

## Partial First Ray Amputations: Success Rates and Biomechanics

by James E. Repko, DPM<sup>1</sup>

The Northern Ohio Foot and Ankle Journal 2 (8): 1

As the prevalence of diabetic foot ulcers increases, the need for partial foot amputations rises. A partial first ray amputation, an amputation at any level of the hallux or first metatarsal, is a common limb salvage procedure in many of these diabetic patients. Many patients opt to have a partial first ray resection rather than more a radical surgery because of the many social and psychological factors that accompany an amputation. Unfortunately, amputations at this level can significantly alter the biomechanics of the foot. This in turn may lead to secondary skin breakdown due to increased pressure on areas of the foot that are not intended to bear these loads. As practitioners, it is our responsibility to provide patients with appropriate information, and the risks with each option, allowing them to make appropriate decisions. This article reviews the mechanical impact of the first ray, and the success rates of resections at various levels throughout the first ray.

**Key words:** First ray amputations, hallux, diabetes, diabetic foot ulceration, biomechanics

**Accepted:** August, 2015

**Published:** September, 2015

This is an Open Access article distributed under the terms of the Creative Commons Attribution License. It permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. ©The Northern Ohio Foot and Ankle Foundation Journal. ([www.nofafoundation.org](http://www.nofafoundation.org)) 2014. All rights reserved.

The incidence of type II diabetes is approximately 387 million people worldwide. The National Health and Nutrition Surgery (NHANES) reports an increase in prevalence of type II diabetes from 5.9% to 9.5% over the past two decades. In addition, a rise in childhood obesity around the world has been noted. Undoubtedly, this will increase the number of diabetic adults that will require treatment in the foreseeable future.<sup>1</sup>

Complications associated with diabetes include, but are not limited to, cardiovascular and neurological dysfunction. This manifests in the foot and ankle in the form of arterial occlusion, total ischemia, peripheral neuropathy, and thin, dystrophic skin due to autonomic dysfunction. Ultimately, this leads to these patients

developing various types of ulcerations. Diabetic foot ulcerations (DFU) are notoriously problematic and difficult to treat because of these complications. In addition, the wounds are a tremendous drain on the health system. Patients are commonly seen every 1-2 weeks by physicians for care. Perhaps most importantly, DFUs lead to an increased risk of amputations at various levels of the lower extremity. It is estimated that up to 15% of people with diabetes will require an amputation in their lifetime. Additionally, once an amputation is done, there is a 50% chance that patients will undergo a second amputation of the contralateral limb within 2 years of the original amputation.<sup>2</sup>

As foot and ankle specialists, we treat a significant number of DFUs, including ulcerations at various levels of the first ray. It is well understood that the first ray plays a significant role in the biomechanics of the foot and ankle.

<sup>1</sup>Resident, Department of Foot and Ankle Surgery, HealthSpan Physicians Group, Cleveland, OH

Address correspondence to: [jrepko@healthspan.org](mailto:jrepko@healthspan.org) Department of Foot and Ankle Surgery, HealthSpan Physicians

Alteration in the structure of the first ray undoubtedly impacts these mechanics. Literature discussing the long-term success of partial first ray amputations has been published with variable results. Most surgeons performing an amputation at this level tout it as a limb salvage procedure, however little high-level evidence exists on the long-term outcomes of these patients. An argument exists that a more proximal amputation can be successfully achieved at a later date. This leaves the questions to be answered if patients would be better served with a more proximal amputation to begin with. More proximal amputations may be more predictable, allow patients to return to activity more rapidly and save healthcare costs via preventing long term care. This article will evaluate mechanics and success rates of partial first ray amputations.

### **Biomechanics**

The first ray is one component of the medial column of the foot and therefore a primary load bearer during gait. The first ray consists of the hallux, the first metatarsal, and the medial cuneiform. It functions in the frontal and longitudinal planes following subtalar joint (STJ) motion. As the STJ pronates, the first ray dorsiflexes and inverts. Inversely, as the STJ supinates, the first ray plantarflexes and everts. These motions allow the first ray to act as a shock absorber or rigid support structure pending its motion.<sup>3</sup>

The medial column is often referred to as a beam and truss structure. During the early stance phase of gait, the pronated STJ allows the first ray to dorsiflex while it comes into contact with the ground. This motion aids in dispersion of shock from heel strike. During heel strike, the first ray is acting as a beam resisting tensile forces. A lack of dorsiflexion leads to increased pressure under the 1<sup>st</sup> metatarsal head. In addition, a lack of dorsiflexion of the first ray prevents internal tibial rotation and calcaneal eversion, further preventing the proximal limb from aiding in shock absorption.<sup>3</sup>

