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Influence of venous stasis on survival of epigastric flaps in rats

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Abstract

Venous congestion results in tissue damage and remains the most common reason for failure of transfer of microvascular free flaps if it is not recognised early. The purpose of this study was to measure the critical duration of venous congestion and the resultant survival of flaps according to the duration of venous stasis. A standard epigastric flap was raised and repositioned in 35 rats, seven of which acted as controls. The superficial inferior epigastric vein was fully occluded for four, five, six, or seven hours in the rest (n = 7 each group). Subsequently, the rats were monitored for one week, and the resultant necrotic areas were photographed. After five, six, and seven hours of venous stasis, the incidence and area of necrosis were significantly increased (p = 0.04 in each) above that of the control. The degree of necrosis after seven hours of venous stasis was significantly greater than that after four or five hours (p = 0.01 and 0.02, respectively). The duration of venous congestion is therefore a potential risk for the survival of free flaps, as it results in operative complications and may jeopardise the whole procedure. After a critical period of venous stasis we reach a point of no return, and any attempt to salvage the compromised flap will be in vain. Based on these results, we think that monitoring by an experienced surgeon at intervals of no longer than three hours is essential for the successful salvage of venous congestion in microvascular free flaps.

Keywords: venous congestion; blood flow analysis; free flap survival

Introduction

Functional and aesthetic reconstructions using a range of vascularised cutaneous and composite flaps are standard procedures in reconstructive surgery. There are many indications for reconstruction, which makes them suitable for a challenging group of patients with many coexisting conditions.[1–3] Screening and monitoring are used before, during, and after the flap has been raised to try and reduce the rate of failure,[4] particularly among the increasing number of patients with compromised vascular systems. Early identification of flaps at risk, and return to the operating theatre for a salvage operation with revision of the vascular anastomosis, are the current standards of care.[5] Missed opportunities for salvage of compromised free flaps can lead to failure, which results in a prolonged stay in hospital, inferior functional and aesthetic outcomes, and a reduced quality of life.[6]

Despite high rates of successful transfer of free flaps, venous congestion remains the most common reason for failure,[7–9] and causes include a pedicle that is too short or the wrong shape, or inadequate venous drainage because of technical error, compression, or kinking of the vein.[10–12]

Most experimental and clinical studies have focused on the detection of ischaemia in the microvascular free flap. Although some authors have stated that compromised circulation can be re-established after 8–12 hours because of the

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"no-reflow" phenomenon,[13,14] venous congestion remains critical and if the microcirculation is compromised by microthrombi they must be removed by complex rheological and anticoagulant processes.

We designed the present study to find out the duration of time during which venous congestion results in no harm to survival of the free flap after complete re-exploration and vascular salvage. This information is incorporated into advice for the timing of monitoring during the postoperative period.

Material and methods

Ethics statement and animal welfare

The study conformed with current German guidelines for animal welfare and the international principles of laboratory animal care. The local government approved the animal experiments. The animals were housed in filter-top cages under hygienic conditions according to the guidelines of the Federation of Laboratory Animal Science Associations, and had free access to water and standard rodent diet (Altromin; Altromin Spezialfutter GmbH & Co. KG; Lage, Germany). The rats were visited twice a day postoperatively by one of the authors (LMR or LHS). The daily observations were made according to a standard protocol that took account of animal welfare (reaction to pain, animal's gesture, behaviour, healing of the abdominal wound, and movement).

Design of the experiment

After the induction of anaesthesia by intraperitoneal injection of a weight-dependent mixture of ketamine-xylazine (1 ml/kg/weight and 0.25 ml/kg/weight, respectively), the procedures were done under intravenous anaesthesia by access through the femoral vein in the right inguinal region after insertion of a microcatheter (Premicath; VYGON GmbH & Co. KG; Aachen, Germany). For further support of the anaesthesia, one-eighth doses of 10% ketamine were given when needed, as previously described elsewhere.[15,16]

The abdomen was shaved, and a standard 4 × 4 cm fasciocutaneous epigastric flap on the left side was raised. All perforators were ligated and cut.[17] The vascular pedicle consisted solely of the superficial inferior epigastric artery and vein (SIEA and SIEV) and was carefully mobilised and separated before the first flowmeter reading was taken (TS-420; Transonic System Inc.; Ithaca, NY, USA) (Fig. 1).

The flap was subsequently sutured back with interrupted sutures (6/0 Ethilon®, Ethicon; Norderstedt, Germany) leaving the caudal border open. The SIEV was temporarily occluded with a single Acland clip, the caudal border was closed, the microcatheter was removed, and the rats were roused from anaesthesia with the Acland clip in place. After the interval of 100% venous stasis for four, five, six, or seven hours (n = 7 each), the temporary clip was removed under a short anaesthetic according to the protocol described.

Finally, the wounds were closed, and the rats were observed for one week. The control group (no venous stasis) had had no temporary venous clipping. After one week, the rats were re-anaesthetised using the same protocol, each flap was documented photographically (500D Canon, Germany, mounted on a stand perpendicular to the wound bed), and a final flowmeter reading was taken (SIEV and SIEA). The photographic images were planimetrically analysed for the presence of clinically vital and necrotic skin areas with NIH Image Software (ImageJ 1.41o, National Institutes of Health, USA).[18]

The rats were killed under deep anaesthesia by intracardiac injection of pentobarbital, 60 mg/kg body weight (Narcoren®, Fa. Rhone.Merieux GmbH, Laupheim) following a standard protocol[19] after all measurements had been made.

Blood flow analyses

Blood flow was measured at each time point on the SIEA and SIEV for 30 seconds with a flowmeter (TS-420; Transonic System Inc.; Ithaca, NY, USA). A mean of five measurements was calculated within these 30 seconds to reduce bias caused by movement or temporary vascular spasm.

Statistical analyses

We used IBM SPSS 23.0 for Windows software (IBM Corp, Armonk, NY, USA), and figures were generated with Excel® (Microsoft Excel® 14.2.3 for Mac, Microsoft Corp., Redmond, WA, USA). The significances of differences between the areas of necrosis were evaluated with the Mann-Whitney *U* test. Probabilities (two-tailed) of less than 0.05 were accepted as significant.

Results

Descriptive results

The incidence of necrosis increased with the time of venous stasis, as did the median necrotic area of flaps in the subgroups after zero, four, five, six, and seven hours of venous stasis (Table 1, Fig. 1). After an interval of five hours of venous stasis, the incidence and size of the areas of necrosis significantly increased compared with those of the control group (each p = 0.04).

Flowmeter analysis

The flow in the SIEA and SIEV was comparable before venous clipping and ranged between 0.35–0.42 ml/minute and 0.39–0.5 ml/minute, respectively. The arterial flow had decreased in the follow-up measurements after one week,

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