Tissue expansion has become a well-recognized technique for reconstructing a wide variety of skin and soft tissue defects. Its application in the pediatric population has allowed the plastic surgeon to achieve functional and aesthetic goals that were previously unobtainable. This technique can be applied to a variety of reconstructive problems, including the management of giant congenital nevi and the secondary reconstruction of extensive burn scars, making possible the use of sensate tissue of similar color, texture, thickness, and hair-bearing characteristics to resurface the affected areas. However, when using tissue expanders, one must be prepared for complications, because they are inherent in a process in which skin is expanded by the repeated filling of an implanted foreign body. Complication rates increase when serial expansion of the same tissues is performed repeatedly, or if expanders are placed in the lower extremities. Outcomes are dependent on thorough preoperative planning, parent and patient teaching, meticulous technique, close follow-up, and patient compliance.

The authors review the use of tissue expansion in the pediatric population, with particular emphasis on indications, operative technique, and regional considerations. They also address concerns that have been expressed about the complications associated with this technique.

**Historical overview**

The expansion of skin was first reported in 1957 by Neumann [1], who used a rubber balloon with an external port in the reconstruction of a traumatic ear defect. The periauricular skin was serially expanded over a four-month period without extrusion or infection. This procedure was ignored until 1976, when Radovan [2] presented his experience with breast reconstruction. Austad and Rose [3] followed with their description of a self-inflating expander in 1982. The first description of tissue expansion in the pediatric population was in 1983 by Argenta et al [4], who used it in the treatment of neck contractures in burn patients.

**Characteristics of expanded tissue**

Both animal and human studies have documented histologic changes in soft tissue undergoing expansion. Mechanical force on skin influences numerous aspects of cellular architecture and function, including cytoskeleton structure, extracellular matrix, enzyme activity, second-messenger systems, and ion channel activity [5,6]. Expansion in a guinea pig model demonstrated significant thickening of the epidermis as early as 1 week after the start of the procedure. By contrast, the dermis thins during expansion. Austad et al [7] concluded that the epidermis exhibits increased mitotic activity soon after expansion begins, with a spike in activity 7 days later. Such mitotic activity is not present in the dermis. These phenomena have been observed in other animal models, as well as in humans [8,9].

In human studies, it does not appear that expander volume or anatomic location has any influence on dermal thickness. No histologic differences appear to distinguish adults undergoing expansion from children. Light microscopy reveals flattening of the rete ridges as well as epidermal thickening. Skin appendages demonstrate no histologic changes during
expansion. Capillaries in the papillary dermis are dilated on light microscopy. Electron microscopy reveals longer and thicker elastic fibers and active fibroblasts with an abundance of rough endoplasmic reticulum [9].

Subcutaneous tissue displays significant fat atrophy with flattening of adipocytes. Muscle under expansion also atrophies and can be replaced by fibrous tissue. Expander capsule thickness does not seem to be related to expander volume, location, or patient age [9].

Samples of human skin taken some time after completion of expansion and removal of the expander showed a reversal in the epidermal thickening and dermal thinning that occurred with expansion. Blood vessels of the skin and subcutaneous tissue were normal in size and number [9].

Indications for tissue expansion in pediatric plastic surgery

Initially described in the modern literature as a modality for ear reconstruction, tissue expansion is now used for a variety of clinical problems [10–15]. Burn scars that would otherwise have been left untreated can now be addressed regardless of size, reducing the physical and emotional morbidity of such wounds [16]. Giant congenital nevi can be treated in a satisfactory manner with single-stage or serial expansion and excision, regardless of location and size. This technique has replaced partial excision and dermabrasion and helped to eliminate some of the risks that may accompany incomplete excision of such premalignant lesions [17,18]. Ideally, expansion is begun in the early months of life to avoid the peer-group pressure that develops later in childhood. Early reports warned that deformities of the craniofacial skeleton might result from expansion in infants and children, but there appears to be no permanent disturbance of growth or skeletal deformity [19,20]. It has been advocated that expanders with semirigid backing be used if there is a concern about distortion of underlying structures. In addition, expansion should be delayed until the patient is 6 to 9 months of age if molding of the cranium is evident [21].

