The Journal of Undergraduate Research

Volume 13 Article 6

2015

# Four-Digit Hand: Anatomy of Ray II Amputation

Sadie Volk
*South Dakota State University*

# Four-Digit Hand: Anatomy of Ray II Amputation

Author: Sadie Volk

Faculty Sponsor: Scott Pedersen, PhD

Department: Biology- Anatomy

# ABSTRACT

The South Dakota State University anatomy program received a male cadaver, age eighty-four, in January 2014. Upon arrival, the cadaver was observed for any signs of surgery, skin ulcerations, or abnormality. The inspection revealed that his right hand only had four digits. In order to observe such a unique extremity, a dissection was conducted to understand the anatomy of the four-digit hand. This dissection would search for standard anatomical landmarks as well as abnormalities that could have been in relation to the absent finger. In this case study, both amputation and a possible birth defect were taken into account and researched. There were no signs of a birth defect, such as malformed fingers on either of the hands. The dissection showed many hallmark signs of amputation.

**Keywords**: hand, deviations, amputation, dissection, case study

# INTRODUCTION

It is a way of investigating the world, a tool of dexterity, a source of force, an extension of leverage, and a way of expressing emotion (Smith, 2014). The hand is a vital part of the human body, allowing us to conduct very strong maneuvers to very fine touch (Smith, 2014). Not only are the hands important for day-to-day physical tasks, the hands have a significant role in different emotional aspects, such as body image (Beasley, 2003). Since hands are so individualized and personable, many people hold self-worth to the appearance and function of their hands, just as someone would value his or her face (Beasley, 2003). This understanding is very important in the subject of hand surgery, including amputation, because surgeons and physicians must be receptive to the emotional stress a disabled hand may cause the patient.

Grip is a very common role performed by the hand; one can grab a book off the shelf, hold the handle of a heavy bag of groceries, unscrew a cap off a bottle, and even pull a needle through fabric (Edwards et al., 2003). Even the index finger, also known as the second phalange, has many of its own types of grasps (Boscheinen- Morrin et al., 1992). In one study, each finger of the hand was evaluated to see how much it contributed to the function of the hand; the thumb (first phalange) supplied forty percent, while the second and third phalange each contributed twenty percent, and the fourth and fifth phalange supplied each ten percent of functionality (Boscheinen- Morrin et al., 1992).

Besides grip and functionality, the fingers also have an incredible ability to feel much more perceptively than most other parts of the body (Smith, 2014). According to homunculus drawings, the motor and sensory areas of the brain have a large percentage dedicated to the hand in proportion to other areas of the body (Martini et al., 2009). Not all areas of the hand are innervated equally; the finger pads contain many more neurovascular bundles than other aspects of the hand, especially in comparison to the dorsal surface. If there is damage or removal to a digit, the hand loses a certain amount of ability to operate normally; hand surgery must be done with care in order to limit the amount of sensory and motor functionality lost (Lister, 1984). This is the science behind surgery and amputation of any portion of the hand (Murdoch and Wilson, 1998).

There are many reasons for altered hand structure including: birth defects, injuries, and surgery. Birth defects can cause many issues with the ability of the hand to perform its many tasks, all depending on the type and severity of the deformity (Flatt, 1994). Although birth defects are not extremely common (seven percent of live births), the amount of anomalies that occur on the upper limb include one in every 626 of the congenital anomaly births (Flatt, 1994).

Injuries of the hand are very common; almost every task involve the hands. Depending on the severity of the injury, reconstructive surgery and microsurgery may be performed. If the injury cannot be fixed by reconstructive surgery, or the surgery did not work properly, amputation is another intervention that would be selected to provide the most functionality of the injured hand (Murdoch and Wilson, 1998). Certain amputations allow the hand to have more range of motion or better grip from the removal of a dysfunctional stump (Murdoch and Wilson, 1998).

The South Dakota State University anatomy lab received an 84 year-old (at death) male cadaver from the University Of South Dakota Sanford School Of Medicine medical anatomy laboratories. It appeared that his second digit was missing on his right hand, leaving only four digits. This was an extraordinary opportunity for me to pursue in-depth dissection in order to explore how the gentleman came to have a digit missing and how the hand adapted to the absent digit.

# METHODS

This cadaver body was dissected for the South Dakota State University anatomy class, and done so in the manner of prosection for teaching purposes. The right arm had been dissected down to muscle; few superficial veins that were kept on the forearm included the basilic and cephalic. The nerves that were kept on the forearm included the median, ulnar, and radial. The skin on the hand was intact until the exploratory dissection began. The hand was amputated in order to allow more mobility of the extremity during the dissection. I completed the hand dissection and it was done separately from the full body prosection done for the anatomy class.