As the STJ supinates into midstance and the propulsive period, the first ray plantarflexes and everts. This motion allows the medial arch and transverse arches to lock into place on the rearfoot. Increased congruency of the talonavicular and calcaneocuboid joints, also called the midtarsal joint, can be seen and is referred to as locking of the joint complex. The locking mechanism stabilizes the first ray against the rearfoot at the midtarsal joint. With the calcaneus firmly pressed into the ground and the forefoot “locked” onto the rearfoot, the medial column has transitioned into a truss structure. The bases of the truss are the first metatarsal head against the ground anteriorly,

along with the calcaneus posteriorly. The midtarsal joint is considered the apex of the truss. With this joint locked into place, opposing oblique forces from both arms of the truss stabilize the triangle.

With the truss formed, the arch of the foot is established. As the gait cycle proceeds with the first metatarsal firmly pressed against the ground, the hallux dorsiflexes at the 1<sup>st</sup> metatarsophalangeal joint. Dorsiflexion at this joint, activates the windlass mechanism, providing further soft tissue support across the base of the truss of the 1<sup>st</sup> ray.<sup>3</sup>

Now that we have a foundational understanding of 1<sup>st</sup> ray mechanics and functions, one can then postulate how amputations may affect these loading bearing mechanics of the foot. Clearly any alteration at the 1<sup>st</sup> metatarsophalangeal joint, 1<sup>st</sup> metatarsocuneiform joint, or 1<sup>st</sup> metatarsal itself will abnormally transfer loads laterally.

### **History of Partial Ray Amputations**

As discussed earlier, patients with diabetes are predisposed to peripheral neuropathy, leading to autonomic and sensory dysfunction. With these changes, plantar skin that is intended to bear weight becomes increasingly prone to breakdown and ulceration with normal mechanics. When mechanics are altered, areas of skin that were never intended to bear these loads or tensile forces are directly subjected to them. Given this dynamic change in both required function and physiologic dysfunction, these abnormal areas of pressure will be especially prone to breakdown.

Murdoch et al claimed that 60% of diabetic foot amputations occur at the level of the first ray.<sup>2</sup> Ulcerations along the first ray most commonly occur at: 1. The hallux (distal tip, plantar medial, plantar interphalangeal joint, 2. The plantar first metatarsophalangeal joint or 3. The first Metatarsal head (plantar or medial).<sup>4</sup> Due to the biomechanical stabilizing function of the first ray in early weightbearing and propulsive function of the distal first ray, one can again easily conceive why these areas would be prone to ulceration.

Murdoch was one of the first to look at the long-term success rates of partial first ray amputations. They undertook the task of reviewing the history of great toe amputations in 1997. His group looked at 90 patients retrospectively. The number of and level at which the amputation took place in this study is displayed in figure 1.

Level of Amputation	# of Amputations	# of Complications
Hallux	19	14
1 <sup>st</sup> MTPJ	36	24
1 <sup>st</sup> MT Neck	22	10
Proximal 1 <sup>st</sup> MT shaft	12	3
1 <sup>st</sup> MTCJ	1	0

Figure 1. Level and Number of Amputations from Murdoch et al 1997.

Of these 90 patients, 50 went on to have a second amputation. Further breakdown of these numbers shows that 14 out of 19 patients receiving an amputation at the level of the hallux had secondary amputation. Five patients had more proximal 1<sup>st</sup> ray amputations, 4 had lateral foot amputations, 3 went to TMA and 2 had contralateral limb amputations. Of the 48 patients who had an original amputation at the level of the first metatarsophalangeal joint, 15 went on to more proximal 1<sup>st</sup> ray amputations, 10 had more lateral foot amputations and 6 went on to contralateral limb amputations. The 23 patients receiving amputations at any the level of the first metatarsal went on to 1 more proximal 1<sup>st</sup> MT amputation, 2 lateral foot amputations, 6 transmetatarsal amputations and 0 contralateral limb amputations. All secondary amputations occurred within an average of the first year following the primary amputation. Of important note, many patients went on to contralateral limb amputations. Additionally, 21% of patients went on to a 3<sup>rd</sup> and 7% of patients went on to a 4<sup>th</sup> amputation.

The major weakness of this article was that due to its retrospective nature, vascular status of these patients could not be obtained. It has been well established that vascular testing is required to determine appropriate level of a definitive amputation.<sup>5</sup> This lack of information clearly hurts the papers ability to extrapolate conclusions about the success rates of first ray amputation success. Nonetheless, the study does call into question the primary success rate and long-term viability of the partial first ray amputation.

