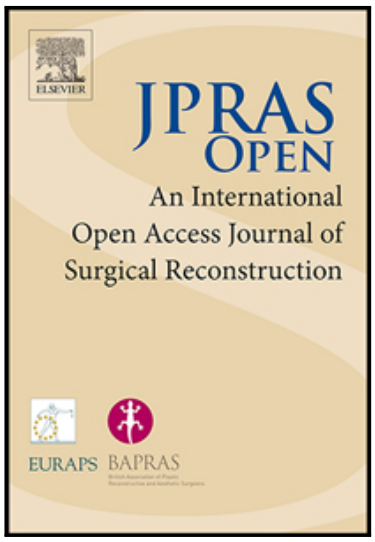

Tissue expansion reconstruction of head and neck burn injuries in paediatric patients – a systematic review

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Literature review

Tissue expansion reconstruction of head and neck burn injuries in paediatric patients – a systematic review

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Abstract

Tissue expansion reconstruction in clinical practice has existed for over half a century. The technique was initially used for breast reconstruction but later found its use in reconstruction of excisional defects resulting from a variety of causes including surgery for post-burn/post-traumatic deformities, congenital giant naevi, skin cancer, etc. It offers an improved matching of skin colour and texture, and avoids the high infrastructure requirements of microsurgery for free flap transfers. We present a systematic literature review of 35 worldwide English language articles with representative cases of paediatric tissue expansion reconstruction of burn injuries of the head and neck. The review identified 68 children of an average age of 11.3 years. The most common burn aetiology was flame burn injury. The average area to be reconstructed was of 206 cm^2 and patients went through expansion processes for an average of 99.7 days. Three articles included cases in which patients had more than one expansion session. Supportive techniques provide examples of developments in the area of tissue expansion reconstruction such as self-inflating expanders and endoscopic approaches. Further studies focussing on particular indications, age groups and anatomical locations of tissues to be expanded are required in order to improve the understanding of this technique's limitations and continue its development.

Word count: circa 4600 (excludes captions, tables, figures, headings, subheadings, abstract and references).

Key words

Tissue expansion, tissue expander, head and neck, burns, burn injury, children, paediatrics paediatrics, reconstruction

1. Introduction

The expansion of tissues is not an exclusively reconstructive concept. As highlighted by Wagh and Dixit (1), pregnancy illustrates the body's adaptation of a tissue placed under tension over time. Additionally, obesity followed by weight loss provides us with a physiological tissue expansion resulting in extra tissue.

In clinical practice, tissue expansion reconstruction was first described by Neumann in 1957 who reconstructed an adult gentleman's ear that was left with a defect affecting the upper two thirds of the pinna following trauma (2). Tissue expansion was then primarily developed as a breast reconstruction technique introduced by Radovan (3) in 1976 and described by Becker later in the 1980s (4). This reconstructive technique has then been applied to other indications including post-burn scar reconstruction.

The tissue expansion is usually a 2-stage procedure. In the first stage a tissue expander (TE) (silicon balloon with an injection port) is usually inserted adjacent to the area requiring reconstruction in a procedure done under general anaesthetic. The tissue expander is placed in sub-galeal plane in the scalp and in subcutaneous position elsewhere. The expander is inflated gradually, over a period of weeks or months, with saline solution in order to expand the overlying skin. In most patients, this is done without the use of anaesthetics in the outpatient setting. However, particularly in young children, the use of topical (e.g.: gel) anaesthetic agents applied 1 hour prior to expansion, has been a useful pain relief tool (1). In the second stage the TE is removed and the expanded skin is used for reconstruction as a full-thickness graft, a local flap or a free flap (5) usually under general anaesthetic.

In comparison to other techniques such as skin grafting or flap transfers, tissue expansion allows for improved colour and texture skin matching, also reduced scarring and reduced

donor site morbidity. Furthermore, it preserves hair follicles and sensory nerves. Additionally, it does not require microsurgery demands in terms of skills and infrastructure or its complications (e.g.: vascular thrombosis leading to flap necrosis). The expanded skin also offers high vascularity which is superior to delayed flaps (6-8).