# RESULTS

The dissection will be described using standard terminology: supination of the extremity so the palm of the hand is exposed upwards with the digits extended; medial refers to being closer to the midline of the body with lateral being the opposing term; the medial aspect of the hand in anatomical position refers to the pinky finger and the relating palmar side; distal is a term used to describe something that is further from the core of the body than something else. The fingers are distal to the palm of the hand, whereas the palm of the hand is proximal to the fingers. Anterior and ventral both mean the front of the body, while posterior and dorsal relate to the back of the body. The fingers are referred to as phalanges, and a single finger is a phalange. The phalanges are named laterally to medially from one to five. The first digit is known as the thumb, and the fifth digit is known as the pinky. The bones that make up the phalange are the metacarpal and the proximal, middle and distal phalanx bones (Martini et al., 2009). The dissection findings will be compared to the standard set by Netter in The Atlas of the Human Body, 2006.

## Skin

The skin of the hand was very thin and fragile which could be contributed to the age of the body with no signs of trauma or scars from an amputation. Initially, only the epidermis and dermis were removed, noting that a straight line was visible while holding the skin to the light. This line traveled between the third digit and the first digit and began on dorsal side of the hand at the area of the second metacarpal head, moving towards the palmar side, with a lateral angle and is consistent with the Ray II amputation. The skin on the posterior aspect of the hand was much thinner with an estimated three times more cutaneous nerves and neurovascular bundles attached to the skin on the anterior or palmar surface of the hand compared to the posterior surface.

## Dorsal Superficial Veins and Nerves

Around the most distal aspect of the second metacarpal showed a venous network of interconnecting veins that did not appear around any of the other knuckles of the hand. This venous network created an arch with many branches off of it, running on the medial aspect of the thumb, arching towards the head of the first metacarpal, and then moving medially towards the third metacarpal. This network formed an arch around the distal portion of the head of the second metacarpal. The typical route of the cephalic vein travels on the lateral aspect of the dorsal side of the wrist, then branch into two digital veins; one of these veins would travel to the medial side of the thumb while the other one would continue to the second digit, branching again to both sides of the second digit (Netter, 2006). This differentiation appeared to be a sign of possible amputation, as the venous system seemed to have adapted to some sort of trauma to the area.

The superficial nerves of the posterior aspect of the hand were also observed. The superficial branch of the radial nerve was terminated at the area of the second metacarpal head. The typical path of this nerve starts at the dorsal lateral aspect of the wrist, and branches to the first phalange as well as the second phalange; the branch that runs to the second phalange is the digital branch demonstrated on the cadaveric hand (Netter, 2006). The end of the nerve was thicker than the more proximal end, possibly indicating a neuroma. The dorsal branch of the ulnar nerve seemed to follow the pathway described in the Atlas (Netter, 2006).

## Dorsal Tendons and Correlating muscles

The next layer on the back of the hand was exposed, which demonstrated the extensor tendons. The branch of extensor digitorum that belonged to the third digit was not linear; the tendon curved laterally toward the first digit. This was a clear indicator that the symmetry of the hand was shifted, as the third digit extensor digitorum tendon travels down the midline (Netter, 2006).

The extensor digitorum branch was supposed to terminate on the distal portion of the second digit (Netter, 2006). Instead it was tethered to the other tendon in close proximity, which was the extensor indicis. This tendon was supposed to travel to the second digit, but was interwoven to the deep side of the extensor digitorum without possibility of separation. The fibers of both tendons were woven into each other, making a mesh of tendon that did not dominantly belong to one tendon or the other. These tendons together fanned out and attached to the head of the second metacarpal, the extensor digitorum to the third digit, and to the second dorsal interosseous tendon. Just proximal to the fanning of the tendons, the tendon appeared atrophied in diameter, darkened in color, and slightly translucent which did not seem to be caused by the preservation of the body.

The fan of the tendons was fibrous and expansive with no obvious insertion. From observing how the tendon was attached, the extensor digitorum and extensor indicis to the second digit may have acted on extending the third metacarpal. Although no muscle measurements were done, the extensor indicis appeared to be an average size; if the indicis muscle was not being used, the muscle belly would be extremely atrophied.

