was then divided into subgroups in order to determine whether or not the changes in angulation and bone length ratios during the postoperative period were significantly different depending on certain aspects of the patient and the digit corrected. This sub-analysis examined the difference in the effect of treatment across gender, age at the time of surgery, preexisting syndromes, additional hand abnormalities, surgical techniques, and the type of digit that was corrected.

There were a number of factors affecting our quantitative data including variation in patient age, the magnitude of initial deformity, and time between measurements for different patients. Our study also needed to take into account that there were repeated measures on the same subjects over time. Additionally, there was data missing either because radiographs were not available or because certain aspects of a bone could not be
distinguished on radiographs that were accessible. We analyzed the changes in angulation and bone length ratios using piecewise linear mixed models in order to take all of these factors into account.

The piecewise nature of the model takes into account our expectation that there would be a difference between changes with surgery and changes during the postoperative period. The change in measurements with surgery made up the first slope of the piecewise linear mixed models, while the second slope consisted of the change between the immediate and final postoperative values. The correlation structure for each model was chosen depending upon which fit the data best. For the analysis of changes in angulation and primary ratios, a compound symmetry correlation structure was used. An autoregressive correlation structure was used for the analysis of the change in secondary ratios. There was no deviation from the assumptions made by each model upon residual analysis.

The overall rate of recurrence was estimated along with a 95% confidence interval. Possible factors associated with recurrence were analyzed using univariable and multivariable logistic regression. Odds ratios with 95% confidence intervals were also calculated for factors significantly associated with recurrence. All tests in our study were two-sided, and p-values less than 0.05 were considered significant.
RESULTS

We were able to identify a total of 89 digits among 62 patients who fit our inclusion criteria and had at least one radiograph available. Three of the eight patients with a genetic syndrome had Russell-Silver syndrome. Other congenital syndromes present in our study included Apert syndrome, Townes-Brocks syndrome, Von Willebrand disease, Raynaud’s phenomenon, and Pfeiffer syndrome. One patient included in our study had two syndromes. The most common secondary hand abnormalities were syndactyly and polydactyly. Additional hand abnormalities included brachydactyly, camptodactyly, cleft hand, aphalangia, macrodactyly, transverse bones, metacarpal synostosis, and swan necking of fingers. A summary of the demographics of our patients and their affected digits is presented in Table 2.
<table>
<thead>
<tr>
<th>Patient characteristic (N=62)</th>
<th>N (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age at presentation (years; mean ± SD)</td>
<td>2.6 ± 3.74</td>
</tr>
<tr>
<td>Gender (% male)</td>
<td>40 (65%)</td>
</tr>
<tr>
<td>Race/Ethnicity</td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>46 (74%)</td>
</tr>
<tr>
<td>African American</td>
<td>2 (3%)</td>
</tr>
<tr>
<td>Asian</td>
<td>3 (5%)</td>
</tr>
<tr>
<td>Hispanic/Latino</td>
<td>3 (5%)</td>
</tr>
<tr>
<td>Other/unknown</td>
<td>8 (13%)</td>
</tr>
<tr>
<td>Syndrome</td>
<td>8 (13%)</td>
</tr>
<tr>
<td>Additional hand abnormality</td>
<td>39 (63%)</td>
</tr>
<tr>
<td>Side</td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>20 (32%)</td>
</tr>
<tr>
<td>Right</td>
<td>19 (31%)</td>
</tr>
<tr>
<td>Bilateral</td>
<td>23 (37%)</td>
</tr>
</tbody>
</table>

| Condition and treatment characteristic (N=89) |        |
| Age at surgery (years; mean ± SD) |        |
| Thumb | 4.8 ± 3.68 |
| Finger | 2.7 ± 3.08 |
| Index | 5.8 ± 3.53 |
| Digit |        |
| Thumb | 30 (34%) |
| Triphalangeal | 10 (33%) |
| Finger | 59 (66%) |
| Index | 19 (32%) |
| Middle | 5 (8%) |
| Ring | 5 (8%) |
| Small | 30 (51%) |
| Delta Phalanx | 76 (85%) |
| Segment |        |
| Proximal | 35 (39%) |
| Middle | 54 (61%) |
| Surgery type |        |
| Opening wedge | 9 (10%) |
| Closing wedge | 32 (36%) |
| Reverse wedge osteotomy | 32 (36%) |
| Excision of entire bone | 11 (12%) |
| Other* | 5 (6%) |

*Includes physiolysis, joint fusion, and non-wedge osteotomies
Patients were significantly different ages at the time of operation depending on the type of digit corrected (p<0.001). On average, patients were 2.7 years old when a thumb was surgically corrected and 5.8 years old when a finger was corrected. Of the 89 digits surgically corrected, there were five digits that were noted to have complications. Two patients had a pin that loosened or fell out, one patient had a stitch abscess, one patient had a minor reaction to the sutures, and one patient had scar thickening that caused radial deviation postoperatively. None of these complications required further surgical care. A second surgery was performed on five other digits that had recurrent deformity.

