Systematic Review of Tissue Expansion: Utilization in Non-breast Applications

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Background: Tissue expansion is a versatile reconstructive technique providing well-vascularized local tissue. The current literature focuses largely on tissue expansion for breast reconstruction and in the context of burn and pediatric skin/soft tissue replacement; however, less traditional applications are also prevalent. The aim of this study was to systematically review the utilization of tissue expansion in such less well-characterized circumstances.

Methods: The authors conducted a systematic review of all publications describing non-breast applications of tissue expansion. Variables regarding expander specifications, expansion process, and complications were collected and further analyzed.

Results: A total of 565 publications were identified. Of these, 166 publications described tissue expansion for “less traditional” indications, which fell into 5 categories: ear reconstruction, cranioplasty, abdominal wall reconstruction, orthopedic procedures, and genital (penile/scrotal and vaginal/vulva) reconstruction. While lower extremity expansion is known to have high complication rates, tissue expander failure, infection, and exposure rates were in fact highest for penile/scrotal (failure: 18.5%; infection: 15.5%; exposure: 12.5%) and vaginal/vulva (failure: 20.6%; infection: 10.3%; exposure: 6.9%) reconstruction.

Conclusions: Tissue expansion enables index operations by providing additional skin before definitive reconstruction. Tissue expanders are a valuable option along the reconstructive ladder because they obviate the need for free tissue transfer. Although tissue expansion comes with inherent risk, aggregate outcome failures of the final reconstruction are similar to published rates of complications without pre-expansion. Thus, although tissue expansion requires a staged approach, it remains a valuable option in facilitating a variety of reconstructive procedures.

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INTRODUCTION

First introduced in 1957 in the context of ear reconstruction, tissue expansion has evolved as a commonly used reconstructive technique. The advantages of using tissue expanders (TEs) include providing locally sourced vascularized tissue, decreasing donor site morbidity by obviating the need for free tissue transfer, and preserving local skin color, texture, and hair-bearing characteristics. TEs are not without drawbacks: a lengthy process of expansion, the need for multiple operations, and a temporary aesthetic deformity that may not be tolerated.

The current plastic surgery literature provides robust data on utility and outcomes for tissue expansion in the context of breast reconstruction, burn reconstruction, and pediatric skin/soft tissue replacement. This study aimed to provide a similar assessment for less traditional indications for tissue expansion by systematically reviewing studies describing the use of TEs before index operations. Two case examples in which TEs are used to facilitate index operations (1 cranioplasty and 1 orthopedic procedure) are presented.
METHODS
The databases Medline (National Library of Medicine), Embase (Elsevier), and Scopus (Elsevier) were searched from inception to September 17, 2019. Each database was searched using a combination of keywords to represent the concepts of tissue expansion, surgery, and reconstruction. The full searches are available in SDC 1. (See appendix, Supplemental Digital Content 1, which displays the search strategy report. http://links.lww.com/PRSGO/B559.)

The search was supported by a medical librarian. Non-human studies, editorials, comments, and conference abstracts were removed from the results when the databases allowed it. Search results were compiled in EndNote and then imported into Covidence. The risk of bias was not assessed.

All English language studies that reported the results of tissue expansion in non-breast reconstruction patients were included. Exclusion criteria included the use of external stretching devices, intraoperative expansion only, and self-filling expanders. The publications were independently screened by 2 reviewers with conflicts broken by the first author (HL).

Studies were then categorized into traditional and less traditional groups. Traditional was defined as studies utilizing TEs for burn reconstruction or skin-/soft tissue replacement; less traditional publications encompassed all other applications. For these less traditional indications, we reviewed the patients’ age, disease etiology, TE specifications, final TE volume, and the process of tissue expansion. Complications analyzed were TE failure, TE exposure, TE infection, hematoma, wound dehiscence, superficial infection, skin flap necrosis, and any other reported complications. TE failure was defined as any instance in which a TE was removed prematurely. Superficial infection was defined as erythema that was reported to be limited to the skin and not involve the TE, and TE infection was specifically noted in the study to involve the expander. For studies describing traditional indications, we collected information about the indication for TE and number of patients.

RESULTS
After removal of duplicates, 5083 studies were screened and 765 full-texts were reviewed. Of these, 92 were excluded due to the use of interventions such as external or self-filling expanders and to the use of intraoperative expansion only. Eighty-eight were excluded due to the lack of patient-specific outcomes, and 20 were excluded because full-texts could not be located by the reviewers or medical librarian (Fig. 1).