## Ventral Structures

On the ventral portion of the hand, the palmar fascia was easy to find and follow, except in the area where the second digit was missing where it was almost impossible to find traces of the fascia. After the removal of the remaining fascia, all of the underlying structures were exposed. There was very little adipose or connective tissue in the distal area between the first and third metacarpal, leaving the arteries and nerves very superficial.

## Ventral Superficial Arteries

The palmar arch was followed from the ulnar artery on the medial portion of the hand. Instead of forming an arch, the artery formed a tortuous pattern. The ulnar artery was followed until the flexor digitorum tendon of the fourth digit, a few centimeters distal to the origin of the thenar muscles. The artery then turned a ninety degree angle, heading laterally towards the thumb. At the angle, an artery branched off of the palmar arch and headed distally. This section only continued for about a centimeter then stopped and created a forty-five degree angle continuing medially for about a centimeter. At the angle, a branch went straight and distally to supply blood to the lateral aspect of the fifth digit and the medial portion of the fourth digit. Continuing medially after the second angle, the artery created a second forty-five degree angle towards the fifth digit. It then continued distally, formed a full loop on itself, and then traveled to the medial side of the fifth digit. This is demonstrated in Figure 1.

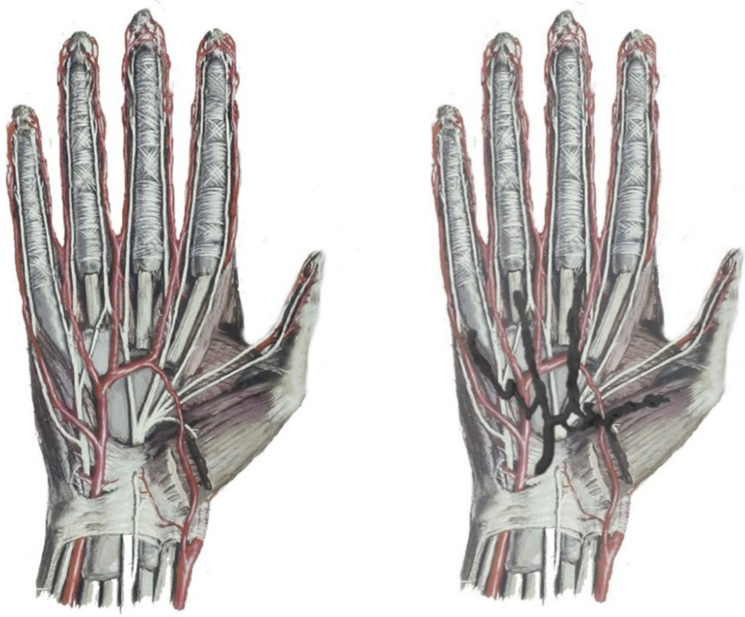

**Figure 1: The palmar arch according to *The Atlas of Human Anatomy* (left) compared to vasculature of observed hand, demonstrated with black lines (right) (Netter, 2006).**

From the stem of the ulnar artery that took a 90 degree angle, the artery continued straight for about a centimeter, and then divided into two branches, one diving into the thenar muscles, and one creating a 45 degree angle towards the third digit. This pattern of 45 degree angles continued until the artery became too minute to follow. There were also two branches off of the palmar arch that traveled into the thumb, which were very irregular in shape.

The digital arteries that branched off the palmar arch continued distally towards the fingers, doubled back, made loops, and became small towards the distal phalange. The artery between the fourth and the fifth digit dove into the digital nerve, splitting it into two and then rejoining again on the far side of the artery. The arteries running towards the medial side of the third digit had a very interesting weaving relationship with the digital nerves. The artery traveled with the nerve, so much that it was impossible to separate the two structures without compromising the integrity of each. This artery also made four tight loops while traveling toward the digit. The artery on the lateral side of the third digit was too small to be followed more than halfway of the metacarpal. There was only one arterial branch that separated from the palmar arch and traveled proximally instead of distally. This artery branched between the third and fourth metacarpal and dove deep into the space between the third metacarpal tendons and the thenar (thumb) muscles.

The ulnar artery appeared to have what appeared to be a stent placed in it from the flexor retinaculum to the palmar arch. It was assumed to be a stent because there was very distinct circular bands that were visible with the naked eye. Under a dissecting microscope, the circular bands were shown to be the muscular layer of the artery layered between the fibrous layer and the tunica interna. Since the muscular layer was visible by the naked eye, this could indicate stenosis of the artery. When the dissection of the ulnar artery was performed under the dissecting microscope, the smooth muscle layer was cut, and the circular bands fell apart into sharp fragments, which would be consistent of stenosis in the arteries. These circular bands were observed on the ulnar arteries on both the right and the left hand.