Of the 89 digits in 62 patients that were operated on, 27 digits in 22 patients did not have available follow-up radiographs. An additional 16 digits in 14 patients lacked follow-up data beyond one year after surgery. Thus, there were 46 digits in 31 patients with at least one year of follow-up data and 39 digits from 26 patients with a radiograph available at least two years after surgery. The mean values of the angle of deviation, primary ratio, and secondary ratio at different points in time are shown in Tables 3A and 3B.

<table>
<thead>
<tr>
<th>Table 3A. Outcome Measures by Time Point.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Months from surgery</td>
</tr>
<tr>
<td>Angulation (degrees)</td>
</tr>
<tr>
<td>Primary ratio</td>
</tr>
<tr>
<td>Secondary ratio</td>
</tr>
</tbody>
</table>
Table 3B. Outcome Measures by Time Point.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Final follow-up (Minimum 1 year)</th>
<th>Final follow-up (Minimum 2 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean ± SD</td>
</tr>
<tr>
<td>Months from surgery</td>
<td>46</td>
<td>71.8 ± 46.39</td>
</tr>
<tr>
<td>Angulation (degrees)</td>
<td>45</td>
<td>17.5 ± 12.12</td>
</tr>
<tr>
<td>Primary ratio</td>
<td>18</td>
<td>0.37 ± 0.21</td>
</tr>
<tr>
<td>Secondary ratio</td>
<td>36</td>
<td>0.33 ± 0.18</td>
</tr>
</tbody>
</table>

Changes in Angulation with Surgery

Angulation decreased significantly with surgery from a mean preoperative angle of 40.4° to an average angle of 9.2° immediately after surgery (p<0.001). The mean angle of deviation was 17.4° at the time of final follow-up when data included was a minimum of two years after surgery. When comparing preoperative with final follow-up radiographs, there was a significant mean decrease in angulation of 23° when follow-up data was at least one year after surgery and a significant mean decrease of 23.3° for patients with follow-up data at least two years after surgery (p<0.001).

Postoperative Changes in Angulation

Overall there was a significant increase in angulation between the time of the immediate postoperative and final follow-up measurements (Figure 15). This was true regardless of whether the final data was restricted to a minimum of one or two years after surgery (p=0.002; p=0.003). Angulation increased from an average of 9.2° immediately after surgery to 17.4° when final follow-up data was restricted to a minimum of two years after surgery.
Figure 15: Change in Angulation Over Time. The above graph shows the results of piecewise linear mixed models for angulation by digit type measured preoperatively, postoperatively and at most-recent follow-up. There was at least two years between the time of surgery and final follow-up data. There was a significant decrease with surgery and a significant increase between the postoperative and final follow-up values. There were no significant differences between thumbs and fingers.

A sub-analysis of this data was then conducted in order to determine whether there were any factors associated with the change in angulation between the time of the immediate postoperative and final follow-up radiographs. There was no significant difference in the change in angulation during this period of time based on the patient’s gender, patient’s age at the time of surgery, type of digit, presence of a second hand anomaly, or presence of a congenital syndrome.

However, the change in angulation between the immediate postoperative and final follow-up dates proved to be significantly different depending on the type of surgery performed. This was true regardless of whether final follow-up data was restricted to one or two years after surgery (p=0.02; p=0.005). Using post hoc comparisons, we were able to determine that digits corrected with reverse wedge osteotomies showed little to no
change in angulation when comparing immediate postoperative and final follow-up measurements. Digits corrected with closing wedge osteotomies, however, showed a significant increase in angulation when comparing immediate postoperative and final follow-up measurements. These digits increased an average of 9.7° during this time period when final follow-up data was restricted to one year after surgery and 9.1° when restricted to at least two years postoperatively (p=0.007; p=0.04).

