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Three-dimensional digitalized virtual planning for retrograde sural neurovascular island flaps: a comparative study

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ABSTRACT

Background: The purpose of this study was to explore the effectiveness and safety of three-dimensional (3D) digitalized planning for the sural neurovascular island flap in repair of soft tissue defects in the ankle and foot.
Methods: This study included 40 patients with soft tissue defects of the ankle and foot who underwent soft tissue reconstruction between October 2008 and June 2012. The patients were randomly assigned into two groups: 3D-reconstruction group (Group A, $n = 20$) and control group (Group B, $n = 20$). Three-dimensional, digitalized virtual planning was performed in the patients in Group A, who underwent computed topographic angiography. The survival rate, operation time, and surgical accuracy were compared between the two groups.
Results: All flaps in Group A survived and the recipient site primarily healed, but 4 flaps in Group B had marginal necrosis after the operation. During the 6–12 month follow-up period, all flaps in Group A had good skin quality. In Group B, hard scarring and mild contracture occurred in 4 cases, and the patients experienced pain when walking. The survival rate of the flap in Group A (100%) was significantly higher than in Group B (70%). The operation time in Group A was significantly less than in Group B. The surgical accuracy in Group A was significantly better than in Group B.
Conclusion: The preoperative use of 3D digitalized virtual planning for the sural neurovascular island flap improves the surgical accuracy, decreases the operation time, and increases the survival rate of the flap.
Clinical question/level of evidence: Therapeutic III.

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1. Introduction

Soft tissue defects around the ankle and foot are often as a result of trauma, ischemia, infection, or surgical removal of tumors. These defects represent challenging reconstructive problems because of the limited availability of the overlying skin, poor circulation of the skin, and exposure of the bones, joints, and tendons [1]. Many reconstructive procedures have been used to repair defects in this region, including local fasciocutaneous flaps, pedicled muscle flaps, and free fasciocutaneous or musculocutaneuos flaps [2–4]. Since Masquelet et al. first reported the anatomical study and application of sural neurovascular flaps in the leg in 1992[5], the distally pedicled sural neurovascular flap has become one of the most commonly used flaps for the treatment of soft tissue defects in the ankle, foot, and distal one third of the lower leg [6,7].

Sural neurovascular flaps have advantages in treating ankle, foot, and leg defects, including proximity to the recipient site, easy excision, no injury to large blood vessels, good sensation recovery in the flap, and good skin quality [8,9]. However, the clinical application of sural neurovascular flaps has been restricted by some complications such as postoperative swelling, congestion, and flap necrosis [10–12]. It has been reported that an inappropriate sized flap or an oversized flap without inadequate blood supply contribute to low survival rates of the flap [13]. Traditionally, the preoperative design of the flap is to examine the blood vessels using two-dimensional imaging techniques such as Doppler ultrasonography and digital subtraction angiography. However, the caliber of the sural nerve nutritional blood vessel is very small, and cannot be detected by Doppler ultrasonography and angiography. Therefore, the size and shape of the excised flap cannot be accurately designed before operation.

Recently, the development of digitalized techniques and diagnostic imaging techniques in the field of microsurgery has made it possible to apply three-dimensional (3D) reconstruction to observe the stereoscopic anatomy of the flap [14]. The flap blood supply can be visualized stereoscopically preoperatively, thus allowing the best design of the flap, the best surgical approach, and the most suitable therapy protocol. 3D reconstructed images have been used in surgical reconstruction with latissimus dorsi muscular flaps, anterolateral thigh flaps, and dorsalis pedis flaps [15–17]. There are few reports regarding the application of digitalized techniques in sural neuromuscular flaps. Zhang et al. [18] reported the application of digitalization in sural neuro fascio myocutaneous flap transferring in 5 patients with soft tissue defects in the foot and found that all flaps survived. However, the effects of 3D digitalized planning for sural neurovascular flaps have not been studied in a large population of patients with soft tissue defects in the ankle and foot.

In this study, we investigated the effects of 3D digitalized virtual planning for retrograde sural neurovascular island flaps in patients with soft tissue defects in the ankle and foot. The purpose of this study was to determine the effectiveness and safety of 3D digitalized reconstruction for designing sural neuromuscular flaps to repair soft tissue defects in the ankle and foot.

2. Materials and methods

2.1. *Patients*

This study was approved by our ethics committee of the Chinese PLA 253rd Hospital, and all patients gave their informed consent prior to inclusion in the study. This study included 40 patients (26 males and 14 females) with soft tissue defects of the ankle and foot who underwent soft tissue reconstruction at our hospital between October 2008 and June 2012. The average age of patients was 42.60 ± 5.78 years (range, 15–65 years). Inclusion criteria were: (1) patient age between 15 and 65 years; (2) male or female patients; (3) deep wound defects in the distal one third of the lower leg, ankle, or foot with exposure of larger blood vessels, nerves, tendons, and bones; and (4) shallow wound defects with exposure of unnamed smaller blood vessels, nerves, tendons, and bones, or had a large soft tissue defect that was poorly repaired using a skin graft. Exclusion criteria were: (1) severe cardiovascular, pulmonary, renal, hepatic, and gastrointestinal diseases; (2) extensive burn and frostbite injuries associated with inhalation injuries and shock; (3) severe injuries of the vital organs in the head, chest, and abdomen, or multiple injuries associated with shock; and (4) osteomyelitis and intra-articular infection.

Causes of soft tissue defects included electrical burns ($n = 3$), hot crush injuries ($n = 11$), frostbite ($n = 5$), trauma ($n = 16$), and pressure ulcers ($n = 5$). Soft tissue defects were located in the distal one third of the lower leg ($n = 9$), around the ankle ($n = 21$), and in the posterior heel with an exposed Achilles tendon and calcaneus ($n = 10$). Fresh soft tissue defects were found in 32 cases, and previous necrotic skin defects in 8 cases. The size of the skin and soft tissue defects ranged from 5 cm × 7 cm to 10 cm × 15 cm. The patients were randomly assigned to two groups: three-dimensional (3D)-reconstruction group (Group A, $n = 20$) and control group (Group B, $n = 20$). Three-dimensional, digitalized virtual planning was performed on the patients in the Group A. Patient age and sex, as well as the cause, size, or site of the defects, were not significantly different between the two groups ($P > 0.05$, Table 1).

2.2. *CT scan and 3D-reconstruction*

Patients in Group A were examined using a 64 spiral CT scanner (GE, USA) at the Department of Radiology of the 253rd Hospital of the Chinese People's Liberation Army. The preoperative iodine allergy test was negative for all patients. Patients were injected with 90 ml of the non-ionic contrast agent Ultravist 300 (Guangzhou Pharmaceuticals Corporation, Guangzhou, China) via the median cubital vein at a rate of 3 ml/s. The main CT scanning parameters were as follows: 120 kV, 200 mA; slice thickness, 2.5 cm (final reconstructed images were partitioned into 0.625 mm thick images). Serial data from the lateral malleolus to the tibial plateau regions in dicom format were imported to a personal computer. 3D reconstruction was then performed using Amira 4.1 software. The 3D reconstruction consisted of: (1) tracing the contours of the anatomical structures to be reconstructed; (2) adjusting the contours of stacked points by geometrical alignment; (3)