Clinical Overview
Pediatric Tissue Expansion: Indications and Complications

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Tissue expansion has become a major reconstructive modality in the past 30 years. Its application in the pediatric population has allowed the plastic surgeon to achieve functional and esthetic goals that were previously unobtainable. Tissue expansion is a major treatment modality in the management of giant congenital nevi and secondary reconstruction of extensive burn scars, allowing sensate tissue of similar color, texture, and thickness to be used to resurface the affected areas. One must be prepared for complications when using tissue expanders, however, because complications are inherent in the process of expanding skin utilizing repeated filling of implanted foreign bodies. 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 planning, meticulous technique, close follow-up, and patient compliance. Tissue expansion has revolutionized plastic surgery in the last 30 years. This technique can be applied to a considerable breadth of reconstructive problems in the pediatric population. Tissue expansion has permitted the plastic surgeon to achieve the goals of reconstruction with tissue of similar color, texture, and thickness, with minimal donor site morbidity. Preservation of sensation in a durable flap has allowed the surgeon to achieve acceptable functional as well as esthetic goals simultaneously.

Key Words: Tissue expansion, pediatrics, complications, congenital nevi, burn reconstruction

Historical Overview

Tissue expansion is by no means a concept of modern plastic surgery. Pregnancy demonstrates the biomechanical ramifications of soft tissue placed under progressive tension. The people of Thailand and Chad have practiced the rituals of cervical and oral-labial expansion, respectively, for centuries. The medical epidemic of obesity and subsequent weight loss through behavior modification or surgical bypass has led to an explosion of a subset of patients seeking “body contouring” for lax and redundant tissue.

It has been reported in the medical literature that Codvila attempted to lengthen a femur with tissue expansion in 1905. In 1957, Neumann published his experience with tissue expansion in the reconstruction of a traumatic ear defect in a 52-year-old gentleman. Using a collapsed rubber balloon and an external port, the periauricular skin was serially expanded over a 4-month period without extrusion or infection. Radovan presented his experience with breast reconstruction in 1976, and Austad and Rose followed with their description of a self-inflating implant. The first description of the application of tissue expansion in the pediatric population was by Argenta et al in 1981 in the treatment of neck contractions in burn patients.

Characteristics of Expanded Tissue

Both animal and human studies have consistently documented histological changes in soft tissue undergoing expansion. Mechanical force on skin influences numerous aspects of cellular architecture and function such as cytoskeleton structure, extracellular matrix, enzyme activity, second messenger systems, and ion channel activity. Expansion in a guinea pig model demonstrated significant thickening of the epidermis as early as 1 week after expansion commenced. In contrast, the dermis appears to thin during expansion. Austad and colleagues, using tritiated thymidine integrated into DNA, concluded that the epidermis exhibits increased mitotic activity early after expansion begins, with a subse-

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quent 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 human beings.8,9

In human studies, it does not appear that expander volume or anatomical location has any influence on dermal thickness. There seems to be no histological difference between adults and children undergoing expansion. Light microscopy reveals flattening of the rete ridges as well as epidermal thickening. Skin appendages demonstrate no histological 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 when compared with normal specimens.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

After completion of expansion and removal of the appliance, human samples reveal a decrease in epidermal and dermal thickness toward baseline. Blood vessels of the skin and subcutaneous tissue are normal in size and number.9

INDICATIONS

Initially described in the modern literature as a modality for ear reconstruction, tissue expansion, like other techniques in plastic surgery, has evolved into a therapy for a number of clinical problems. Tissue expansion has a firm foundation in secondary burn reconstruction in children and adults.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

Large or giant congenital nevi are treated in an efficacious manner with single-stage or serial expansion and excision regardless of location and size. It has replaced partial excision and dermabrasion and eliminated the inherent risks that 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 may result from expansion in infants and children, but there seems to be no permanent disturbance in growth or resultant 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 in the pediatric population has been applied in the treatment of aplasia cutis congenita, meningomyelocele, microtia, hemangioma, scrotal reconstruction, clubfoot deformity, midfacial cleft, Romberg disease, Poland syndrome, tumor ablation, vaginal agenesis, Volkmann contracture, and reconstruction for conjoined twins.20,22-24

TECHNIQUE

General Considerations

Although no study has addressed this issue prospectively, perioperative antibiotics are advocated when tissue expanders are placed, regardless of the patient population. Expanders are usually placed while the patient is under general anesthesia.9

Expander technology has evolved as its applications have become more numerous. Expanders come in a variety of shapes, sizes, contours, and backing configurations. Injection ports may be internal, external, remote, or integrated into the expander. Neumann’s application in 1957 used an external port in an adult.2 Internal ports subsequently became more popular, because such a setup ensures a “closed” system with presumed less likelihood for port disruption and expander infection.