A total of 565 publications were included after full-text review. There were 399 traditional use publications and 166 less traditional use publications. The traditional group included a total of 7767 patients. Patients with TEs for breast reconstruction were excluded in the screening stage and are not included in this review. The most common indication for TE in the traditional group was burn (52.3%), followed by congenital nevi (11.7%) and scar revision (5.0%) (Table 1). The less traditional group included a total of 10,800 patients with ear reconstruction comprising 93.5% (Table 2). Some surgeons use tissue expansion for soft tissue coverage in ear reconstruction, but many others use skin grafts or fascial flaps. A 2014 review found that most surgeons use the techniques developed by Nagata and Brent. Given that tissue expansion is only one of many methods utilized during microtia reconstruction, ear reconstruction was included in the less traditional group in this review. Results of the expansion process, TE shape, and complications are summarized in Tables 3–5 and detailed below.

Ear Reconstruction
A total of 44 publications describing 10,101 patients who received a TE before ear reconstruction were included. The average age of the patients was 15.3 years (range, 7–41). The indication for ear reconstruction was microtia in 96.5%, trauma in 3.2%, congenital ear deformities other than microtia in 0.28%, and tumor in 0.01%. The plane of expansion was subcutaneous in 37 papers (84.1%), subfascial in 3 (6.8%), dual-plane (subcutaneous and subfascial) in 3 (6.8%), and subgaleal in 1 (2.3%). The average duration of expansion was 2.3 months. Nineteen papers reported a period of static expansion, which is the time when no additional fluid is inserted, on average 4.9 weeks before the index procedure. The average follow-up was 25.7 months. Of the 10,101 patients, 132 (1.3%) had TE failure, 19 (0.19%) TE infection, 127 (1.3%) TE exposure, 196 (1.9%) hematoma, 30 (0.30%) wound dehiscence, 2 (0.020%) superficial infection, and 77 (0.76%) skin flap necrosis. Other reported complications included 289 (2.9%) patients with hypertrophic scarring, 99 (0.98%) framework or suture wire exposure, 21 (0.21%) framework absorption or deformity, 9 (0.089%) TE leakage, 9 (0.089%) framework infection, 7 (0.060%) seroma, 6 (0.059%) skin graft loss, and 4 (0.040%) venous congestion.

Cranioplasty
A total of 14 publications describing 74 patients who received a TE before cranioplasty were included. The average age of the patients was 31.6 years (range, 8–55). The indication for cranioplasty was tumor in 32.4%, trauma in 12.2%, epilepsy in 10.8%, vascular cerebral accident in 2.7%, and unspecified in 41.9%. The TE was placed in the subgaleal plane for all patients. The average duration of expansion was 3.6 months. The average follow-up was 22.4 months. Of the 74 patients, 3 (4.1%) had TE failure, 2 (2.7%) TE infection, 2 (2.7%) TE exposure, 1 (1.4%) hematoma, and 1 (1.4%) wound dehiscence. Other reported complications included 6 patients (8.1%) with permanent implant exposure or removal and 1 (1.4%) with seroma.

Abdominal Wall
A total of 30 publications describing 150 patients who received a TE before abdominal wall reconstruction were included. The average age of the patients was 26.9 years (range, 3 weeks to 61 years). The indication for abdominal
wall reconstruction was ventral hernia repair in 82.0% and repair of congenital defects, most commonly omphalocele, in 18.0%. The plane of TE placement was subcutaneous in 15 papers (50%), intermuscular in 8 (26.7%), intra-abdominal in 3 (10.0%), and multiple planes or not specified in 4 (13.3%). The average duration of expansion was 2.8 months. Four papers reported a period of static expansion, on average 9 weeks before the index procedure. The average follow-up was 31.3 months. Of the 150 patients, 8 (5.3%) had a TE failure (6 subcutaneous and 2 intermuscular), 7 (4.7%) TE infection (6 subcutaneous, 1 intermuscular), 4 (2.7%) TE exposure (3 subcutaneous, 1 not specified), 11 (7.3%) hematoma, 4 (2.7%) wound dehiscence, 5 (3.3%) superficial infection, and 1 (0.67%) skin flap necrosis. Other reported complications included 1 patient (0.67%) with enterocutaneous fistula, 1 (0.67%) insufficient skin after expansion for closure, 1 (0.67%) femoral nerve neuropraxia, 2 (1.3%) port failure, and 1 (0.67%) small bowel gangrene. Of the 123 patients who had a ventral hernia repair, 10 (8.1%) had recurrence of the hernia.