Due to the small sample size of digits corrected with opening wedge osteotomies, bone excision, and other surgical techniques, the significance of the change in angulation between the immediate postoperative and final follow-up radiographs for these digits could not be determined. On average, digits that were corrected with an opening wedge osteotomy, bone excision, and other type of surgery increased 7.5°, 15.1°, and 17.3°, respectively, when follow-up was at least one year after surgery. When final follow-up data was restricted to a minimum of two years after surgery, there was a mean increase of 9.1° for opening wedge osteotomies, 31.8° when a bone was excised, and 15.5° for other surgical corrections. The change in angulation for digits corrected with various surgical techniques is shown in Figure 16.
Figure 16: Change in Angulation for Different Surgical Techniques. This graph shows the results of piecewise linear mixed models for angulation by surgery type measured preoperatively, postoperatively and at the final follow-up date available at least two years after surgery.

Recurrence

An increase in angulation does not equate with recurrence. As stated before, our definition of recurrence was a final angulation of $10^\circ$ or greater along with an increase of at least $10^\circ$ from the immediate postoperative angle of deviation. There were 19 digits that met our criteria for recurrence after surgical correction. There did not appear to be a significant association between recurrence and any of the factors we considered in our study. Table 4 shows the association of various characteristics with recurrence for patients with at least one year between the time of surgery and the final follow-up data.
Information about recurrence with a minimum of two years between surgery and the time of final follow-up is shown in Table 5.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Recurrence (n = 19)</th>
<th>No recurrence (n = 25)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
<td></td>
</tr>
<tr>
<td>Age at presentation</td>
<td>2.6 ± 2.80</td>
<td>2.2 ± 2.77</td>
<td>0.62</td>
</tr>
<tr>
<td>Age at surgery</td>
<td>5.4 ± 3.26</td>
<td>4.4 ± 2.96</td>
<td>0.30</td>
</tr>
<tr>
<td>Thumb</td>
<td>4 (21%)</td>
<td>6 (24%)</td>
<td>0.82</td>
</tr>
<tr>
<td>Syndrome</td>
<td>2 (11%)</td>
<td>4 (16%)</td>
<td>0.60</td>
</tr>
<tr>
<td>Abnormality</td>
<td>16 (84%)</td>
<td>15 (60%)</td>
<td>0.09</td>
</tr>
<tr>
<td>Abnormality or syndrome</td>
<td>16 (84%)</td>
<td>18 (72%)</td>
<td>0.34</td>
</tr>
<tr>
<td>Surgery type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Opening wedge</td>
<td>0 (0%)</td>
<td>1 (4%)</td>
<td>0.16</td>
</tr>
<tr>
<td>Closing wedge</td>
<td>10 (53%)</td>
<td>5 (20%)</td>
<td></td>
</tr>
<tr>
<td>Reverse wedge osteotomy</td>
<td>4 (21%)</td>
<td>15 (60%)</td>
<td></td>
</tr>
<tr>
<td>Excision of entire bone</td>
<td>3 (16%)</td>
<td>3 (12%)</td>
<td></td>
</tr>
<tr>
<td>Other*</td>
<td>2 (11%)</td>
<td>1 (4%)</td>
<td></td>
</tr>
</tbody>
</table>

*Other surgeries included physiolysis, joint fusion, and other types of osteotomies
Table 5. Characteristics by Recurrence with Minimum Two-Year Follow-up (N=44).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Recurrence (n = 16)</th>
<th>No recurrence (n = 21)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age at presentation</td>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
<td></td>
</tr>
<tr>
<td>Age at surgery</td>
<td>2.6 ± 2.93</td>
<td>2.6 ± 2.89</td>
<td>0.95</td>
</tr>
<tr>
<td>Thumb</td>
<td>5.6 ± 3.53</td>
<td>4.7 ± 3.00</td>
<td>0.42</td>
</tr>
<tr>
<td>Syndrome</td>
<td>3 (19%)</td>
<td>4 (19%)</td>
<td>0.98</td>
</tr>
<tr>
<td>Abnormality</td>
<td>2 (13%)</td>
<td>4 (19%)</td>
<td>0.60</td>
</tr>
<tr>
<td>Abnormality or syndrome</td>
<td>14 (88%)</td>
<td>15 (71%)</td>
<td>0.06</td>
</tr>
<tr>
<td>Surgery type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Opening wedge</td>
<td>0 (0%)</td>
<td>1 (5%)</td>
<td>0.75</td>
</tr>
<tr>
<td>Closing wedge</td>
<td>8 (50%)</td>
<td>4 (19%)</td>
<td></td>
</tr>
<tr>
<td>Reverse wedge osteotomy</td>
<td>4 (25%)</td>
<td>13 (62%)</td>
<td></td>
</tr>
<tr>
<td>Excision of entire bone</td>
<td>3 (19%)</td>
<td>2 (10%)</td>
<td></td>
</tr>
<tr>
<td>Other*</td>
<td>1 (6%)</td>
<td>1 (5%)</td>
<td></td>
</tr>
</tbody>
</table>

