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Amputation stump perfusion is predictive of post-operative necrotic eschar formation

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ABSTRACT

Background: A large proportion of patients develop poor amputation stump healing. We hypothesize that Laser-Assisted Fluorescent Angiography (LAFA) can predict inadequate tissue perfusion and healing.
Methods: Over an 8-month period we reviewed all patients who underwent lower extremity amputation and LAFA. We evaluated intra-operative LAFA global and segmental stump perfusion, and post-operative modified Bates-Jensen (mBJS) wound healing scores.
Results: In 15 patients, amputation stumps with lower global perfusion demonstrated higher mBJS ($P = 0.01$). Lower suture-line perfusion also correlated with more eschar formation ($P < 0.001$). Diabetic patients had higher mBJS ($P = 0.009$), lower stump perfusion ($P = 0.02$), and increased eschar volume ($P < 0.001$).
Conclusion: LAFA is a useful adjunct for intra-operative stump perfusion assessment and can predict areas of poor stump healing and eschar formation. Diabetic patients seem to be at higher risk of stump eschar formation.

Introduction

More than 130,000 major lower extremity amputations are performed in the United States each year for critical limb ischemia (CLI).[1] In up to 40% of patients, poor amputation site healing is associated with surgical site necrosis, dehiscence, and infection, often requiring stump revision and/or re-amputation.[1,2] The consequences of re-intervention in these highly vulnerable patients is associated with increased disability, morbidity, mortality, and healthcare costs.[3,4]

Conventional modalities for pre-operative assessment of lower extremity arterial inflow and outflow include ankle-brachial index (ABI) with or without lower extremity segmental pressures, transcutaneous oxygen measurement ($tcPO_2$), or contrast-based angiography. These diagnostic tools are sometimes used to predict the level at which a below knee amputation (BKA) or above knee amputation (AKA) stump is likely to heal.[5,6] However, tcPO2 does not provide any specific information about where post-operative wound complications may occur,[7] and ABIs only have a modest performance in predicting wound healing following surgical intervention.[8] It is evident that specific patient populations are particularly prone to poor wound healing, and segments of an amputation stump may develop poor healing even in the setting of adequate arterial inflow to the surgical site.[9–11] These limitations suggest that a 'real-time,' intra-operative approach for assessing stump arterial perfusion at the time of amputation can potentially help identify patients who at risk of poor stump healing.

Laser-assisted fluorescence angiography (LAFA) with the SPY Elite® imaging system (Novadaq, Bonita Springs, FL) is an FDA-approved non-invasive imaging modality that utilizes intravenous florescent agents such as indocyanine green dye (ICG) to evaluate tissue perfusion. The clinical utility of LAFA was previously demonstrated in liver, cardiac, and intestinal surgery.[12–14] LAFA has also been shown to predict viability of mastectomy reconstruction flaps.[15,16] Despite this, there are only a few reports of LAFA use in patients with lower extremity peripheral arterial disease.[17] In this study, we retrospectively evaluated whether intra-operative LAFA can identify specific areas of amputation stump mal-perfusion and if these areas are predictive of surgical site healing. We hypothesized that amputation stumps with LAFA-detected mal-perfusion will more likely exhibit signs of prolonged post-operative healing.

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Methods

Patients

From February to November 2016, all patients who received a major lower extremity amputation (AKA or BKA) and intra-operative LAFA by a single surgeon at our institution were included in the study analysis. Amputation and LAFA were performed as clinically indicated in patients with critical limb ischemia (CLI) who consented for both procedures after a detailed discussion of the risks and benefits. The amputation level (AKA vs BKA) was determined based on the extent of arterial inflow as demonstrated by pre-operative ABIs, cross-sectional angiographic imaging, and the surgeon's preference. Perioperative patient demographics, comorbidities, and medications were collected and evaluated. Patients were classified as being diabetic based on a review of their past medical history, clinician notes, and usage of anti-glycemic medications (metformin, insulin, thiazolidinediones, etc.).

