Predictors of Healing and Functional Outcome Following Transmetatarsal Amputations

Gregory J. Landry, MD; Daniel A. Silverman, BS; Timothy K. Liem, MD; Erica L. Mitchell, MD; Gregory L. Moneta, MD

**Objectives**: To evaluate factors that predict healing and to assess functional outcome and survival following transmetatarsal amputations (TMAs) for forefoot gangrene.

**Design**: Retrospective case-control study.

**Setting**: University hospital.

**Patients**: All patients undergoing TMA from January 1, 2004, through December 31, 2010.

**Intervention**: Transmetatarsal amputations performed in all patients.

**Main Outcome Measures**: Transmetatarsal amputation healing, ambulation, living status, and survival. Demographic characteristics, preoperative vascular status, and perioperative variables were analyzed as predictor variables. Univariate and multivariate analyses were performed to determine predictors of healing and survival.

**Results**: Sixty-two TMAs were performed in 57 patients. Healing occurred in 33 TMAs (53%), with 22 TMAs (35%) in patients who proceeded to below-knee amputation and 7 TMAs (11%) in patients who died without healing. No demographic or perioperative variables significantly predicted healing. Independent ambulation was achieved in 24 patients with healed TMAs (73%) but in only 4 patients with nonhealed TMAs (14%) ($P < .001$). Mean survival was 16.5 months (range, 0-94 months), with no difference between patients with healed and those with nonhealed TMA. Significant predictors of mortality were dialysis-dependent renal failure (odds ratio, 4.85; 95% confidence interval, 1.01-23.30) ($P = .047$), non-independent living (17.80; 3.03-104.80) ($P = .001$), and need for preoperative revascularization (4.80; 1.24-18.50) ($P = .02$).

**Conclusions**: Transmetatarsal amputations have low healing rates, and patient demographic characteristics and preoperative assessment do not help predict healing. Transmetatarsal amputation healing, however, significantly predicts subsequent ambulatory status and should be pursued in patients with good rehabilitation potential.

Arch Surg. 2011;146(9):1005-1009

---

FOR MANY PATIENTS WITH MULTIPLE TOE OR DISTAL FOOT GANGRENE, A TRANSMETATARSAL AMPUTATION (TMA) IS THE LAST HOPE FOR PARTIAL FOOT SALVAGE. PRESERVATION OF A SENSATE HEAL IS DESIRABLE FOR MAINTAINING AMBULATORY FUNCTION. HOWEVER, WOUND HEALING OF TMA IS FREQUENTLY A MAJOR CHALLENGE. WOUND HEALING RATES FROM MULTIPLE SERIES RANGE FROM APPROXIMATELY 40% TO 70%. NONHEALING OF TMA INEVITABLY LEADS TO MULTIPLE OPERATIONS AND HOSPITALIZATIONS, ULTIMATELY RESULTING IN A MORE PROXIMAL, FREQUENTLY TRANSSTIBIAL, AMPUTATION.

Although transstibial amputations heal more reliably than TMAs, patients are often resistant to this procedure, and subsequent amputation with a prosthesis is often more difficult than amputation on the native heal and forefoot. Given the difficulty in healing of TMA, however, it would be desirable to predict which patients are less likely to heal and to possibly avoid the prolonged periods of medical care in these patients.

See Invited Critique at end of article

Typically, the judgment of an experienced physician is one of the best indicators of subsequent healing. Other adjunctive measures, such as ankle brachial indices, toe pressures, laser Doppler skin perfusion pressures, angiography, and Doppler assessment of foot vasculature, are occasionally used to assist in this decision. In our practice, we have used a variety of tests to help determine optimal amputation levels, most recently, skin perfusion pressures. Here, we review our experience with TMA healing and examine factors that might help predict amputation healing.
strict non–weight-bearing status for 1 month was encouraged. Wounds were primarily closed, whereas grossly infected wounds were left open at the initial operation for delayed primary or secondary closure. Eleven of 17 patients (65%) whose wounds were left open ultimately healed, with a mean healing time of 5.2 months (range, 1-36 months). There was no difference in wound healing between primary and delayed primary or secondary closure (P = .39). In 36 TMAs (58%), the patients underwent either surgical or endovascular revascularization beforehand, whereas in 26 TMAs (42%), the patients were either believed to be adequately perfused or did not have revascularization options at the time of amputation, 35 patients had measurable ankle brachial indices with a mean (SD) of 0.96 (0.18), whereas 27 had noncompressible ankle brachial indices.