Kadukammakal et al retrospectively analyzed success rates of solitary first ray amputations in 50 patients at various levels for ischemia, infection, chronic wound or ischemia+infection. Patients were followed for 4 months. They found that 52% of patients healed uneventfully. Of the 48% who did not heal the primary amputation, 12 went on to TMA and 12 had developed wound complications. This complication rate is similar to what was found in previously performed studies. However in this paper, the numbers were further broken down to include level of amputation and complication rates seen at various levels (Figure 2). Amputations at the 1<sup>st</sup> MTPJ level required 5 additional surgeries (1 transmetatarsal amputation) vs. 15 surgeries at more proximal locations (7 transmetatarsal amputations). They conclude that

amputations at the level of the metatarsal phalangeal joint are more viable than more proximal first ray amputations.

Level of Amputation	# of Amputations	# of Complications
1 <sup>st</sup> MTPJ	13	14
Head of 1 <sup>st</sup> MT	5	30
Neck of 1 <sup>st</sup> MT	25	3
Diaphysis/Base 1 <sup>st</sup> MT	7	3

Figure 2. Level of amputation and complication rates. Kadukammakal et al 2003.

The group suggests that a longer 1<sup>st</sup> metatarsal allows for more functional load sharing along the medial column and less transfer laterally. Given the load bearing biomechanics of the first ray, the theory is sound. Additionally, one may postulate that a more distal amputation would leave the windlass mechanism intact thus allowing more efficient sharing of tensile forces across the plantar foot. Nonetheless, the paper is flawed, as it did not differentiate results seen in patients with known ischemia.<sup>5</sup>

In 2013 Borkosky et al published an 11-year review of patients undergoing partial first ray amputations associated with peripheral neuropathy and diabetes mellitus. They excluded patients requiring vascular intervention or had diagnosis of non-reconstructable ischemic disease. Twenty-four patients had amputation at the level of 1<sup>st</sup> MTPJ, 12 in metatarsal midshaft, 7 at IPJ of hallux, 3 at MTPJ including sesamoid removal, 2 at base of MT and 1 at base of proximal phalanx of hallux. All of these patients healed their incision within 20 months of initial procedure. During the follow-up period, 25 required more proximal amputations including: 9 below knee, 6 transmetatarsal, 4 digital amputations, 2 MT midshaft, 2 Chopart amputations and 1 above knee amputation. In addition to amputation complications, 41 of the patients acquired an average of 3.1 new ulcerations at an average of 10.5 months. Twenty-one of these patients required new ancillary procedures and each patient had an average of 2.1 procedures. These new ulcerations required an average of 26.6 additional clinical visits and 2.3 antibiotics postoperatively. Their conclusion is that almost half of these patients underwent more proximal amputation within 25 months and 1/2 died at an average of 3 years after the original amputation date (ranging from 1 to 122 months).<sup>6</sup> Associated morbidity and mortality of diabetic patients requiring this procedure is displayed in this study. Given the decreased life expectancy of patients requiring this procedure, one may need to re-define the meaning of “long term viability”.

In 2014, Sano et al. published an article discussing the initial presentation of necrosis in digits and its correlation with unfavorable limb salvage prognosis. Forty-four

patients presented with great toe ischemic ulcerative changes and 86 had ischemic changes of the lesser toes. CLI and PAD was assessed in all patients and revascularization was performed in order to allow patients the greatest chance to heal. No significant differences were noted in patients' systemic parameters, risk factors or preoperative lab values. Patients with great toe ischemia had a statistically significant increased risk of whole toe amputation and of major amputation (50% and 24% respectively) compared to lesser digits (27.3% and 9.3% respectively). Great toe ischemia had an odds ratio of 3.1 for increased risk of major amputation. They concluded that ischemic changes of the great toe may have great predictive value of lower limb salvage<sup>7</sup>

The group does not discuss or define what they deem as a major amputation, however it is the first paper discussing location of digital necrosis having a predictive value of limb salvage. The only theory that is discussed in the paper as to why poorer results occur with great toe necrosis is a vascular theory. The theory proceeds as follows: the great toe's arterial supply comes from all 3 main pedal arteries vs. lesser digital supply from 1-2 main pedal arteries. Thus, if necrosis occurs in the great toe, there is likely severe arterial occlusive disease to the entire foot.