Table 1. Indications for Tissue Expansion in the Traditional Group

| Indication            | % Patients |
|-----------------------|------------|
| Burn                  | 52.5       |
| Nevi                  | 11.7       |
| Scar                  | 5.0        |
| Alopecia              | 2.1        |
| Traumatic wounds      | 2.1        |
| Pressure ulcers       | 1.8        |
| AVM                   | 1.4        |
| Cancer                | 1.4        |
| Skin graft            | 1.3        |
| Aplasia cutis congenita| 0.3        |
| Other                 | 3.2        |
| Not specified         | 17.3       |

AVM, arteriovenous malformation.

Table 2. Indications for Tissue Expansion in the Less Traditional Group

| Indication                           | % Patients |
|--------------------------------------|------------|
| Ear reconstruction                   | 93.5       |
| Genital reconstruction               | 1.9        |
| Penile/scrotal reconstruction         | 1.6        |
| Vaginal/vulva reconstruction          | 0.27       |
| Orthopedic reconstruction            | 1.6        |
| Abdominal wall reconstruction        | 1.4        |
| Cranioplasty                         | 0.69       |
| Other                                | 1.0        |
Orthopedic Procedures

A total of 22 publications describing 170 patients who received a TE before an orthopedic procedure were included.93–114 The average age of the patients was 30.5 years (range, 1–76). The indication for orthopedic intervention was total knee arthroplasty in 61.8%, clubfoot in 19.4%, foot and ankle surgery besides clubfoot in 11.8%, kyphoscoliosis in 4.1%, femur pathology in 1.8%, tibial bone grafting in 0.6%, and quadriceps lengthening and patellar re-alignment in 0.59%. The average duration of expansion was 2.2 months. Three of 22 papers reported a period of static expansion, on average 5 weeks before the index procedure. The average follow-up was 21.8 months. Of the 170 patients, 18 (10.6%) had TE failure, 6 (3.5%) TE infection, 6 (3.5%) TE exposure, 4 (2.4%) hematoma, 9 (5.3%) wound dehiscence, 12 (7.1%) superficial infection, and 7 (4.1%) skin flap necrosis. Other reported complications included 3 patients (1.8%) with TE leakage, 2 (1.2%) with TE migration, and 5 (2.9%) with skin blistering.

Genital Reconstruction

Penile/Scrotal Reconstruction

A total of 17 publications describing 168 patients who received a TE before penile or scrotal reconstruction were included.115–131 The average age of the patients was 30.1 years (range, 3–57). The indication for penile or scrotal reconstruction was hypospadias in 35.7%, trans-gender surgery in 31.0%, epispadias in 24.4%, trauma in 4.2%, infection in 3.0%, bladder extrophy in 0.59%, cryptorchidism in 0.59%, and congenital adrenal hyperplasia in 0.59%. The average duration of expansion was 3.4 months. One publication reported a period of static expansion of 12 weeks before the index procedure. The average follow-up was 39.0 months. Of the 168 patients, 31 (18.5%) had TE failure, 26 (15.5%) TE infection, 21 (12.5%) TE exposure, 2 (1.2%) hematoma, 6 (3.6%) wound dehiscence, 10 (6.0%) superficial infection, and 1 (0.6%) flap necrosis. Other reported complications included 25 (14.9%) patients with TE leakage, 28 (16.7%) urinary fistula, 5 (3.0%) TE migration, 12 (7.1%) residual chordee, 17 (10.1%) urethral stricture, and 4 (2.4%) port failure. Six of the 60 (10.0%) hypospadias patients had residual hypospadias.