Tissue expansion has been applied in the pediatric population in the treatment of aplasia cutis congenita, meningomyelocele, microtia, hemangioma, scrotal reconstruction, clubfoot deformity, midfacial cleft, Romberg’s disease, Poland’s syndrome, tumor ablation, vaginal agenesis, and Volkmann’s contracture and in the reconstruction after separation of conjoined twins [20,22–24].

Expansion of soft tissue may be employed to increase the size of full-thickness skin grafts, local or regional flaps, or distant or free flaps before transfer. The advantage of harvesting expanded full-thickness skin grafts or flaps is that maximum yield is obtained with reduced donor-site morbidity. No evidence has been found of greater contraction or decreased durability of the expanded tissue when compared with a nonexpanded full-thickness graft or flap [25].

Operative technique

General considerations

Antibiotic use

Because no study has addressed this issue prospectively, the use of perioperative antibiotics should be considered on a case-by-case basis.

Choice and placement of the expander

Expanders are available in a variety of shapes, sizes, contours, and backing configurations. Expander shape and size are chosen based on the dimensions of the defect and the configuration of the surrounding normal skin. This selection process has largely been guided by the preference of the surgeon, because no data indicate that an expander of a given shape is more advantageous for placement in a given site. In some situations, a custom-designed expander may be preferable, to facilitate maximal expansion with less likelihood of donor-site morbidity. Several authors have demonstrated that employing calculations to predict the area expanded often leads to an overestimation of actual expander yield [26,27]. Because contraction is expected, the expander should create a flap that is 30% to 50% longer than necessary when maximally filled [28].

Expanders are usually placed while the patient is under general anesthesia. Incisions for placement of the expander should be carefully planned. Consideration must be given to the advancement or rotation of the planned flap, the effects of expansion on the overlying skin, and the potential donor-site morbidity. Making straight incisions along the border of the defect should usually be avoided. Options when placing an incision include placement perpendicular to the direction of expansion and placement of a V- or U-shaped incision away from the defect [28]. If an incision must be placed near the defect, the pocket should be dissected as far from it as possible. The authors recommend a margin of 2 cm or greater from the incision to the desired expander pocket to
minimize the risk of dehiscence when expansion commences. Expansion should be delayed until wound healing has progressed sufficiently, usually at least 2 weeks. When planning for a large congenital nevus that will require serial expansion, one should place the incision within the lesion, removed from the proposed expander pocket, to avoid compromising subsequent expansions [21,29].

The expander pocket should be made as close to the size of the expander as possible so as to avoid subluxation of the expander. Blunt dissection is frequently indicated to preserve the overlying vessels. This measure is especially important where longitudinal vessels are present and serial expansion will be needed [30]. Dissection is usually done over the deep fascia unless the underlying muscle is to be included in the flap. In the case of a nevus, the pocket dissection should extend to the junction of normal skin and nevus. This measure should prevent expander migration under the nevus and subsequent stretching of the nevus, while allowing the skin–nevus junction to serve as the edge of the advancement flap. In the scalp, expanders are usually placed in a subgaleal pocket.

Injection ports may be internal or external and remote or integrated into the expander. Neumann’s application in 1957 employed an external port in an adult [2]. Internal ports subsequently became more popular, because this arrangement ensures a “closed” system with presumably less likelihood for port disruption and expander infection. However, this advantage has been disputed. Jackson et al [31] presented their experience with external reservoirs with only a 5.6% complication rate, which was far less than the 20% to 40% complication rate noted in many series that used internal ports. Lozano and Drucker [32] reported their experience using 34 expanders with external ports in 28 pediatric patients, most of which were placed in the head and neck. They noted a combined infection and exposure rate of 17.6%. These authors cited reduced dissection, painless port access, and earlier detection of leaks as reasons to use external ports. In reporting their experience using internal ports, Bauer et al [21] emphasized that the port should be low-profile in areas where there is potential undue pressure on the overlying skin and should be remote from the expander to ensure that the expander is not punctured when it is accessed. In planning the placement of remote ports, the surgeon must consider that the distance between the expander and the port may change when expansion commences. What appears to be an adequate distance at the time of placement may be insufficient when the expander is fully inflated.

Some authors advocate the use of drains, whereas others emphasize strict hemostasis and initial filling of the expander intraoperatively to render a drain unnecessary [21,22].