*Other surgeries included physiolysis, joint fusion, and other types of osteotomies

The rate of recurrence was 43.2%. The 95% confidence interval is between 28.7% and 58.9% when the final follow-up data is a minimum of one year after surgery and between 27.5 and 60.4% when the final follow-up data is at least two years after surgery.

Changes in Primary and Secondary Ratios

There was a significant decrease in the primary ratio with surgery from 0.35 preoperatively to an immediate postoperative ratio of 0.27 (p=0.03). The change in the primary ratio was not significant when comparing immediate postoperative measurements with those at the time of final follow-up when measurements were at least
one year after surgery. However, the primary ratio did increase significantly from immediately after surgery to 0.40 at the time of final follow-up when there was a minimum of two years between surgery and the final follow-up data (p=0.04) (Figure 17). There was no significant change in the value of the secondary ratio between the preoperative and immediate postoperative measurements. A ratio that does not significantly change indicates that either the phalanx and the metacarpal grew at the same rate or that neither bone grew and therefore maintained a steady ratio. The change in secondary ratio between the immediate postoperative and final follow-up measurements was also not significant regardless of whether final follow-up data was a minimum of one or two years after surgery (Figure 18).

![Graph showing change in primary ratio over time](image)

**Figure 17: Change in Primary Ratio Over Time.** The above graph shows the results of a piecewise linear mixed model for the primary ratio measured preoperatively, postoperatively and at most-recent follow-up at least two years after surgery. Both the decrease with surgery and the postoperative increase were significant (p=0.03; p=0.04).
Figure 18: Change in Secondary Ratio Over Time. The above graph shows a piecewise linear mixed model for the secondary ratio measured preoperatively, postoperatively and at most-recent follow-up at least two years after surgery. Neither the decrease with surgery nor the postoperative increase in the secondary ratio was significant.

There were no significant differences in the change of either ratio between immediate postoperative and final follow-up measurements across gender, age at the time of surgery, type of digit, presence of a second hand anomaly, presence of a congenital syndrome, or the type of surgery performed. The lack of significance is present with both one and two year minimums between the date of surgery and the date of the final follow-up radiographic data.
DISCUSSION

Safety and Effectiveness of Surgery

Our initial hypothesis was that surgery to correct clinodactyly is safe, effective, and results in few complications. In our study there was not a single case of nonunion or infection noted. Four of the five complications reported could be corrected by nonsurgical means. The fifth complication, scar thickening, was not corrected. Our data supports the claim that the surgical correction of clinodactyly is relatively safe and leads to few complications.

The question of whether or not this surgery is effective is much more complex. There was a statistically significant decrease in angulation with surgery (p<0.001). Considering this analysis alone, surgery effectively reduced the degree of angulation in digits with clinodactyly. However, there was also a significant increase in angulation postoperatively (p<0.01). Of all the digits that were surgically corrected, 43.2% met our definition of recurrence (95% CI: 27.5%-60.4% with a two year minimum for final follow-up data). Despite the significant postoperative increase in angulation, the angle of deviation of a digit on average decreased 23° from the preoperative to final follow-up radiographs. As a whole, our data does support the statement that surgery was effective in decreasing the angle of deviation in digits with clinodactyly.
Effects of Different Surgical Techniques

There was a significant difference in the change in angulation postoperatively depending on the surgical technique that was used. Reverse wedge osteotomies resulted in digits that had little to no postoperative changes in angulation. This may be due to the physical alterations made to the phalanx with this surgical technique. When a reverse wedge osteotomy is performed, a wedge of bone from the affected digit is horizontally flipped and creates a barrier in the longitudinal epiphyseal bracket. Dividing the bracket into two separate pieces may have contributed to the lack of change in angulation postoperatively. Digits that were corrected using a closing wedge osteotomy showed a significant increase in deviation between the time of surgery and the final follow-up. This postoperative increase in angulation could be due to the fact that a longitudinal epiphyseal bracket present prior to surgery remains intact after the digit is corrected. The complete bracket may be continuing to restrict the elongation of one edge of the phalanx and therefore contributing to the increase in angulation postoperatively as the child continues to grow.