The effects of demographic factors on TMA healing are listed in Table 2. There were no significant demographic differences between heelers and nonheelers, although there was a trend toward decreased healing in patients with renal failure, chronic obstructive pulmonary disease, and cardiac disease. Other factors, including a history of diabetes, did not influence TMA healing.

Skin perfusion pressure was measured with laser Doppler in 23 patients. Measurement of skin perfusion pressures at the transmetatarsal and ankle levels did not predict subsequent TMA healing. Mean (SD) skin perfusion pressures at the transmetatarsal level were 17.9

<table>
<thead>
<tr>
<th>Table 1. Demographic Data for Patient Cohorta</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor</td>
</tr>
<tr>
<td>Age, mean (SD); y</td>
</tr>
<tr>
<td>Male sex</td>
</tr>
<tr>
<td>BMI, mean (SD)b</td>
</tr>
<tr>
<td>Active smoker</td>
</tr>
<tr>
<td>Hypertension</td>
</tr>
<tr>
<td>Coronary artery disease</td>
</tr>
<tr>
<td>Congestive heart failure</td>
</tr>
<tr>
<td>COPD</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
</tr>
<tr>
<td>Renal insufficiency</td>
</tr>
<tr>
<td>Renal failure</td>
</tr>
<tr>
<td>Hypercholesterolemia</td>
</tr>
</tbody>
</table>

Abbreviations: BMI, body mass index; COPD, chronic obstructive pulmonary disease.

a Data are given as percentage of patients unless otherwise specified.
b Calculated as weight in kilograms divided by height in meters squared.

METHODS

PATIENTS

The study was approved by the institutional review board at Oregon Health & Science University (Portland). The study was a retrospective analysis of outcomes of TMA performed in the Division of Vascular Surgery at Oregon Health & Science University from January 1, 2004, through December 31, 2010. Consecutive patients with a history of TMA were included, regardless of outcome.

DEMOGRAPHIC CHARACTERISTICS

Each patient’s age, sex, and body mass index were documented. In addition, the following factors were recorded: current smoking status and documented history of cardiovascular disease, pulmonary disease, diabetes mellitus, renal insufficiency or failure (with renal insufficiency defined as a blood creatinine level >1.5 mg/dL [to convert to micromoles per liter, multiply by 88.4] on 3 separate occasions surrounding the operation and with renal failure defined by need for dialysis), hypertension, and hypercholesterolemia. All patients with hypercholesterolemia were receiving statin therapy. All patients were receiving antiplatelet therapy, either aspirin, clopidogrel bisulfate, or both.

PERIOPERATIVE AND POSTOPERATIVE DATA

Preoperative data evaluated included ankle brachial index, toe brachial index, and skin perfusion pressure. Preoperative cardiac evaluation was performed in patients with recent (within 6 months) history of myocardial infarction, unstable angina, electrocardiographic changes, or poor functional status (American Society of Anesthesiology class III or IV). Revascularization, either endovascular or surgical, before amputation was performed at the discretion of the surgeon if perfusion for wound healing was believed to be inadequate. Transmetatarsal amputation was then performed later as a second-stage procedure. Likewise, amputation without prior revascularization was at the discretion of the surgeon. Transmetatarsal amputations were performed using standard published techniques. In the absence of gross infection, wounds were primarily closed, whereas grossly infected wounds were left open at the initial operation for delayed primary or secondary closure. Casting was not performed following TMA, but strict non–weight-bearing status for 1 month was encouraged.

Both intraoperative and postoperative factors that are believed to potentially affect wound healing were assessed. Intraoperatively, blood pressure and temperature were recorded. In addition, 24-hour postoperative data of blood pressure, temperature (high and low), blood glucose (high, low, and mean), and oxygen saturation were recorded. Additional postoperative factors evaluated were primary wound closure, time to secondary wound closure, time to below-knee amputation if performed, total number of operations, postoperative ambulatory status, living status (independent or nonindependent), limb salvage, and survival. Postoperative data were retrieved from the electronic medical records (Epic; Epic Systems Corporation, Madison, Wisconsin), and mortality data were obtained from the electronic medical record or Social Security Death Index. Data were recorded in a computerized database (Excel; Microsoft Corporation, Redmond, Washington).

STATISTICAL ANALYSIS

All data were analyzed using SPSS, version 19.0 (SPSS, Inc, Chicago, Illinois). Both univariate and multivariate analyses were conducted. Continuous variables were compared using the t test. Categorical variables were compared using the Pearson χ² test or Fisher exact test, as appropriate. Stepwise logistic regression analysis was performed to assess factors associated with TMA healing. Limb salvage and survival were calculated with Kaplan-Meier analysis. The level of significance was set at P < .05.