## Ventral Nerves

When the carpal tunnel was exposed, the median nerve was not visible. A cut of the carpal tunnel on a normal hand would be done in line with the third digit, and the median should sit most superficially once the carpal tunnel was opened. After searching, the median nerve was found more laterally and deep, in close proximity to the origins of the thenar muscles. This was consistent with adaption, as the symmetry of the hand had changed to compensate for the absent second digit.

There was a very interesting relationship between the arteries and the nerves as previously indicated in the information about the ventral superficial arteries.

Instead of one branch, there were two digital branches from the median nerve that traveled to the space between the fourth and third metacarpals with the destination of the medial aspect of the third digit.  It was impossible to separate the digital nerve branches from the digital artery without causing damage to the structures. The digital branch of the median nerve that traveled to the lateral aspect of the same third digit was surrounded in scar tissue. This made it very difficult to follow the nerve distally. On this same side of the third digit, there were two masses at the end of the two separate nerve branches. These neuromas were also embedded in scar tissue, making it hard to provide accuracy of their size. The approximations of their dimensions were 6 mm long by 4 mm wide, and the second one measured at 5 mm wide and 6 mm long. These are shown in Figure 2.

The median nerve was followed to the palmar then digital branches that would innervate the absent second digit. The end of this branch terminated around the space of the thenar muscles where a large neuroma was found, an indicative sign of amputation. The neuroma measured 8 mm long and 8 mm wide.

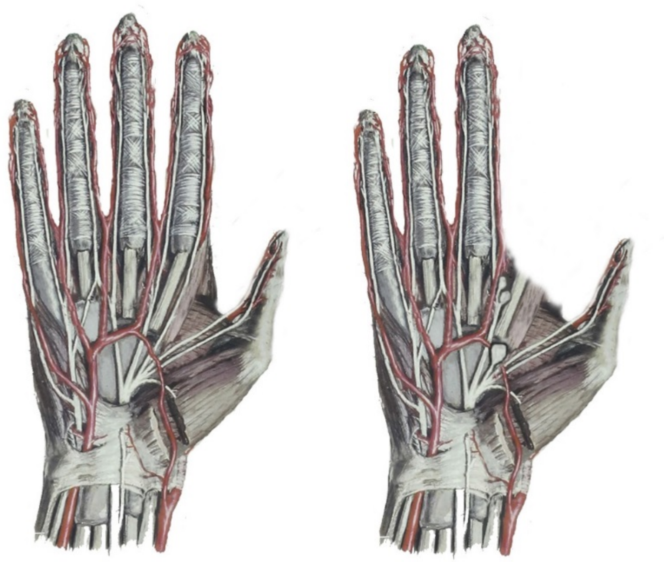

**Figure 2: Three neuromas are shown on the right image with the atlas comparison on the left. Two neuromas are on the end of the digital branch of the median nerve that would travel up the medial aspect of the second digit. The third neuroma developed from the digital branch of the median nerve that would travel on the lateral aspect of the second digit (Netter, 2006).**

## Ventral Tendons and Musculature

Just as the tendons of the back of the hand demonstrated asymmetry, the flexor digitorum tendons for the third digit were curved laterally, with the tendons for the fourth digit appearing to be at the center of the hand. The palmaris brevis was very large, stretching to the thenar musculature, while the palmaris longus was absent.

Flexor digitorum superficialis and profundus were found for the second digit. The two flexors for the second digit each had different insertions at which they created a fanlike structure that spanned across the fibrous scar tissue between the third and first digit. The flexor digitorum profundus inserted more proximal than the flexor digitorum superficialis. Both of their proximal to distal paths together seemed to dive under adductor pollicis and continue to the distal aspect of the hand to the tendinous mass that terminated before the boundary of the head of the third metacarpal. These tendons dove more laterally under the thenar muscles than observed in the atlas (Netter, 2006). They were also very difficult to follow distally as they were embedded in scar tissue just proximal to the insertion of the tendons. Their appearance changed from glossy tendon to atrophied, darkened, and semi-translucent tissue, similar to the extensor tendons discussed earlier. The tendon fibers attached to the fibrous tissue on the lateral aspect of the third metacarpal proximal to the head of the bone and also expanded to join with the second dorsal interosseous muscle and first palmar interosseous. This area was also where the third digital branch of the median nerve on the lateral side was embedded as well.