Vaginal/Vulva Reconstruction

A total of 10 publications describing 29 patients who received a TE in a labial or subcutaneous pocket before vaginal or vulva reconstruction were included.132–141 The average age of the patients was 15.4 years (range, 1–23). The indication for vaginal or vulva reconstruction was a congenital anomaly in all patients, including 65.5% with...
congenital vaginal agenesis, 13.8% bladder extrophy, 10.3% congenital adrenal hyperplasia, 3.4% cloacal extrophy, 3.4% urogenital sinus, and 3.4% with utero-vaginal aplasia. The average duration of expansion was 1.8 months. One publication reported a period of static expansion of 3 weeks before the index procedure. The average follow-up was 10.8 months. Of the 29 patients, 6 (20.7%) had TE failure, 3 (10.3%) showed TE infection, 2 (6.9%) had TE exposure, 2 (6.9%) showed hematoma, and 1 (3.4%) had wound dehiscence. The only other reported complication was chronic vaginal stenosis in 1 (3.4%) patient.

Other Indications
A total of 29 publications describing 108 patients who received a TE before a variety of other index operations were included.72,142–169 Thirty-eight patients underwent tissue expansion before conjoined twin separation, 30 before nasal reconstruction for congenital nasal deformities, 28 prior craniofacial cleft repair, 6 before myelomeningocele repair, 2 before subcutaneous colon interposition, 2 before orbital hypertelorism correction, 1 before agnathia reconstruction, and 1 before esophageal reconstruction. All 5 instances of TE failure among these patients occurred in the context of twin separation.

Case Examples
Patient 1 presented at age 36 after resection of an oligodendroglioma. His postoperative course had been complicated by wound infection necessitating 2 operative debridements and eventual removal of his native bone “flap.” He was subsequently referred to Plastic Surgery for consideration of cranioplasty. At the time of initial consult, he had a 20-cm curvilinear left parietal scar (Fig. 2). Given this extensive scalp defect, a 2-stage reconstruction was planned.

During the first stage, a 550 cm³ rectangular TE was inserted in the frontoparietal scalp and inflated with 50 cm³ of normal saline. After healing for 3 weeks, he underwent weekly serial expansion for 3 months without complication (Fig. 3). During the second stage, a custom titanium implant was placed to reconstruct the left temporoparietal defect (Fig. 4). For soft tissue reconstruction, a 20 × 30 cm fasciocutaneous scalp flap based on the right superficial temporal and posterior auricular vessels was raised. Next, the left temporoparietal flap that was previously covering the dura was mobilized to create a 12 × 12 cm flap based on the left superficial temporal vasculature. The flaps were then rotated and advanced to sufficiently cover the defect. He is healing well, with no further complications in the 7 months since surgery (Fig. 5).

Patient 2 was involved in a car accident at age 4 that resulted in an open right distal tibia fracture requiring treatment with an external fixator and coverage of a medial ankle defect with a rotational flap and split-thickness skin graft. He presented 1 year after the accident for evaluation of an acquired right ankle deformity and leg length discrepancy. Radiographs demonstrated obliteration of the distal tibia physis with varus deformity of the ankle (Fig. 6). Given the adherent and unstable nature of his skin graft site, he was evaluated by Plastic Surgery and a 2-stage approach was planned. In the first stage, 2 TEs, one 90-cm³ crescent expander and one 60-cm³ rectangular expander, were placed in a subfascial plane superior to the grafted wound. After 3 weeks of healing, he underwent weekly serial expansion for 3 months. By the end of expansion, the distal TE was insufflated to 30 cm³ and the proximal TE was insufflated to 54 cm³ (Fig. 7).
During the second stage, the lower extremity TEs were removed, the unstable, contracted scar was excised, and the expanded flaps were rotated and advanced for closure. Orthopedic surgery performed tibial and fibular osteotomies and applied a spatial frame for later distraction osteogenesis. Eighteen months postoperatively, right ankle radiographs demonstrated proper distraction at the osteotomy site with improved ankle alignment and bone formation. At his 21 months follow-up, he had healed well and ambulates without difficulty (Fig. 8).

DISCUSSION

Tissue expansion provides healthy, well-vascularized skin that can enable reconstruction in any area of the body. Although TEs have been extensively studied in the settings of breast reconstruction, burn reconstruction, and skin lesion excision, there are several less traditional indications that have not been comprehensively reviewed. These indications predominantly fell into 5 major groups: ear reconstruction, cranioplasty, abdominal wall reconstruction, orthopedic procedures, and genital (vaginal/vulvar, and penile/scrotal) reconstruction.