RESULTS

During the study period, 62 TMAs were performed in 57 patients. Demographic data on the study cohort are listed in Table 1. In the study population, 79% of the patients had diabetes and 31% had dialysis-dependent renal failure. Thirty-three TMAs (53%) healed. Twenty-two TMAs (35%) resulted in below-knee amputation. In 7 TMAs (11%), the patient died without complete TMA healing. Primary closure was performed in 45 TMAs (73%), whereas 17 TMAs (27%) were left open for delayed primary or secondary closure. Eleven of 17 patients (65%) whose wounds were left open ultimately healed, with a mean healing time of 5.2 months (range, 1-36 months). There was no difference in wound healing between primary and delayed primary or secondary closure (P = .39). In 36 TMAs (58%), the patients underwent either surgical or endovascular revascularization beforehand, whereas in 26 TMAs (42%), the patients were either believed to be adequately perfused or did not have revascularization options at the time of amputation, 35 patients had measurable ankle brachial indices with a mean (SD) of 0.96 (0.18), whereas 27 had noncompressible ankle brachial indices.
(15.3) mm Hg in nonhealers and 26.9 (24.3) mm Hg in healers (P = .32) and at the ankle level were 44.4 (18.4) mm Hg in nonhealers and 40.8 (29.7) mm Hg in healers (P = .76). Transcutaneous oxygen levels and toe pressures were infrequently measured and, therefore, not further analyzed.

Intraoperative and perioperative factors evaluated are presented in Table 3. No intraoperative data (systolic blood pressure and temperature) were predictive of subsequent healing. These parameters measured during the first 24 hours after operation likewise did not predict healing. On univariate analysis, patients with healed TMA had higher glucose levels (mean and high) than did nonhealers. In the multivariate model, no demographic or perioperative factors were predictive of TMA healing (data not shown).

The mean survival of the entire patient cohort was 16.5 months (range, 0-94 months). Mean survival did not differ between patients with and those without TMA healing (15.1 [16.4] vs 18.0 [18.8] months; P = .52). Three patients (5%) died within 1 month of surgery: 1 of myocardial infarction, 1 of sepsis and multisystem organ failure, and 1 of undetermined cause (patient was in a skilled nursing facility). Survival at 12, 24, and 36 months for the entire group was 67%, 52%, and 35%, respectively. There was no difference in survival in patients with healed vs nonhealed TMA at the same times (healed: 64%, 45%, 37%; nonhealed: 75%, 59%, 33%; P = .90) (Figure). On univariate analysis, significant predictors of mortality included renal failure (74% mortality in patients with renal failure vs 40% in patients without renal failure; P = .03), nonambulation (62% vs 36%; P = .04), nonindependent living (79% vs 21%; P < .001), and pre-TMA revascularization (64% vs 31%; P = .01).

Multivariate predictors of death included renal failure (odds ratio, 4.83; 95% confidence interval, 1.01-23.30; P = .047), nonindependent living (17.80; 3.03-104.80; P = .001), and need for preoperative revascularization (4.80; 1.24-18.50; P = .02).

The mean amputation-free survival for the entire patient cohort was 8.1 months. Twenty-two of 29 patients with nonhealing TMA underwent below-knee amputation within 4 months of the TMA surgery, with no further amputations after 4 months. The remaining 7 patients died without TMA healing. Nonhealers underwent...
Transmetatarsal amputation was first described as a method of partial foot preservation by McKittrick et al\textsuperscript{12} in 1949. The present findings support those of prior studies showing suboptimal rates of healing of TMAs. Our TMA healing rate was 53\%, which is consistent with data from multiple studies.\textsuperscript{1-7} Unfortunately, no preoperative measures were able to accurately predict which patients would go on to heal their amputations, so clinical judgment still remains an important factor in deciding who should be offered this operation.

Preoperative assessment of arterial perfusion is typically pursued in patients with critical limb ischemia. In patients with foot gangrene, attempts were made to optimize arterial perfusion to the affected extremity with revascularization, either open or endovascular, when possible. Sheahan et al\textsuperscript{4} found that a revascularization procedure performed subsequent to partial foot amputation was a predictor of subsequent limb loss and advocated early revascularization to optimize amputation healing. In the current series, patients undergoing TMA following revascularization had healing rates no different from those of patients who underwent amputation without revascularization. This may still indicate a delay in revascularization, because patients presented for revascularization with significant foot gangrene. Healing rates would likely be improved if patients were referred with less severe tissue loss. In addition, it is reasonable to surmise that revascularization before amputation did allow healing for some patients who might have gone directly to transfibial amputation if revascularization had not been performed.