The first lumbrical muscle was located originating on the flexor digitorum profundus tendon for the second digit at the base of the opponens pollicis brevis. The original insertion point of this muscle was absent, so the muscle stayed continuous along the tendon.

Tendons from the flexor digitorum profundus and superficialis that traveled to the fourth and fifth digit were found in this layer as well. The sheath enclosing the flexor digitorum superficialis tendons was fibrous and almost impossible to separate from the tendons without causing damage. The tendons within the sheath were brittle. The tendon traveling toward the fourth digit divided in the same sheath, and then would weakly reconnect distally. They appeared damaged because of fraying and a rough surface of the tendons. These findings were not thought to be a result of preservation.

In relation to the overall size of the hand and the other muscles of the hand, it appeared that the thumb muscles, the adductor pollicis, the flexor pollicis brevis, the abductor pollicis brevis, and the abductor pollicis transversus appeared hypertrophied although no measurements were done. The transverse head of the adductor pollicis appeared to have the most distal portion of its origination on the sheath of the flexor digitorum superficialis.

## Dorsal Deep Musculature

Once removing the tendons of the palmar and dorsal sides of the hand, the deep muscles were visible. The first dorsal interosseous muscle, which was supposed to insert on the lateral side of the second proximal phalanx, inserted on the distal tip of the shortened second metacarpal where the shortened muscle belly was still attached.

First palmar interosseous muscle belly was shorter as well, reaching the whole length of the second metacarpal then attaching to the fibrous area on the lateral portion of the third metacarpal. Another origination point on the second metacarpal bone was a portion of the oblique head of the adductor pollicis.

## Deep Structures

Just as the superficial palmar arterial arch was tortuous, the deep palmar arterial arch followed a similar pattern with less distinct angles.

When dissecting the musculature from the second metacarpal bone, the muscles were easiest to remove from the medial aspect of the bone. All other areas of the bone had well attached muscle fibers. The measurements from the second metacarpal were taken once it was removed, and consist of 40 cm long, 2.5 cm wide, and 5 cm deep. The bone was shaped like a triangle, with a wide proximal base, moving to a distal tip. There was a flat edge angled at a downward toward the medial aspect of the metacarpal. The bone appeared to be about half the length of the other metacarpal bones. At the end of the bone, there was a large tuberosity on the palmar side which could have been a bone scar.

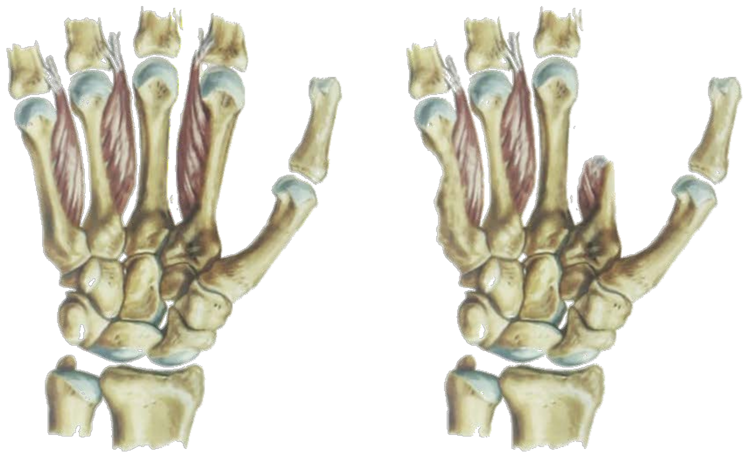

**Figure 3: The right image shows the shortened metacarpal bone as well as the fracture of the fifth metacarpal bone (Netter, 2003).**

The musculature was removed from the other metacarpals and it was found that the fifth metacarpal had a healed fracture with poor alignment of the bone. The proximal portion of the metacarpal was in alignment with the other metacarpals. At the fused fracture, the bone jutted anteriorly, and then continued in a straight line few centimeters anteriorly than the rest of the metacarpals which is demonstrated in Figure 3.

The carpal bones were all present. The trapezoid bone was dark with a reddish, dark brown color and cracked. The capitate also had a darkened area; it was located in the center of the dorsal aspect of the bone. It had a central, dark area moving outward into a lighter-colored bone, then more outward into the normal bone color. At the articulation of the radius and the scaphoid, both bones had a darkened area which was aligned when the hand was straight with the forearm. This may have been a result of a fall that happened before death.