The advantage of internal versus external ports has been disputed. Jackson and colleagues25 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 other series that used internal ports. Lozano and Drucker26 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 less dissection, painless port access, and earlier detection of leaks as reasons to use external ports. On reporting their experience using internal ports, Bauer et al21 emphasized that the port should be low profile in areas where there is potential undue pressure of the skin and remote from the expander to ensure that the expander is not punctured when accessed.

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 sur-
Incisions for placement of the expander should be carefully planned. Consideration of flap advancement or rotation, subsequent expansion, and donor site morbidity is paramount. Placement of straight incisions bordering the defect should be avoided, because this may enlarge the lesion to be excised as well as diminish the capacity of the flap to cover the defect. Many authors recommend that a small V- or U-shaped incision be made away from the defect. Incisions should be placed radially (perpendicular) relative to the direction of expansion. If an incision must be placed near the potential defect, the pocket should be dissected as far from the lesion as possible.

Longitudinal blood supply, particularly in the trunk, must be preserved when undertaking serial expansion. Furthermore, the expander pocket should be dissected wider than the base of the expander in a blunt fashion to preserve the longitudinal blood supply. If expander placement is performed for reconstruction of a giant congenital nevus, we prefer placing the incision within the nevus, at least 2 cm from the nevus junction. The expander pocket can be dissected beneath normal skin, extending to but not beyond the junction of normal skin and nevus. This limits subsequent expander migration to avoid stretch on the nevus and the initial incision while allowing the normal skin- nevus junction to serve as the edge of the advancing flap that is to be used for the subsequent reconstruction. The expander should be placed on top of the deep fascia unless underlying muscle is to be integrated into the flap. Expanders in the head are placed in a subgaleal pocket. Some authors advocate the use of drains, whereas others emphasize strict hemostasis and initial filling of the expander during surgery so as to avoid drain placement.

The interval and volume of expansion may vary by region and wound type. The rate of inflation of the expanders varies between surgeons but seems to depend on physical findings and patient comfort. Inspection of skin color (blanching), capillary refill, and simple palpation is to be performed when considering additional expansion. When pain is experienced, injection should cease and removal of saline should be considered. Overinflation of tissue expanders beyond the manufacturer’s recommended fill capacity seems to be the norm in clinical practice. In one clinical study, overexpansion has been shown to be associated with a lower complication rate compared with underexpansion. 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 overinflation of 80 times the manufacturers’ stated capacity can be achieved.

Expansion of soft tissue may be used to harvest full-thickness skin grafts, to advance local or regional flaps, or to augment distant or free flaps before transfer. The advantage of harvesting expanded full-thickness skin grafts is that maximum yield is obtained with minimal donor site morbidity. This is always a viable option when regional flaps are too limited to expand. Full-thickness skin grafts are harvested from the dome of the expander while inflated. There seems to be no evidence of greater contraction or decreased durability relative to a nonexpanded full-thickness graft. The donor site is closed in layers after the capsule is excised.

Local and regional flaps should be planned according to the principles discussed previously, with emphasis on incision placement and pocket dissection that avoids enlarging the defect. Selecting expander size may not be straightforward because of the difficulty in calculating actual flap gain. A number of techniques have been proposed to optimize local flap advancement after maximum expansion. A technique of double back-cuts to the height of the expander or a single back-cut can be performed before inset. Most local expansion employs an advancement flap, a transposition flap, or a combination thereof.

The combination of free tissue transfer and tissue expansion has added a new step to the reconstructive ladder. This technique allows fabrication of flaps of a specific size and thickness. Some authors have noted that the caliber of the pedicle vessels is augmented. Donor sites that would otherwise be too bulky can provide tissue that is thin as a result of the fat necrosis from expansion. Donor site closure is also facilitated with pre-expansion of distant flaps or free flaps. It is questionable whether pre-expansion influences microvascular failure. One study noted that dissection of the flap is more challenging because of the obliteration of tissue planes and the formation of a capsule.
Regional Considerations

Head and Neck

Tissue expansion has been applied to all aspects of pediatric plastic surgery. Reconstruction of the head and neck presents a particular challenge, requiring expansion without oral, visual, or airway compromise while preserving facial esthetic units.