More than half of the patients in this series had noncompressible ankle brachial indices, which is typical of a population in which a high percentage have diabetes and renal failure. Toe pressures were infrequently obtained because of the nature of the extensive foot gangrene. In the later years of the series, we typically performed assessment of skin perfusion pressure with laser Doppler to assess amputation healing potential. Others have found a skin perfusion pressure of more than 30 mm Hg to predict wound healing, particularly in more proximal limb amputations.\textsuperscript{8} In this study, skin perfusion pressures did not predict ulcer healing, which likely indicates that arterial perfusion, while important, is not the only predictor of wound healing.

The findings regarding the effects of perioperative glycemic control on wound healing were somewhat paradoxical in this study. The cohort of patients with healed TMAs had a higher mean glucose level in the first 24 hours after surgery, compared with the level in the group that did not heal, which was significant in univariate although not in multivariate analysis. Others have shown that hyperglycemia is a risk factor for poor wound healing in patients with diabetic foot ulcers\textsuperscript{13} and that patients with a hemoglobin A\textsubscript{1C} level higher than 8\% experience worse healing of TMA.\textsuperscript{14} In our hospital, perioperative blood glucose levels are tightly controlled with the frequent use of insulin drips, such that hyperglycemic episodes are rare. One could hypothesize that the data indicate that hypoglycemic episodes are equally as disadvantageous in promoting wound healing as hyperglycemic episodes.

With such poor healing rates and survival, it is valid to question the wisdom of proceeding with TMA. Patients with dialysis-dependent renal failure in particular had poor wound healing and survival, as has been demonstrated by others.\textsuperscript{15} Clearly, patient choice becomes an important factor, because patients in general wish to preserve as much of their limb as possible. Below-knee amputation is still a stigmatized procedure that patients will most likely defer as long as possible and at all reasonable cost. However, this and several similar studies demonstrate the importance of tempering expectations. Patients need to be aware of the relatively low likelihood of the success of this operation. Although this awareness is not likely to dissuade patients from pursuing it, at least patients will be informed of the tenuous nature of limb salvage in their particular situation. It is human nature to believe that bad outcomes will happen to someone else and not them, but armed with the knowledge that their operation has a relatively low likelihood of success, patients may be more likely to be compliant with the prescribed postoperative care recommendations, not the least of which is maintaining a non-weight-bearing status until the amputation site has healed. Although this study was not designed to evaluate patient compliance as a variable in amputation healing, we (and likely every surgeon) can anecdotally recall patients in whom seemingly well-healing amputation sites failed to heal and resulted in more proximal amputations because of trauma to the amputation site secondary to patient noncompliance.

This study clearly demonstrates superior functional status in patients in whom TMA healed, with significantly improved ambulatory and independent living status. The poor ambulatory performance of atherosclerotic patients with transfibial amputations is well documented.\textsuperscript{16} Therefore, despite the accepted lower healing rates, it is reasonable to pursue TMA in patients with a higher likelihood of continued ambulation. It is often difficult to determine this preoperatively, because most patients express a wish to walk again. However, in patients in whom ambulation is clearly not a reasonable future goal, TMA is a suboptimal option because of its low healing rate and the need for additional operations and hospitalizations.

This study has several limitations, including its retrospective nature and relatively small numbers, which introduces the possibility of type II error. Because of the tertiary referral nature of our practice, many patients come from long distances, and long-term follow-up of this group is often difficult to obtain. Decisions regarding evalua-
The Elusive Search for Predictors of Healing Following Transmetatarsal Amputation

The role of the surgeon engaged in the treatment of patients with vascular disorders has less to do with eradication of disease and more to do with maintaining or improving quality of life for his or her patients. To that end, the goal of any limb-salvage surgery is to preserve preoperative ambulatory status. Multiple studies have demonstrated amputation rates of less than 50% following below-knee amputation. On the contrary, a patient with a healed forefoot amputation has a high likelihood of ambulation because of the preserved mechanics of normal ambulation and the lack of need for a prosthesis. In this well-written article by Landry and colleagues, the group retrospectively analyzes their experience with 62 transmetatarsal amputations (TMAs) during a 6-year period, and their results validate the importance of the TMA because almost 75% of patients with healed TMA achieved ambulatory status. In addition, although not specifically addressed in the article, the time required to walk with a prosthetic.

REFERENCES