Operative technique

AKA and BKA were performed as previously described.[18,19] Briefly, AKA was performed using a fish-mouth incision in the distal thigh. Following transection of the proximal patellar tendon, the underlying distal femur was circumferentially exposed to the mid-thigh level and transected with a power saw. The femoral vein and superficial femoral artery were each identified at the mid-thigh level within the adductor canal, clamped, transected, and ligated. The sciatic nerve in the posterior compartment was also externalized and transected proximally. The ventral and posterior muscle compartments were then fashioned to facilitate closure, and were tightly approximated over the transected femur with multiple interrupted sutures. Ventral and posterior fascial edges were then approximated also using interrupted sutures, and the transected patellar tendon was used to reinforce the fascial closure. Skin edges were typically closed using simple interrupted sub-dermal sutures, and vertical mattress interrupted dermal sutures or skin staples.

BKA was performed using a long posterior flap technique.[18] Ventral leg incision was made approximately 10 cm distal to the tibial tubercle and posterior incision long enough to ensure adequate flap coverage. The tibia was transected in a smooth slanted fashion 5 cm proximal to the level of the ventral incision. The fibula was also transected at this proximal level. Each tibial vessel was identified, ligated, and transected. Tibial nerves were externalized and transected proximally. Soleal muscle tissue was flapped over the transected tibia using interrupted sutures, and fascial, sub-dermal, and dermal closures were performed similar to AKA.

Intra-operative LAFA

Following amputation stump closure and prior to application of sterile dressings, the SPY Elite® imaging system mobile arm was placed 15 cm from the amputation stump to entirely visualize it with the imaging system. The patient's body temperature was maintained at 36.5–37.5 °C. Indocyanine Green (ICG; 7.5 mg in 3 mL solution) was administered through a peripheral intravenous line and flushed with 10 mL of saline. Immediately following ICG administration, the fluorescence intensity of ICG at the amputation stump was recorded with SPY Elite® imaging system according to the manufacturer's instructions and as previously described,[17] and continued for a total of 180 s following the initiation of image recording. Stump fluorescence densitometry measurements were analyzed using SPY-Q imaging software and ImageJ. Perfusion intensity was measured for the whole stump and along the suture line. Whole stump perfusion is evaluated as “Integrated Density” of the image, which provides a sum of pixel depth over the selected area. Segmental suture line perfusion measurements were expressed as a ratio relative to an equally sized segment with the highest stump perfusion intensity, thereby normalized to each patient.

Amputation stump anthropometric analysis

Post-operatively, patients were evaluated periodically for a 4–8-week period. A modified Bates-Jensen Score (mBJS) wound assessment tool (Table 1) was used to assess stump skin color, epithelialization, amount of exudate, and the presence and volume of eschar.[20] Eschar volume was determined by an observer masked to the intra-operative LAFA using Image J software. Aggregate mBJS were derived for both the whole stump and suture line segments. Wound healing features were evaluated on a 1 to 5 scale system, with lower scores indicating best healing, and higher scores indicating poorest healing. Temporal stump healing was evaluated from stump photographs obtained periodically during the entire post-operative follow-up period. Eschar free period (EFP) and eschar healing period (EFP) were evaluated for each amputation stump.

Statistical analysis

Patient demographics, stump LAFA perfusion parameters, and anthropometric analysis were performed with GraphPad Prism. Statistics were summarized as mean ± SEM. Non-parametric Spearman correlation analysis was used to determine the relationship mBJS and LAFA perfusion. Mann-Whitney tests were used to determine any differences between diabetic and non-diabetic patients. $P = 0.05$ was considered significant.

Ethics

Pre-operatively, patients were informed of the risks, benefits, and alternatives of the procedures. The FDA-approved LAFA procedure was described as part of the routine operative and clinical practice of the surgeon performing the amputation to assess intra-

Table 1
mBJS for amputation stump healing.

Necrotic Tissue Type	1 = None 2 = Non-adherent slough 3 = Adherent slough 4 = Soft eschar 5 = Hard eschar
Necrotic Tissue Volume	1 = None 2 = < 25% of wound bed 3 = 25–50% 4 = 50–75% 5 = 75–100%
Exudate Type	1 = None 2 = Bloody 3 = Serosanguinous 4 = Serous 5 = Purulent
Skin Color Surrounding Wound	1 = Pink 2 = Bright red 3 = Hypopigmented 4 = Dark red 5 = Hyperpigmented
Epithelialization	1 = 100% of wound 2 = 75–100% 3 = 50–75% 4 = 25–50% 5 = < 25%

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