**Expander inflation**

Most authors start the inflation process 2 to 4 weeks after expander insertion and repeat the injections on a weekly basis. The interval and volume of expansion will vary by region and wound type. The rate of inflation of the expanders is also variable and depends on physical findings and patient comfort. Inspection of skin color (blanching), capillary refill, and simple palpation are performed when additional expansion is under consideration. Over-inflation of tissue expanders beyond the manufacturer’s recommended fill-capacity appears to be the norm in clinical practice [22,33]. In one clinical study, overexpansion was shown to be associated with a lower complication rate than was underexpansion [34]. In this study, an expander was inflated 3.5 times its manufacturer’s stated capacity without complication. An ex vivo study of expanders from multiple vendors has shown that mean over-inflation of 80 times the manufacturer’s stated capacity can be achieved [35].

Following closure, a small volume of sterile saline solution is usually injected into the expander both to confirm that the system is working properly and to maintain the volume of the expander pocket during capsule formation. A capsule will begin to form very early after expander placement, and, if the expander has folded on itself or has constricted in the area occupied, the capsule will limit the surface area for expansion to less than that of the planned dissection pocket.

**Expander use with flaps**

Local and regional flaps should be planned according to the principles discussed earlier, with emphasis on incision placement and pocket dissection that avoid enlarging the defect. The flaps most commonly used are an advancement flap or transposition flap, or a combination of the two. Selecting the size of the expander may not be a straightforward process, because of the difficulty of calculating actual flap gain [26,27]. Different techniques have been proposed to maximize the distance the flap can be advanced after full expansion. Zide and Karp [36] described a single or double back-cut to maximize flap advancement while allowing for donor-site closure.
Pre-expansion of a free flap donor site before microvascular free tissue transfer has added a new step to the reconstructive ladder. This technique makes possible the fabrication of flaps of a specific size and thickness [37]. Some authors have noted that the caliber of the pedicle vessels is augmented [38]. Donor sites that would otherwise be too bulky can provide tissue that is thinner as a result of the atrophy of fat from expansion. Donor-site closure is also facilitated [25]. It is questionable whether pre-expansion influences microvascular failure. Placement of the expander must be done carefully so as not to damage the donor-site vessels that will be used for subsequent microvascular tissue transfer. One study noted that dissection of the flap is more challenging because of the obliteration of tissue planes and the formation of a capsule in the flap donor site [25].

**Regional considerations**

**Head and neck**

Reconstruction of the head and neck presents a particular challenge, requiring expansion that avoids oral, visual, and airway compromise while preserving facial aesthetic units. Large congenital pigmented nevi of the head and neck can often be treated with expansion of local tissue. Bauer et al [39] reviewed their experience in 21 patients with lesions involving the forehead and scalp. They advocated medial advancement flaps for midline forehead lesions, serial advancement from the uninvolved hemiforehead in unilateral lesions, and transposition of medial tissue for supraorbital or temporal lesions not involving the hairline. Reconstruction of large lesions of the head and neck can be quite complex, because many of these lesions involve numerous anatomic structures, such as the scalp, forehead, eyelid, postauricular sulcus, and auricle (Fig. 1). Expansion of adjacent tissue cannot address the reconstructive needs of these unique structures, and the authors have found that combined-modality treatment is often required for optimal reconstruction [29]. This treatment often entails expanded flaps, full-thickness skin grafts (both expanded and nonexpanded), and serial excision. Split-thickness skin grafts, with the exception of those harvested from the scalp, provide a poor color and texture match for visible regions of the head and neck. The surgeon should address temporoparietal lesions with combined advancement and transposition flaps, choosing the reconstructive technique that best achieves proper orientation of hair follicles relative to the adjacent scalp.

Expansion has become the principal reconstructive technique for burn scars in the head and neck. Neck contractures should be addressed first, because intubation can be difficult and extrinsic pull may distort the adjacent face [40]. Many authors advocate placing tissue expanders superficial to the platysma in the neck to avoid excessively bulky flaps [41]. Another advantage of this technique is the avoidance of risk to the facial nerve, whose branches run deep to the platysma. The leading edge of unburned neck skin can be advanced by undermining to the level of the clavicle and advancing cephalad after expansion.

If advancement flaps are insufficient, rotation or transposition flaps may be needed. Spence [13] described the use of pre-expanded supraclavicular transposition flaps to treat severe cervical scarring. Pre-expansion permits primary closure of the donor site in the majority of cases.