# DISCUSSION

Overall, the entire dissection indicated signs of amputation in the early life. Since there were signs of adaptation as well as no evidence of scars or stitches, it can be concluded that the amputation was performed at a young age. Tendons are left to retract after an amputation, so distinguishing between adaption and surgical placement is difficult (Beasley, 2003).

When dealing with amputation of the digits, maintaining length is very crucial unless the boundary of the proximal interphalangeal joint is met (Murdoch and Wilson, 1998). If the amputation must be done below the interphalangeal joint, the stump is deemed a burden to the hand and a Ray Amputation is performed (Beasley, 2003). If the second digit is severely injured proximally to this boundary, the pinch function between the first digit and the second digit is dysfunctional (Murdoch and Wilson, 1998). The remaining stump would impair the pinching ability between first digit and the adaptive third digit (Murdoch and Wilson, 1998).

A Ray Amputation is the process of removing the entire digit down to the lower aspect of the metacarpal (Beasley, 2003). It is normally performed when a previous amputation of a finger at a more proximal joint is deemed dysfunctional to the hand (Murdoch and Wilson, 1998). When performed on the second digit, this amputation is called Ray II (Atkins and Meier, 1989). The main reason for this type of amputation is to restore some sort of pinch and grip function; by removing the body of the metacarpal, the distance between the first and third digit is shortened, increasing the likelihood of the third digit to act as the second digit (Beasley, 2003). This amputation is performed by making an incision on the dorsal aspect of the hand, following the groove between the second and third metacarpal. (Wilhelmi, 2013). From this, the skin is purposefully left long so that the flaps are not pulled tight; if skin flaps are taut over this area, web contractures are possible (Green et al., 1999). The incision lines are shown in Figure 4. The second metacarpal is cleaved at an angle; the bone should not be cut proximally enough to interfere with the insertion of the flexor carpi radialis (Wilhelmi, 2013); A tenotomy (process of dividing a tendon) is performed with the tendons cut shorter than the cut length of the metacarpal (Wilhelmi, 2013); (Green et al., 1999). Arteries and veins are cauterized or ligated, and nerves are cut proximally in order to try to prevent neuromas (Wilhelmi, 2013). By doing this type of amputation, the third digit is then capable to act as the second digit, with the same pinch grip that is performed with the first and second digit (Boscheinen- Morrin, 1992). The amount of leverage and strength exhibited by the hand does decreases after this type of amputation because the width of the palm is almost decreased by one fourth of the size (Lister, 1984). This makes actions as simple as swinging a hammer difficult (Lister, 1984). As for emotional adaption to this surgery, the end result is fairly cosmetically pleasing (Beasley, 2003). While first observing the cadaver's hand, it was not obvious that his finger was absent.

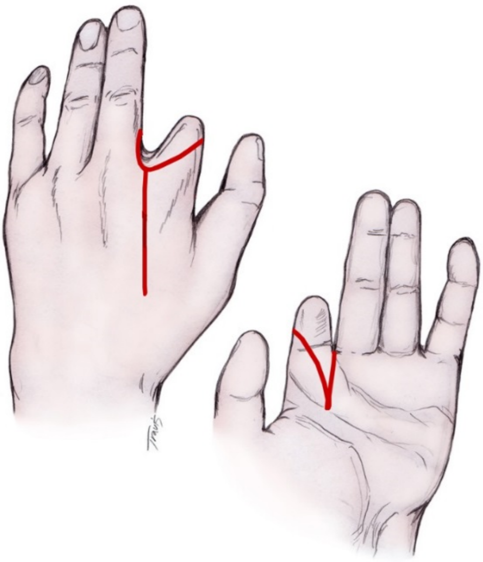

**Figure 4: The red line indicates the incision for Ray II Amputation (Medscape, 2013).**

The venous system on the dorsal aspect of the hand formed an arch with many branches around the remaining knuckle of the second digit. This was not present around any of the other knuckles and could have developed because of the ligation performed during surgery.

The flexor and extensor tendons that were to act on the second digit were found to have formed tendinous fanlike structures with tough scar tissue surrounding it. Studies have shown that tendons can produce collagen after being transected (Tubiana, 1981). In the book *The Hand*, this process of tendon growing was described as "Newly synthesized connective tissue adjacent to loose areolar tissue appears to be induced to form disorganized, loose fibrillar and fibril patterns that favor longitudinal slipping of subunits and lengthening of connective tissue strands" (Tubiana, 1981). This explanation of tendon growth after a cut is consistent with the findings of tendinous masses during dissection as shown in Figure 5.

