Tissue Expansion Using Osmotically Active Hydrogel Systems for Direct Closure of the Donor Defect of the Radial Forearm Flap


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Although widely used, the radial forearm flap has been criticized for the poor quality of its donor site. Attempts to avoid donor-site problems have concentrated on the elaboration of the split-thickness and full-thickness skin graft methods of reconstruction. Skin grafts frequently fail over the flexor carpi radialis tendon, leading to chronic skin breakdown or, at best, tendon adhesion. Tissue expansion appears to be a good alternative that allows the use of local tissues to ultimately improve the forearm donor-site appearance. To avoid the disadvantages of traditional silicone balloon expanders (such as pressure peaks, infection, the valve at a distance from the expander, postoperative fillings), an osmotically active system was used. In an 18-month prospective study, 10 osmotically active hydrogel tissue expanders were placed on the forearms of 10 patients. The radial forearm flap was performed for intraoral reconstruction after surgical resection of oral cavity malignancies. The study showed that, in 8 of 10 patients, the expanded skin achieved was sufficient to cover the donor site after raising the forearm flap. Additionally, the expansion-related swelling pressure was well tolerated by the patients; the cosmetic results were very satisfactory, and the incidence of complications was very low. By using osmotically active hydrogel tissue expanders, there is no postoperative filling and no risk of complications arising from deflating balloon expanders, filling valves, or missing ports. (Plast Reconstr Surg. 108: 1, 2001.)

The radial forearm flap has proved a popular and reliable method of reconstruction in plastic surgery, being a thin, often hairless, well-vascularized flap. Although widely used, the radial forearm flap has been criticized for the poor quality of its donor site. This otherwise advantageous donor site can be problematic because of the ensuing deformity from its use. Poor cosmetic results with sinking deformity are often observed at the donor site of the radial forearm flap. Delayed wound healing, subsequent dysesthesias in areas distal to the harvested flap, swelling of the hand, stiffness of the joints, and cold-induced symptoms have been described. Attempts to avoid donor-site problems have concentrated on the elaboration of the split-thickness and full-thickness skin graft methods of reconstruction. Procedures for the implantation of an artificial dermis and a two-step procedure involving primary wound closure with a fascial split-thickness graft have also been described.

Tissue expansion is another procedure which may be used to avoid problems related to wound closure. Hallcross augmented the remaining dorsal forearm skin by means of a longitudinal, curved silicone expander filled by a weekly percutaneous instillation of saline. This method seemed to be a good alternative that allowed the use of local tissues to ultimately improve the forearm donor-site appearance. However, literature sources document a high frequency (up to 40 percent) of complications with the method. To avoid these complications and other well-known disadvantages of traditional silicone balloon expanders, To avoid these complications and other well-known disadvantages of traditional silicone balloon exp-

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Pandera, we used an osmotically active hydrogel expander system (Osmed, Illmenau, Germany).

**Patients and Methods**

**Patients**

In a prospective study, we documented the surgical procedure of expander implantation, the subsequent tissue expansion, the development of pain and complications, the procedure of explantation, the coverage of the donor-site defect, and the cosmetic results of the covered defect in 10 male patients (aged 39 to 74 years, with a mean age of 54.2). The forearm flaps ranged in size from $5 \times 3$ cm to $8 \times 5$ cm, with a mean size of $6 \times 4$ cm. All of the patients had a diagnosis of oral cancer. No underlying disorder, such as cardiovascular or renal disease, was present.

**Expander**

Self-inflating expanders absorb body fluid from the surrounding tissue through osmotic action, with expander volume remaining stable once the final volume has been reached. We used an osmotically active hydrogel that was a copolymer of methyl methacrylate and vinyl pyrrolidone. The expanders had a rectangular base and a starting volume of 10 ml. Having a swelling factor of 10, the expanders achieved a final volume of approximately 100 ml (Fig. 1). The hydrogel expander was implanted 20 days before raising the forearm flap. The maximum pressure against which the expander could stretch tissue was tested experimentally and averaged 28 mmHg (range, 21 to 30). This osmotically active tissue expander is currently being used in a multicenter clinical test phase in Germany, where substantial animal research using the expander has been done by Wiese. At the moment, however, the expander is only available for study purposes.

**Operation**

All patients were assessed preoperatively, using Allen’s test to determine collateral circulation and an ultrasound Doppler probe to measure the radial and ulnar flow. The nondominant forearm was used in the assessment whenever possible. The radial forearm flap, which was designed in the usual fashion, was placed as much as possible on the volar forearm surface, with its axis parallel to the distal radial artery. To prepare the implant site, an incision approximately 3 cm long was made through the skin and the subcutis above the margo anterior ossis radii, about one handbreadth distal from the bend of the elbow. To insert the tissue expander, the deep fascia of the skin was first identified and separated from the underlying tissues, then subcutaneously tunneled to form a pocket for the expander (Fig. 2). The hydrogel expander was implanted lateral (and adjacent) to the planned radial forearm flap in the epifascial plane, then immobilized with a mild dressing.