The significance of postoperative increases in angulation for digits that underwent opening wedge osteotomies, bone excision, and other surgical corrections could not be assessed due to the small sample size and missing follow-up data. However, of the six digits that underwent bone excision and had radiographic data available, there was a mean increase of 15.1° postoperatively. Although the statistical significance of this trend could not be determined, it is surprising nonetheless. If the delta phalanx was the sole source of deviation, then there should not have been an increase in angulation after the
bone was removed. The postoperative increase in the angle of deviation may have been caused by irregular articular surfaces on the remaining proximal and distal bones or by abnormalities in the soft tissues of the digit.

**Association Between Recurrence and Other Factors**

The hypothesis that thumbs were operated on at a younger age than fingers was confirmed (p<0.001). However, there was no significant association between recurrence and the age of operation or the type of digit corrected. We had also hypothesized that there would be a difference in recurrence between patients who had a congenital syndrome or an additional hand abnormality and those who did not. Our data did not show a significant relationship between recurrence and these factors. This could be explained by the structural similarities of digits with clinodactyly despite the presence of underlying genetic differences in patients.

**Changes in Primary and Secondary Ratios**

The immediate and significant decrease in the ratio of primary ossification centers with surgery was expected. Of all digits corrected for clinodactyly, 36% were corrected with closing wedge osteotomies, where a wedge of bone is removed and thus immediately decreased the length of the phalanx. There was no significant change in the primary ratio postoperatively when there was a minimum of one year for follow-up data. With a time restriction of at least two years for follow-up data, there was a significant increase in the primary ratio.
Since we used a ratio of bone lengths, there were a few possible explanations for the lack of a significant change in the primary ratio with a minimum of one year for follow-up data. The first possibility is that neither the phalanx nor the metacarpal grew after surgery. This is possible if the growth plates of these bones were closed at the time of operation. However, the mean age at the time of surgery was 4.8 years, with a standard deviation of 3.68 years. A child’s growth plates are typically open until after puberty. Therefore, it is unlikely that this is the only explanation of our data. Another possibility is that the phalanx and metacarpal continued to grow at the same rate. Given the data found by the radiographic measurements taken by Garn et al. (1972), this is consistent with bone growth in unaffected digits. It is reasonable to conclude that surgically corrected bones grew at the same rate as unaffected phalanges because none of the surgical techniques to correct clinodactyly interfere with the physis at the proximal end of the phalanx.

The significant increase in the primary ratio when follow-up data was restricted to at least two years after surgery was unexpected and therefore difficult to rationalize. It suggests that the phalanx was growing at a faster rate than the metacarpal, assuming that the metacarpal was growing at a normal rate. It is possible that one year was not enough time for sufficient bone growth to occur and make changes in the primary ratio significantly apparent. The fact that the primary ratio decreased with surgery and then increased postoperatively explains why there was not a significant change when comparing the primary ratio preoperatively and at the time of the two-year restricted follow-up.
Regardless of whether the ratio is increasing or not changing significantly, it is important that the ratio is not significantly decreasing after surgical correction. A decrease in the ratio of the phalanx to the metacarpal would suggest that the corrected phalanx was growing at a slower rate than the metacarpal. The hypothesis that there was continued growth of phalanges after surgery was statistically supported by our study. Both follow-up data restricted to one and two years after surgery supports this. However, the existence of a congenital syndrome or a second hand abnormality did not play a significant role in the change in either the primary or secondary ratios postoperatively. This again supports the idea that genetic differences in patients do not have as much influence on postoperative changes as the physical structure of the phalanx itself.

**Limitations**

It is important to take into consideration the fact that the data in our study only described the small number of digits with clinodactyly that required surgical correction. Therefore, the characteristics of the patients and digits included in our study are not necessarily generalizable to all patients with clinodactyly. Another factor to take into account is that the data was collected from patients who visited Boston Children’s Hospital, which is ranked as one of the top pediatric hospitals in the country (Top Ranked Pediatric Hospitals for Orthopedics). Many complicated cases are referred to Boston Children’s Hospital, which may have affected the type of cases and patients present in our study and introduces selection and treatment biases.
The fact that surgery to correct clinodactyly is not very common is evident with the relatively small number of patients in our study. In the 15-year period that we analyzed, only 89 digits were operated on and had at least one radiograph available. One of the biggest limitations of our study was that few patients had long-term radiographic data. Only 27 digits had radiographs at least two years after surgery. This may be due to a number of reasons. Patients may have been satisfied with their surgical results and therefore chose not to continue with postoperative clinical visits. It is also possible that the patient was referred to Boston Children’s Hospital only for surgery and continued to postoperative follow-up visits with their local physician.