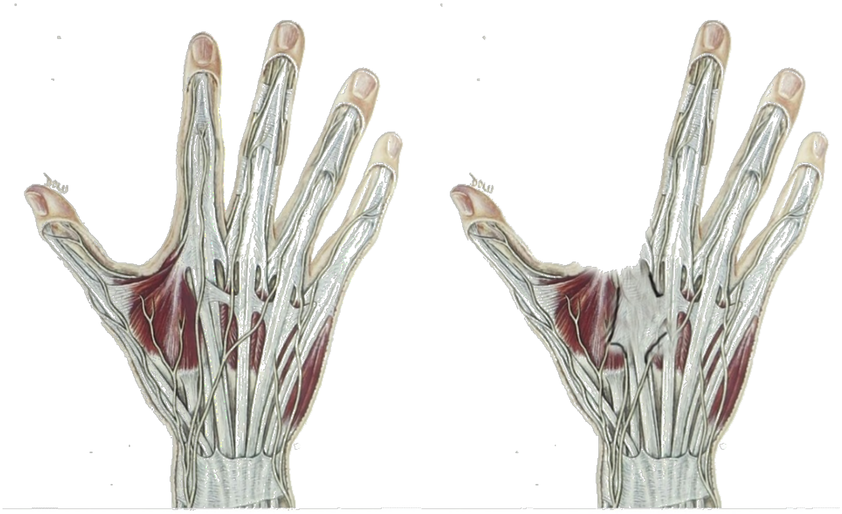

**Figure 5: The tedinous mass found on the back of the hand is demonstrated on the right side, with an atlas comparison on the left (Beasley, 2003).**

Both of the digital branches of the median nerve that traveled to both the medial and lateral aspect of the second digit were cut during the amputation. When dissected, three neuromas were found. The process of forming a neuroma consists of a nerve that begins to "extrude a new axoplasm, and in the absence of distal Schwann tubes into which to regenerate, the nerve endings curl up and become encapsulated in a fibrous mass called a neuroma." (Beasley, 2003). Two of the neuromas are consistent with the medial and lateral digital branches running to the second digit. The third neuroma is the terminal end of the division off of the lateral branch.

There are many different ways to amputate the bone in the Ray II amputation; in the most recent explanation of the surgery, the metacarpal bone was described as “transected” meaning to cut at an angle (Green et al., 1999). In older texts, the bone was described as having to be kept cylindrical with most cuts being completely longitudinal (Green et al., 1999). There was no definitive description of how the bone was cut. Since bone constantly remodels, there is a possibility that the bone changed its shape after amputation to accommodate for the new situation.

The fifth metacarpal of this hand had a rejoined facture known as a transverse mid-shaft metacarpal fracture (Beasley, 2003). The cause of injury is normally due to a direct force to that area (Beasley, 2003). It is unknown if this injury was done to the second digit at the same time as the fifth metacarpal.

# CONCLUSION

Learning about the human body allows health care providers make better decisions that affect many people. Constantly, procedures are being evaluated and changed to promote the best outcomes possible. Surgery and amputation performed on portions of the hand have been performed and evaluated for centuries (Vasconcelos, 1945). The importance of establishing certain procedures that could be shared to other physicians about the hand increased during the time of World War II (Vasconcelos, 1945). By examining the hand with four digits, more knowledge was gained about the Ray II Amputation and the effects on the hand.

This dissection exposed many different anatomical variations from the altas (Netter, 2006). Although it is not possible to say all of the abnormalities found were due to the Ray II Amputation, it can be speculated that the hand did adapt after the surgery. The tendinious fans that were found can be attributed to the growth after the amputation, but the tortious arteries may have a different cause. Finding these abnormalities was the goal of this dissection, in order to understand how an amputation can affect the hand.

Only assumptions can be made as to the situations that led up to this gentleman having his second digit amputated and his fifth metacarpal broken. The dissection exposed the important anatomical structures of the hand with four digits. The range of capabilities that the hand could perform is information that is not able to be confirmed from dissection or research.

# LIMITATIONS

The limitations that occurred during this research project included the lack of information about the donor, including a medical record, health history, and personal information such as occupation. There were also stipulations regarding the photographic documentation of the dissection, which forced more verbal description of the findings. The University Of South Dakota Sanford School Of Medicine emphasized the importance of confidentiality for the donor. The skill required to dissect the delicate and intricate structures of the hand was also a barrier as only sixty hours of dissection training was achieved before the initiation of this project.