Despite their inherent complications, TEs facilitated the definitive reconstruction in nearly all patients. All cranioplasty patients who were pre-expanded went on to receive their implants. For abdominal wall reconstruction patients, 96.7% successfully underwent the index procedure. Two children died on the organ transplant list and 2 others did not receive reconstruction after attempted expansion.64,89 In the orthopedic reconstruction group, TE facilitated the index procedure in 96.5% of patients, with 1 patient resorting to a cross-leg flap and 5 abandoning reconstruction.98,100,104,105,114 All patients who were pre-expanded before ear reconstruction underwent the index operation. In the genital reconstruction groups, TE facilitated the index operation in 95.8% of the scrotal/penile reconstruction patients and 96.6% of the vaginal/vulva reconstruction patients.

Within these 5 categories of index operations, complications varied. Given the contaminated environment of the perineum, it is unsurprising that TE failure rates and TE infection rates were highest for genital reconstruction. Although the 2011 meta-analysis by Huang et al reports that lower extremity TEs are the most likely sites to develop complications, their review did not include genital reconstruction.170 Thus, although lower extremity TEs are indeed at high risk for complications, this review shows that genital reconstruction is associated with even higher rates of TE complications. Many patients in the cranioplasty, orthopedic, and abdominal wall reconstruction groups had prior failed reconstructions due to infection or implant exposure.52,53,71,96,103 Despite this inherently high-risk, multiply re-operated cohort, the TE failure, exposure, and infection rates were acceptable, all at <6% for cranioplasty and abdominal wall reconstruction and <11% for orthopedic procedures.

In addition to discussing the risks of TEs, it is important to also consider the outcome of the index operations. Among techniques using autologous cartilage for microtia reconstruction, a recent systematic review found no difference in overall complication rates between pre-expansion (14.18%) and no expansion (22.23%) methods.171 Although our review encompasses more than autologous microtia reconstruction patients, the overall complication rate in this review of 11.8% supports the assertion that the use of TEs does not increase the overall complication rate. For the cranioplasty group, 8.1% of patients had...
implant exposure or removal. This is similar to the rate of cranioplasty removal (12.8%) reported in a recent large cohort study of primary synthetic cranioplasty patients.\textsuperscript{172} Recurrence of hernia after abdominal wall reconstruction using TEs was 8.1%, which is slightly lower than the 11.7% rate of recurrence reported in a 2017 systematic review of these patients, and on the lower end of reported rates of hernia recurrence ranging from 1.4% to 28% after ventral hernia repair without pre-expansion.\textsuperscript{173–175} There were no cases of implant failure after orthopedic procedures in our review. It is known that urethral fistulas and strictures are 2 of the most common complications after penile reconstruction, with rates ranging from 5% to 44%.\textsuperscript{177–181} The rates of fistula and strictures in this review are within this accepted range at 16.7% and 10.1%, respectively.

There are several limitations to this study. Excluding the ear reconstruction group, the average number of patients per study was 5.7. These case reports or small cohort studies may not accurately capture the true complication rate of these less traditional TE indications. Second, the groups in our review lack homogeneity in terms of patients’ disease etiology and specific index procedures,
which prohibited any statistical analysis within the groups. There is also a potential bias given that it was not possible to clearly elucidate and remove duplicate patients. Finally, although outcome failures of the definitive reconstruction are inherent TE complications, tissue expansion success is significantly lower in the setting of ear reconstruction, abdominal wall reconstruction, and cranio-plasty. Outcome failures of the definitive reconstruction, such as cranio-plasty exposure, hernia recurrence, and urinary fistula, are in line with published rates of overall complications without pre-expansion. Thus, although TEs postpone the final reconstruction by 2–3 months, they remain a valuable option along the reconstructive ladder.

**CONCLUSIONS**

This review assures surgeons and patients that despite inherent TE complications, tissue expansion successfully facilitates the definitive reconstruction in nearly all patients. Surgeons should advise patients that intrinsic TE complications are highest in genital reconstruction, followed by orthopedic procedures, whereas the risk of TE failure is significantly lower in the setting of ear reconstruction, abdominal wall reconstruction, and cranio-plasty. Outcome failures of the definitive reconstruction, such as cranio-plasty exposure, hernia recurrence, and urinary fistula, are in line with published rates of overall complications without pre-expansion. Thus, although TEs postpone the final reconstruction by 2–3 months, they remain a valuable option along the reconstructive ladder.

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**PATIENT CONSENT**

The patient provided written consent for the use of his image.
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