Ideally, we would have been able to collect radiographic measurements from perfect anteroposterior radiographs showing both the primary and secondary ossification centers at equal intervals of time for all patients. This was impossible for a number of reasons. The hard copies of older radiographs often could not be found or had been destroyed. Other times preoperative or postoperative radiographs simply had not been taken. The length of time between surgery and a patient’s final follow-up varied for each patient, and the visibility of the ossification centers depended on the age of the patient. Thumbs often did not have a perfect anteroposterior view available. Some radiographs that were clearly meant to be from an anteroposterior view showed digits with minor degrees of rotation. Other times a digit was bent or visibility was obscured by the presence of a cast. All of these factors lead to the small number of digits with complete data and further limited the number of digits with perfect data.
There were a few factors that led to our decision to create a ratio between the corrected phalanx and the corresponding metacarpal. It would not have been wise to compare the length of the affected phalanx with the same digit on the other hand since clinodactyly is often bilateral. As far as considering changes in bone length, it would not have been sensible to compare the ratio of the length of primary ossification centers to anything besides other ratios of primary ossification centers. Therefore, the change in length ratios of digits could not be analyzed if a digit did not have multiple measurements of either the primary or secondary ratios.

Due to the small number of patients that undergo surgical correction of clinodactyly and the even smaller number that had long-term follow-up data, we attempted to include as many patients as possible. By allowing different types of digits and patients with additional congenital differences to be included in our study, we ended up with an extremely heterogeneous cohort. While our study was able to consider whether various factors were associated with changes in growth and angulation, the inclusion of so many different characteristics may have affected our results.

**Conclusions**

We can conclude that surgery to correct clinodactyly is effective and relatively safe. There was a significant decrease in angulation of digits when preoperative measurements were compared with both immediate postoperative and final follow-up measurements. This was true despite the increase in angulation that occurred between the immediate postoperative and final follow-up measurements and the fact that 43.2% of
patients had recurrent deformity. There was a significant increase in angulation between the immediate postoperative and final follow-up measurements in digits corrected with closing wedge osteotomies, while there was little to no change during this time period for digits corrected with reverse wedge osteotomies. Our study was unable to identify any factors that were associated with recurrence. The primary ratio decreased significantly with surgery and then increased significantly between immediate postoperative measurements and those taken at least two years after surgery. This significant increase in the primary ratio suggests that the phalanx grew at a faster rate than the metacarpal after the digit was surgically corrected.

Our study is the first to quantify the postoperative change in bone length of digits surgically corrected for clinodactyly. The fact that neither the primary nor secondary ratios decreased between the immediate postoperative and final follow-up measurements indicates that surgery does not inhibit phalangeal growth. Although we did not identify any factors significantly associated with recurrence or postoperative growth, it does not mean that factors associated with these changes do not exist. A larger sample size with longer follow-up data would provide more information on the subject.
REFERENCES


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Coursework: Biochemistry, Human Physiology, Pharmacology,
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Research Experience:

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• Orthopaedics Department
• Reviewed medical records and X-rays to study the
effects of the surgical correction of congenital
clinodactyly

2/11 to 6/12  Salk Institute for Biological Studies
• Private, non-profit, research organization
• Plant genomics laboratory
• Laboratory assistant performing DNA extractions,
polymerase chain reactions and gel electrophoresis
exploring knock out genes in plants
Volunteer Activities:

10/13 to now  Volunteer at Tufts Medical Center
- Boston, MA
- Patient visitor
- Visited inpatient units to provide nonmedical assistance, comfort, and conversation with patients

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- Teaching assistant for the Readings in Translational Research course in the division of Graduate Medical Sciences
- Assisted students with presentations and class discussions of scientific articles

4/10 to 3/11  Active Students for Kids
- San Diego, CA
- Assisted children age six to eight in elementary schools who have ADHD or who were struggling in class in order to improve reading, writing, and math skills

Work Experience:

9/08 to 6/09  University of California, San Diego
- Food service at Plaza Café in San Diego, CA
- Worked alongside other students to serve meals while maintaining a fun and friendly environment for our customers

5/08 to 9/08  Oak Park Veterinarian Hospital
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- Worked as a veterinary technician
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