Large congenital pigmented nevi of the forehead and scalp. The authors advocate 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 anatomical structures such as the scalp, forehead, eyelid, postauricular sulcus, and auricle. Expansion of adjacent tissue cannot address the reconstructive needs of these unique structures, and we have found that combined modality treatment is often required for optimal reconstruction. \(^3\) Combined modality treatment often uses 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. Temporoparietal lesions should be addressed 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 foundation of secondary burn reconstruction. In patients with scars throughout the head and neck, it is advocated that neck contractures be addressed first, because intubation can be difficult and extrinsic pull may distort the adjacent face. \(^4\) Many authors advocate placing tissue expanders superficial to the platysma in the neck to avoid excessively bulky flaps. \(^4\) Another advantage of placing the expanders in this superficial plane is to avoid the risk of facial nerve damage, because the branches of the facial nerve run deep to the platysma. The leading edge of unburned neck can be advanced by undermining to the level of the clavicle and advancing cephalad after expansion. If advancement flaps are insufficient, rotational or transposition flaps may suffice. 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 most cases.

McCauley and colleagues \(^14\) 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 rotational flaps to restore the anterior hairline. Patchy alopecia cannot be adequately addressed with expansion. Scalp expansion is ineffective in patients with greater than 50% hair loss, because significant thinning of existing hair will occur. \(^4\) Hair-bearing skin may be transposed to the cheek to camouflage scars in men. \(^4\) Neale and colleagues 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 at the mandible should be performed with caution. \(^10\) Ectropion of the lip or lower eyelid and scar widening were encountered. Flaps can be advanced from the level of the hyoid bone to the lip. Caudal advancement rather than a cephalad approach is advised to avoid ectropion. Rotation may be preferred over advancement to take tension off the suture line at the lower face and cheeks. \(^40\) Emphasis on maximal expansion and advancement to ensure minimal tension when insetting the flap in the cheek or lower face is advocated by many authors to avoid eyelid or lip ectropion. \(^40\) Kawashima et al \(^42\) advocate expansion of a cervicofacial flap for cheek defects because of its superior esthetic outcome.

Tissue expansion has been applied to reconstruction of congenital and acquired deformities of the ear. The goal of expansion in this situation 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 a specific shape and size are to be used. \(^43\) The pocket is created away from the incision and dissected to the level of the temporal fascia. Caution must be exercised when expanding because of the thin nature of the skin overlying the underdeveloped ear. The expander is usually removed 1 to 3 months after the final inflation, although this also varies. Some authors advocate removal of the capsule to improve extensibility, although this may compromise blood supply to the overlying skin. \(^45\) 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.\textsuperscript{42}

**Extremities**

Expansion of the extremities has been effective in situations that preclude rotation or advancement of regional and local flaps. Tissue expansion has limitations in the extremities, however, and is associated with a higher complication rate, particularly in the lower extremity.\textsuperscript{7} Expander placement and careful flap design are crucial. The time required for expansion seems to be longer in the extremities than in other regions.\textsuperscript{21} Patient compliance is a more significant factor in the extremities when compared with expansion of the trunk or the head and neck. For the resurfacing of large nevi involving the extremities, expanded full-thickness skin grafts and expanded flaps from distant regions are often used.\textsuperscript{31} If the lesion can be excised in three stages or less, we have guided patients toward serial excision of the lesion rather than expansion of adjacent flaps in the extremities. Borenstein et al\textsuperscript{48} reported reconstruction rather than expansion of adjacent flaps in the extremities. Tissue expansion has been well described for breast development is complete.\textsuperscript{7,11,12,24} The literature on complications of tissue expansion is difficult to interpret, however, in comparison to other regions.\textsuperscript{11,12,24} The literature on complications of tissue expansion is difficult to interpret, however, in part because the studies are retrospective. Many of the end points of these studies, including the definition of "complication," vary between studies.