McCauley et al [14] presented their experience with burn alopecia in 102 children and proposed a classification scheme and corresponding treatment algorithm. Depending on the distribution of existing hair, multiple expansions must be undertaken with a combination of advancement and rotation flaps to restore the anterior hairline (Fig. 2). Patchy alopecia cannot be addressed adequately with expansion. Scalp expansion is ineffective in patients with greater than 50% hair loss, because significant thinning of existing hair will occur [40]. Hair-bearing skin may be transposed to the cheek to camouflage scars in men [41]. Neale et al [10] presented their experience with expansion of the lower face and anterior neck in 52 children and young adults and advised that expansion and subsequent advancement over the mandible should be performed with caution. Ectropion of the lip or lower eyelid and scar widening were among the complications. Flaps can be advanced from the level of the hyoid bone to the lip. The flap should be advanced caudally to avoid ectropion of the lip. Rotation may be preferred over advancement to take tension off the suture line in the lower face and cheeks [40]. Many authors advocate maximum expansion and advancement as the way to ensure minimal tension when inseting the flap in the cheek or lower face and avoid eyelid or lip ectropion [40,42]. Kawashima et al [42] advocate expansion of a cervicofacial flap for cheek defects because of its superior aesthetic result.

Tissue expansion has been applied to reconstruction of congenital and acquired deformities of the ear. The goal is to provide abundant thin, elastic, non–hair-bearing skin to drape over the cartilage framework of the reconstructed ear. Some authors report that expanders of specific shape and size should be
employed [43,44]. The pocket is created away from the incision and dissected at the level of the mastoid fascia and auricular cartilage to maximize the overlying flap thickness. Caution must be exercised when expanding, because of the thin skin present here. The expander is usually removed 1 to 3 months after the final inflation, although this interval varies. At the reconstruction, capsule excision may be needed to allow the skin flap to drape over the cartilage framework, but this may compromise the blood supply to the skin [45,46]. An animal study using a porcine model disputed the importance of the capsule in providing blood to the overlying tissue [47]. Expansion of postauricular skin in acquired defects of the ear is undertaken in a similar fashion. Expansion of scarred, contaminated, or irradiated skin may be more prone to exposure and should be undertaken with extreme caution [42].

**Extremities**

Expansion in the extremities has been effective in situations that preclude rotation or advancement flaps alone [48]. However, tissue expansion in these areas has limitations and is associated with a higher complication rate, particularly in the lower extremities [11,12]. Intraluminal pressure of an expander in the extremity often exceeds that placed in other regions of the body, and pressures may exceed capillary closing pressure without affecting cutaneous

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Fig. 1. (A) A 4-year old boy with a giant congenital pigmented nevus of the forehead, face, and scalp, involving multiple subunits. (B) Two years following completion of tissue expansion with flap advancement for reconstruction of the scalp and face. The forehead has been reconstructed with an expanded full thickness skin graft harvested from the abdomen.
capillary refill [49]. In addition, the surgeon must be aware of the potential for nerve entrapment. Expander placement and careful flap design are crucial. Patient compliance is more important here than it is in expansion of the trunk or the head and neck. For the resurfacing of large nevi, expanded full-thickness skin grafts and expanded flaps from distant regions are often used (Fig. 3) [29]. However, if the lesion can be excised in three stages or less, the authors’ preference is serial excision of the lesion rather than expansion of adjacent flaps.

**Trunk**

Tissue expansion has been well-described for breast reconstruction and secondary burn reconstruction in adults [30,50]. The pediatric population presents unique challenges, including meningomyelocele, giant congenital nevus, and ectopia cordis. In an area with such great potential for donor tissue, expanders can exceed 1000 mL in size. Because of the abundance of donor tissue and the uniformity of the surface to be reconstructed, the authors have found the torso to be the most common location for single-modality treatment of giant congenital nevi with tissue expansion alone (Fig. 4) [29]. Ideally, the expander should have a semirigid back, especially when placed over the abdomen. The back is more difficult to expand than the abdomen or chest, necessitating longer expansion intervals. Most authors prefer to delay the second stage of expansion until the flap created for the initial advancement has firmly adhered. This delay avoids migration of the expander at the next stage.

Burn scars of the chest in a child or adolescent can be more complicated than in an adult. Both breast development and psychological factors influence the timing of reconstruction. An area that has been treated with skin grafts or has healed by secondary intention may restrict expansion. It is recommended that expanders be placed in a submuscular position to avoid ulceration of the skin [41]. The tissue expander is subsequently replaced with a permanent implant once breast development is complete.