The surgical implantation procedure was documented, with tissue expansion monitored every 5 days using skin tattoos (p1, p2, and p3) (Fig. 3). Care was taken to monitor the condition of the distended skin, and possible complications were checked and listed. Pain was assessed using a visual analog scale in which 0 = absolutely no pain and 100 = absolutely maximum conceivable pain. After the radial forearm flap was raised in the standard fashion, the expander was removed and the expanded

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**Fig. 1.** View of a tissue expander before implantation (left) and after explantation (right).

**Fig. 2.** The skin was tunneled subcutaneously to form a pocket for the expander.
skin flap advanced into the donor defect. The range of motion of the wrist was controlled postoperatively. Particular emphasis was placed on the subjective cosmetic results of the donor site.

RESULTS

Operation

Implantation was carried out under general anesthesia in seven of the 10 cases; the other three patients required brachial plexus anesthesia. The average duration of the implantation procedure was 20 minutes, and there were no intraoperative complications.

Tissue Expansion

The diagram in Figure 4 shows the time-related expansion of skin after implantation. Skin expansion occurred relatively rapidly in the first 5 days after implantation, slowing down considerably after the fifth day. An implant’s volume remains stable once its final volume has been reached.10

Pain

Subjective assessment on a scale from 0 to 100 demonstrated relatively low pain scores (average score: 27.94) (Fig. 5). No patients complained of symptoms relating to joint motion or of any functional deficit.

Complications

Apart from initial edema of the hand (in two patients) in the first week after implantation, no prolonged swelling or joint stiffness was encountered. In eight patients, redness of the expanded skin was related to the speed of the initial expansion and usually disappeared after 10 days. An extreme lack of compliance in one patient (who refused to change his habit of wearing a leather jacket with very tight sleeves) resulted in a skin pressure spot over the expanded skin and the subsequent occurrence of skin perforation. Ultimately, this patient’s radial forearm flap had to be raised from the contralateral side.

Explantation and Coverage of the Donor-Site Defect

In the other nine patients, the expanded skin achieved was adequate for sufficient coverage of the donor site.

Cosmetic Result

Patients were followed up for 6 to 18 months. Subjectively, the cosmetic results of the forearms after radial forearm flap dissection were incomparably better with the application of a tissue expander than with split-thickness graft coverage of the defect or primary closure of the donor site (Fig. 6).

DISCUSSION

Most free flap donor sites can be managed by primary closure. However, the forearm flap is a definite exception to this rule. At the time of forearm flap planning, consideration should be given to the treatment of the donor site. Before indication of the radial forearm flap, it is necessary to determine cosmetic and functional consequences for the donor site. Donor-site morbidity can be a problem, even several years after surgery.11 For this reason, some reports also conclude that it is not prudent to use the flap in younger patients and children because of the possibility of hypertrophic forearm cicatization.11 Conversely, in elderly patients, the skin of the forearm is flaccid, permitting advancement of the skin for primary donor-site closure in many instances.12

The principal negative characteristics of the radial forearm flap are scar deformation of the
forearm and donor-site morbidity. Many suggestions have already been made for minimizing the donor-site defect; these include taking the flap only from the volar forearm surface,\textsuperscript{13} overseeing the flexor carpi radialis tendon with neighboring muscle fibers to enhance skin graft adherence,\textsuperscript{4} or transferring the fascia alone.\textsuperscript{3,14}

Other attempts to avoid donor-site problems have concentrated on elaboration of the split skin graft method of reconstruction. One common donor-site problem is poor take of the skin graft over the flexor carpi radialis tendon. Despite precautions to preserve the peritenon,\textsuperscript{2} skin grafts sometimes fail over the flexor carpi radialis tendon, leading to chronic skin breakdown or, at best, tendon adhesion.\textsuperscript{3,4} Nevertheless, the risk of infection arises because the split-thickness skin graft is performed 1 to 2 weeks after harvesting the forearm flap, when the wound is at a high risk of infection and needs to be carefully managed for a longer period.\textsuperscript{6}

Chambers et al.\textsuperscript{5} recommend use of the ipsilateral full-thickness forearm skin graft with V-Y advancement as a simple and suitable method for primary closure of radial forearm free flap defects up to a size of approximately 8 × 6 cm. Wolff et al.\textsuperscript{7} used a two-stage procedure. In the first step, a 0.5-mm split-thickness skin graft was transplanted to the forearm fascia and settled there over a period of 2 weeks. In the second step, the prefabricated fascial split-thickness skin graft (an extremely thin flap) could be raised with complete preservation of the forearm skin. Primary donor-site closure was achieved with minimal aesthetic and functional impairment.

Tissue expansion seems to be a good alternative to skin grafting, allowing use of local tissues to ultimately improve the forearm donor-site appearance.\textsuperscript{8} Disadvantages of the silicone balloon expander include the subcutaneous implantation of the valve at a distance from the expander. Also, pressure peaks after injection of the sodium chloride solution, resulting in temporary tissue hypoxia, are well known.\textsuperscript{10} There is also a risk of infection after frequent percutaneous injections.\textsuperscript{9} To avoid these disadvantages of traditional silicone balloon expanders, we used an osmotically active hydrogel tissue-expander system.