Paola et al. published a study in 2003 discussing ulcer recurrence after first ray amputation in diabetic patients. They included patients receiving amputation at a level proximal to 1<sup>st</sup> MTPJ and excluded patients who had amputations at the level of the joint or distally. Patients in this study underwent rigorous vascular and neuropathy workups to determine the level at which they would be most apt to heal. All patients who were determined to have reduced/absent pedal pulses, ankle brachial indices <1 w/o calcified vessels and/or with TcPO<sub>2</sub> levels <50 mmHg underwent intervention (Percutaneous Transluminal Angioplasty or Bypass) to re-establish direct inline flow the limb affected limb.

A total of 58 patients were "revascularized". Amputations took place at various levels described in figure 3. 65 patients healed primarily and 24 had minor wound complications that healed within 3 weeks. Patients were followed for a mean of 16 months. The group had an extensive postoperative protocol including rocker bottoms shoes with custom inserts that were further customized based off a wear at 6 months postoperatively and indoor slippers with custom inserts. During their extensive follow up period, 15 patients developed recurrence, 11 on the ipsilateral side and 4 on the contralateral side. 8 of these 15 wounds required further procedure as follows: 4 pan metatarsal head amputations, 2 toe amputations, 1 transmetatarsal amputation and 1 lisfranc amputation. Significantly, no patients underwent an above ankle

amputation though follow up was only for a little greater than 1 year. In addition, they cite multiple articles discussing a Transmetatarsal amputation reamputation rate of 20-40% with 21% prevalence of proceeding to below knee amputation.<sup>8</sup>

Level of Amputation	# of Amputations
Head of 1 <sup>st</sup> MT	44
Diaphysis of 1 <sup>st</sup> MT	17
Base 1 <sup>st</sup> MT	28

Figure 3. Level and location of amputations performed in study by Paola et al 2003.

This study reiterates the significance of vascular work-up and optimization prior to proceeding with amputation. Granted, circumstances may exist where this may not be possible, it is ideal for these patients to be "vascularly optimized". In addition, the group's rigorous postoperative offloading protocol may have significantly contributed to their high rate of success in limb salvage. Previously discussed studies had no mention of vascular optimization and/or offloading protocols.

## Conclusion

The studies cited above display mixed results for success rates of partial 1<sup>st</sup> ray amputations. Clearly the inclusion and exclusion criteria of each study itself varies; however the underlying principal investigation of success rates is evident in all studies. It appears that one of the most important factors to address when considering this procedure is a patient's vascular status.

An appropriate workup for a patient with suspected vascular occlusive disease in the setting of diabetes should be performed prior to undergoing any type of surgical intervention. This is supported in the study by Paola et al. In their study, extensive vascular work up and intervention was done to all patients prior to undergoing an amputation of the first ray at any level. Both their primary success rate and end period follow-up results are significantly favorable compared to previous studies mentioned above. In addition to vascular workup, and likely as important, was the group's strict post-operative offloading protocol. Custom extra depth multi-density inserts can aid offloading high-pressure areas and accommodate for the newly modified mechanics of the foot and ankle seen after amputation.

In conclusion, the long-term success of rate partial first ray amputations is not well established in the literature. What may be extrapolated from literature that does exist is: 1. Altered mechanics play a significant role in success of these amputations. 2. Proper offloading and footwear is required in the immediate and long-term post operative period. 3. Nature of the amputation (ie. Ischemia, infection or combination of both) plays a significant role in determining ancillary/concomitant

treatments will be required for successful outcomes.

### References:

1. McCulloch, D., & Robertson, R.(2015, July 24). Risk factors for type 2 diabetes mellitus (J. Mulder & D. Nathan, Eds.). Retrieved August 9, 2015.
2. Mudroch, Doug P. et al. "The Natural History of Great Toe Amputations." *Journal Foot & Ankle Surgery* 36.3 (1997): 204-08
3. Glasoe W M, Yacks H J and Saltzman C L *Physical Therapy* 1999 89: 854-59
5. Kadukammakal, J. et al. (2012). Assessment of Partial First-Ray Resections and Their Tendency to Progress to Transmetatarsal Amputations. *Journal of the American Podiatric Medical Association*, 412-16
6. Borkosky SL, Roukis TS.J. Incidence of Repeat Amputation after Partial First Ray Amputation Associated with Diabetes Mellitus and Peripheral Neuropathy: An 11-Year Review. *Foot Ankle Surg.* 2013 May-Jun;52(3):335-8.
7. Sano H., & Ichioka, S. (2014). Great Toe Necrosis Predicts an Unfavorable Limb Salvage Prognosis. *Plastic and Reconstructive Surgery Global Open*, 2(9), E216.
8. Paola, L. et al. (2003). Ulcer Recurrence Following First Ray Amputation in Diabetic Patients: A Cohort Prospective study. *Diabetes Care*, 26, 1874-1878.