**Complications**

Tissue expansion has been associated with significant complications since its inception. Initial reports of complication rates were as high as 40% in infants and children [23]. The risks have been described in numerous studies and have been categorized by patient age, wound type, surgeon experience, and socioeconomic class. Recent series report overall complication rates in the 13% to 20% range [11,12,24]. However, the literature on complications of tissue expansion is difficult to interpret, in part because the studies are retrospective and the different authors have different definitions of “complication.”

Most authors agree that minor complications do not delay the process of expansion and reconstruction, whereas major complications do. Minor complications include pain at the time of expansion, seroma, widening of scar, and temporary distortion of normal features [51]. Pain at the time of injection is related to inflation pressure. It may well be indicative of ischemia, and the injection should be stopped. If the pain goes away, inflation can continue. Dog-ears usually settle in due course. Attempts at primary correction of these should be discouraged, because flaps may be devascularized. Major complications
include hematoma, infection, expander exposure and extrusion, implant failure, and flap ischemia. Exposure may occur as a result of poor skin closure or incorrect placement of the expander [51].

Overall complications in the pediatric population by anatomic region seem to be greatest in the extremities, particularly in the lower extremities. Pisarski et al [12] reported a series of 281 expanders placed in 224 patients from 1987 to 1995 at the Shriners Burn Center in Cincinnati. These authors found that complications were most prevalent in the lower extremity, followed by the head and neck. Another series of 180 expanders placed in 82 children demonstrated that extremity expansion resulted in more complications than did expansion in other regions, although statistical significance was questionable [11]. Elias et al [23] reported that the scalp, followed by the trunk, was the region associated with the greatest rate of tissue expander–related complications. In contrast, other series, including a large one
from Boston Children’s Hospital, have found no difference in complication rates with the anatomic region treated [20,24,52].

Some debate exists over the relationship between patient age and the complication rate. In a series of 105 patients, Gibstein et al [24] found that children 1 to 12 years of age were at higher risk for developing wound disruption or expander deflation than were infants and adolescents. Another series found that children under age 7 years were at higher risk for complications [11].

Patients undergoing expansion for burn reconstruction have been considered by some to be at higher risk for complications. A series from the Shriners Burn Institute in Cincinnati reported an overall complication rate of 30% from 1984 to 1987 [33]. However, a subsequent report from the same center for 1987 to 1995 showed a rate of only 18% [12]. The authors emphasize that a “learning curve” exists—a point that is highlighted by a series from an urban hospital. The authors of that report concluded that their overall complication rate of 65% was most likely due to the inexperience of the house staff, as well as poor patient education and suboptimal follow-up [52].

Another factor that may be associated with an increased risk for complications is serial expansion [11]. However, Iconomou et al [53] found no correlation between the reason for or technique of expansion and the complication rate.

Contraindications to tissue expansion include poor patient compliance, psychiatric dysfunction, and

Fig. 4. (A) A 3-month-old girl with giant congenital pigmented nevus of the back. (B) At age 2 years, after placement of tissue expanders. (C) Two years after resection of the nevus and resurfacing with back flaps expanded in a single stage.
unsuitable skin. The latter category includes unstable scars, irradiated skin, acute wounds, fresh skin grafts, and sepsis in or adjacent to the area to be expanded.

Summary

Despite its potential complications, tissue expansion in the pediatric population is an effective reconstructive modality. Because of the significant patient and family cooperation and effort needed in the expansion process, patients and families who are cooperative and compliant tend to have the best outcomes. Effective education and guidance, beginning preoperatively and continuing throughout the expansion process, are imperative. Although most of the reported complications may delay final reconstruction, few complications prevent the ultimate success of the reconstruction. For instance, expander rupture is treated by expander replacement, and expander exposure is treated by removal of the expander, advancement of the partially expanded flaps, and reinsertion of another expander once the flaps are healed. In both cases, the final reconstruction is delayed but not lost. Those surgeons who practice tissue expansion on a regular basis and are familiar with the best ways of handling complications as they arise will achieve optimal outcomes. The critical factors in achieving success are proper patient selection, thorough preoperative planning, parent and patient education, meticulous technique, and the ability to modify the reconstructive plan for each patient based on his or her clinical response.

References