# ACKNOWLEDGEMENTS

This research was funded by the Joseph F. Nelson Undergraduate Mentorship program, and I extend my greatest gratitude for helping make this project possible. I would like to thank Dr. Scott Pedersen for helping and encouraging me throughout this project. Another thank you is extended to Mr. Ethan Snow for seeing potential in my abilities and having confidence in me to complete such an amazing project. Finally, I would like to sincerely thank every person, especially this gentleman with a unique hand, who gave back to the anatomy program by the amazing gift of donating their bodies to science.

# REFERENCES

Atkins D. J., and Meier, R. H. III (1989). (Eds.) *Comprehensive Management of the Upper-Limb Amputee*. New York, NY: Springer-Verlag.

Banerjee, S. N. (Ed.) (1982). *Rehabilitation Management of Amputation.* Baltimore, MD: Williams & Wilkins.

Beasley, R. W. (2003). *Beasley's Surgery of the Hand*. New York, NY: Thieme Medical Publishers, Inc.

Boscheinen- Morrin J., Davey V., and Conolly, W.B. (1992).*The Hand; fundamentals of Therapy.* Jordan Hill, Oxford: Butterworth-Heinemann Ltd.

Brand, P. W. (1985). *Clinical Mechanics of the Hand*. St. Louis, MI: C.V. Mosby Company.

Edwards S. J., Buckland D. J., and McCoy-Powlen J. D. (2002). *Developmental and Functional Hand Grasps.* Thorofare, NJ: SLACK Inc.

Flatt, A. E. (1994). *The Care of Congenital Hand Anomalies.* (2nd ed.). St. Louis, MI: Quality Medical Publishing, Inc.

Gray, H. (1985).*Gray's Anatomy*. Clemente C. D. (Ed .). (13th ed.)

Gilula, L. (1992). *The Traumatized Hand and Wrist; Radiographic and Anatomic Correlation.* Philadelphia, PA: W.B. Saunders Company.

Green, D. P., Hotchkiss, R. N., and Pederson, W. C. (1993). *Green's Operative Hand Surgery* (4th ed.). Philadelphia, PA: Churchill Livingstone.

Jupiter, J. B. (Ed.) (1991). *Flynn's Hand Surgery* (4th ed.) Baltimore, MD: Williams & Wilkins.

Kelly, P. J. (1955). *Levels of amputation in occlusive vascular disease: a clinical and pathological study of 319 amputations.* Minneapolis, MN.

Lister, G. (1984). *The Hand; Diagnosis and Indications*. New York, NY: Churchill Livingstone.

London, P. S. (1990). *A Colour Atlas of Diagnosis After Recent Injury.* Ipswich, England: Wolfe Medical Publications Ltd.

Martini, F. H., Timmons, M. J., and Tallitsch, R. B. (2009). *Human Anatomy* (6th ed.). San Francisco, CA: Pearson Education, Inc.

McMinn, R. M. H. and Hutchings, R. T. (1988). *Color Atlas of Human Anatomy* (2nd ed.). Weert, Netherlands: Year Book Medical Publishers, Inc.

Murdoch G. and Wilson A. B. Jr. (1998). *A Primer on Amputations and Artificial Limbs.* Springfield, IL: LTD.

Netter, F. H. (2006). *Altas of Human Anatomy* (4th ed.). Philadelphia, PA: Saunders Elsevier.

Smith J. (Producer). 2014, Feb 18. *The Incredible Human Hand* [Episode 1]. Dissected, Four, BBC. Video retrieved from http://www.bbc.co.uk/programmes/p01mv2jc.

Tubiana, R. (1981). *The Hand*. Philadelphia, PA: W.B. Saunders Company.

Vasconcelos, E. (1945). *Modern Methods of Amputation.* New York, NY: Philosophical Library, Inc.

Wilhelmi, B. J. (2013). *Digital Amputations Treatment & Management.* Medscape. Retrieved from http://emedicine.medscape.com/article/1238395-treatment.

Wood. E. (1965). *The Veins*. London: J&A Churchill Ltd.

## Image References

Beasley, R. W. (2003). *Beasley's Surgery of the Hand*. New York, NY: Thieme Medical Publishers, Inc.

Index Ray Amputation [Online Image]. 2013. Retrieved November 30, 2014 from http://emedicine.medscape.com/article/1238395-overview.

Netter, F. H. (2006). *Altas of Human Anatomy* (4th ed.). Philadelphia, PA: Saunders Elsevier.