**Trunk**

Tissue expansion has been well described for breast reconstruction and secondary burn reconstruction in adults.\textsuperscript{30,50} The pediatric population presents unique challenges, including meningomyeleoce, giant congenital nevus, and ectopia cordis. With such a great potential for donor tissue, expanders can exceed 1,000 ml in size. Because of the abundance of donor tissue and the uniformity of the surface to be reconstructed, we found the torso to be the most common location for single modality treatment of giant congenital nevi with tissue expansion alone.\textsuperscript{31} Ideally, the expander should have a semirigid back, especially when placed over the abdomen.\textsuperscript{21} Most authors prefer to delay placement of a second (serial) expander until the flap has firmly adhered after initial expansion and advancement. The back is more difficult to expand compared with the abdomen or chest, necessitating longer expansion intervals.\textsuperscript{41} This avoids problems with expander migration in an extremely large pocket.\textsuperscript{21}

Breast reconstruction in the context of a burn injury to 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. Burns to the breast that have been treated with skin grafts or that have healed by secondary intention may restrict projection. It is recommended that expanders be placed in a submuscular position and inflation carried out in a manner that avoids ulceration of the skin, especially in scarred tight regions.\textsuperscript{41} The tissue expander is subsequently replaced with a permanent implant once breast development is complete.

**Complications**

Despite its versatility, tissue expansion has been associated with significant complications since its inception. Initial reports of complication rates were as high as 40% when tissue expanders were used in infants and children.\textsuperscript{23} Fortunately, these reports did not deter acceptance of tissue expansion as a major reconstructive modality. The risks of tissue expansion have been described in numerous studies and stratified by patient age, wound type, surgeon experience, and socioeconomic class. Recent series report overall complication rates in the range of 13% to 20%.\textsuperscript{11,12,24} The literature on complications of tissue expansion is difficult to interpret, however, in part because the studies are retrospective. Many of the end points of these studies, including the definition of "complication," vary between studies.

Overall complications by anatomical region in the pediatric population seem to be greatest in the extremities, particularly in the lower extremities. Pisarski et al\textsuperscript{10} reported on 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 expansion in other regions, although statistical significance was questionable.\textsuperscript{11} Elias et al\textsuperscript{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 series from Boston Children’s Hospital, have found no difference in complication rates based on the anatomical region treated.\textsuperscript{20,24,31}
There is debate about the correlation between the age of the patient and the complication rate of tissue expansion. In a series of 105 patients, Gibstein and colleagues found that children 1 to 12 years of age were at higher risk of developing expander-related complications than infants and adolescents. These authors suggested that children aged 1 to 12 years are more prone to disrupting or deflating their expander than teenagers or infants. Another series looking at children undergoing tissue expansion between the ages of 8 months and 15 years found that children under the age of 7 years were at higher risk for complications.11

Serial expansion is another factor that seems to be associated with increased risk of expander-related complications.11 Some authors have questioned whether the burn population in general has a higher complication rate when undergoing tissue expansion. On evaluating 37 expanders placed in 14 children, Iconomou and colleagues found no correlation between disease process and complication rate. An initial series from Shriners Burn Institute in Cincinnati reported an overall complication rate of tissue expanders of 30% from 1984 to 1987.12 A subsequent report from these authors covering the period from 1987 to 1995 demonstrated an overall complication rate of only 18%, however.12 The authors emphasize that a “learning curve” exists for effective tissue expansion. A series from an urban public hospital concluded that the overall complication rate of 65% was likely a result of inexperience on the part of the surgical house staff, poor patient education, and suboptimal patient follow-up.51

Tissue expansion in the pediatric population is an effective reconstructive modality, despite its potential complications. Because of the intense patient and family cooperation and effort involved in the expansion process, patients and families who are cooperative and compliant are most likely to have a better outcome. Effective education and guidance beginning before surgery and continuing throughout the expansion process are imperative to achieve this outcome. Although most reported complications serve to deter or delay the final reconstruction, few complications make the desired reconstruction less likely to be achieved as a result of tissue expansion. As an illustration, expander rupture is treated by expander replacement; the final reconstruction is delayed but not lost. Similarly, expander exposure is treated by removal of the expander, advancement of the partially expanded flaps, and reinsertion of a tissue expander once the flaps are healed. Once again, the final reconstruction is delayed but not lost. Those surgeons who practice tissue expansion on a regular basis and are familiar with how best to handle complications as they arise achieve optimal outcomes. Proper patient selection, thorough preoperative planning, meticulous technique, and the ability to modify the reconstructive plan for each patient based on the clinical response to tissue expansion are critical factors to achieving the desired outcome.

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