In this study, the expanded skin achieved was adequate for sufficient donor-site coverage. This extra skin allowed the defect to be closed using the same quality tissue. The swelling pressure was well tolerated by the patients, and the cosmetic results were very satisfactory. The hydrogel expanders used in the study have a strong synthetic form and are easier to handle, more robust, and less susceptible to damage than balloon expanders.\textsuperscript{16} In addition, with osmotic expanders, less surgery time is required to implamt and explant than with traditional silicone expanders. Any expander shape can be produced. Moreover, the surgeon himself can individually adapt the expander before implantation. There is no postoperative filling and no risk of complications due to defective balloon expanders, filling valves, or missing ports.

Despite these advantages, there are nevertheless potential problems with the pre-expansion of flaps. One such problem would be the danger of wound dehiscence and skin necrosis, such as happened with one of our patients. Because of this danger, the surgeon should closely monitor the process of skin expansion. However, such monitoring can be
problematic when using the hydrogel expander system, because as skin expansion progresses “autonomously,” a patient displaying poor compliance fails to appreciate the need for regular medical checks. As a result, the follow-up may be insufficient.

Another disadvantage lies in the fact that the volume of the expander cannot be reduced in the event of impending complications (such as skin perforation). Once a problem has occurred, the expander has to be removed. We are currently working on a hydrogel expander that has a slightly slower swelling curve. If the initial swelling proceeds at a slower rate, it will be possible to implant larger expanders in the forearm area. At the moment, however, the hydrogel expander system is only indicated for relatively small radial forearm flaps.

A clear disadvantage of preapplication of skin expansion in general is the need to wait at least 20 days before proceeding to a cancer ablative procedure. Because the radial forearm flap in our patients was intended for intraoral reconstruction after surgical resection of malignancies, we used this period of time for preoperative radiotherapy.

Initial clinical tissue expansion experiments using the hydrogel expander in the scalp area have already been successfully concluded. Use of the osmotically active expander is also currently undergoing multicenter clinical testing in reconstructive breast surgery. Other ranges of application, such as the expansion of fascia, blood vessels, or nerves, will be tested in the next stage.

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Discussion

Tissue Expansion Using Osmotically Active Hydrogel Systems for Direct Closure of the Donor Defect of the Radial Forearm Flap


Discussion by Wolfgang Mühlbauer, M.D.

In 1980, together with a small German/Austrian delegation, I visited several hospitals in the People's Republic of China. At Ba-Da-Chu Hospital for Plastic and Reconstructive Surgery near Beijing (headed by Dr. Ruyao Song), a number of free forearm flaps used for the release of burn contractures aroused our interest. It was only some time later that we learned that Drs. Yang Guofan, Chen Baoqui, and Gaou Yuzhi of the Shenyang Military General Hospital were in 1978 the originators of this peculiar flap. After engaging in experimental and clinical studies, we successfully applied the Chinese radial forearm flap as a free or pedicled neurovascular axial-pattern flap and added a number of variations.12

After the 1982 publication of our experiences with the forearm flap in Plastic and Reconstructive Surgery,3 use of this flap became very popular among plastic, hand, maxillofacial, and orthopedic surgeons for its well-known qualities. In that publication, we mentioned the cosmetic and functional impairment of the donor site when covered with split-thickness or full-thickness skin grafts. Initially, we tried to overcome this problem through secondary expansion of the adjacent forearm skin with subsequent partial or total excision of the skin grafts on the donor site. Later, we progressed to the principle of expanding the adjacent skin before raising the flap for direct closure of the donor defect with a linear scar.4

In their article, Bergé et al. describe the same principle, using osmotically active hydrogel systems instead of conventional inflatable expanders. The indication for this new system is seen in the well-known shortcomings and complications of inflatable expanders, including repeated injections with pressure peaks resulting in temporary tissue hypoxia and pain, accidental leaks and deflation, threatening penetration of the skin or scar, and infection.

In contrast, the originally small volume of the hydrogel expander is easier to insert and resistant to damage, with essentially painless, continuous self-inflation by osmosis and a swelling factor of 10 over a relatively short period of time. The authors mention only one major complication—a skin perforation over the expander attributed mainly to a lack of compliance by the patient. The authors therefore advise the surgeon to closely monitor the process of skin auto-expansion. A potential disadvantage is seen in the fact that the volume cannot be reduced in the event of impending complications. However, to further reduce the potential for complications, the group is currently working on a hydrogel that expands at a slower rate. They should also define the maximum volume of an individual hydrogel implant to aid the surgeon in practice in choosing the correct size.

The osmotically active hydrogel expansion appears to be a very interesting modality that has the same indications as the classic inflatable expander. It promises more comfort to patient and surgeon alike, with a lower rate of complications. Other groups have recently re-
ported successful hydrogel expansion for breast reconstruction. 5

The authors are to be congratulated for their well-designed clinical study and for its results, which promise wide clinical applications as soon as this material is available on the market.

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