Tissue expansion is also widely used in children's reconstructive surgery. It is important that prior to the expansion, the patient (if applicable) and the family understand the long term implications of the process. They must also be aware of the temporary disfigurement that the expansion period will cause. However, it has been reported that young children are less affected by this due to the reduced awareness of social pressure (9). There have also been concerns regarding the risk of deforming the cranio-facial skeleton for which it is advised to employ a semi-rigid tissue expander and to delay expansion until the infant is 6 to 9 months of age (10). However, it has been noticed that cases remain without a permanent damage of said deformity.

Other authors recommend to delay the expansion until the patient is seven years old as waiting until the patient reaches this age could improve cooperation with the procedure. Additionally, this delay can minimise complications as it was found ~~that having a~~ patient' age under seven years ~~of age~~ was a factor associated with a statistically significant increase in complications (11). This information, however, contradicts a more recent study done in Bulgaria which included 62 paediatric cases whose various skin defects (including burn, trauma or pigmented lesions) were treated with tissue expansion reconstruction. This study reported the lower percentage of complication rates (3.2%) in the group of children between the four to seven years of age. Overall, 85% of cases reported an excellent aesthetic outcome (12).

Indications for tissue expansion in the paediatric patient group include: burn scar revision, giant congenital naevi, aplasia cutis congenita, haemangioma, myelomeningocoele, microtia,

scrotal reconstruction, clubfoot deformity, midfacial cleft, Romberg disease, Poland syndrome, tumour ablation, vaginal agenesis, Volkmann contracture and conjoined twin reconstruction (10, 13)

As noted, tissue expansion can be applied to all regions of the body. The head and neck regions remain the most commonly affected ones by burn injuries. Associated with these, is the disfigurement secondary to contractures or scarring which owing to its exposed and visible location, leads to social limitations and therefore also functional limitations (14).

When tissue expansion reconstruction is applied to the head and neck, while allowing preservation of facial aesthetics, there is a particular aspect to bear in mind, this is that airway, visual or oral compromise need to be avoided. A further difficulty encountered in this region is that defects may involve a number of anatomical locations (e.g.: scalp, forehead, eyelids, etc.). In these cases, expansion of adjacent tissues may not be enough for a satisfactory reconstruction. Therefore, a combination of techniques may be required, and these techniques include: use of expanded flaps, full-thickness skin grafts (including expanded and non-expanded) and excisions done in a serial manner (10, 15).

The authors aimed to carry out a systematic review of the available literature on the tissue expansion reconstructive technique and its implications when applied to paediatric burn patients who have been affected particularly on the head and neck anatomical locations. We will also illustrate our findings with 2 case reports and images depicting the tissue expansion reconstructive technique. Within the 2 cases, we present two original flaps: the Frontal-Rauf-Coronal-Split-Expanded (FRCSE) flap and the Gulraiz, Advanced, Transposition Expanded (GATE) flap which are flaps that have not been previously published but that have been developed by the senior author.

2. Materials and Methods

A systematic literature review was carried out following the PRISMA 2009 statement (16). A literature search used databases such as Ovid (Medline), EMBASE, Web of Science and Pubmed during the period until 5th October 2018.

The selected articles had to comply with the four key aspects of this review which are:

1. Tissue Expansion Reconstruction
2. Paediatric cases (under 18 years of age at the time of reconstruction).
3. Burn injury/sequelae
4. Head & neck anatomical location of defect.

Key words utilised included: Tissue expansion/expanders, Paediatric/pediatric, reconstruction, head, neck, scalp, face, burns, scald. Articles which did not comply with the above were excluded. In addition, we also excluded articles which were not in English or whose full-texts were unavailable, as well as articles which did not comply with the minimum required information related to the reconstruction technique (see below).

The data collected included the following:

Major data:

- Article's details (author, country, year),
- Patient demographics (or the average if a case series was identified),
- Tissue expander size, total volume,

Minor data:

- Burn defect and aetiology,
- Reconstructive flap location,
- Additional techniques used,
- Outcome,
- Complications and
- Follow up.

We are aware that not all articles will have all the information available for each case, and we therefore established that we required all major criteria, and ideally at least 3 of the minor criteria of at least one relevant case available per article. Descriptive statistics of quantitative data and simple processing of the quantitative data was carried out using Microsoft Excel 2013.

Our hypotheses are as follows:

- That the population of this review will be on average over 7 years of age due to implications with early skull growth and improved patient cooperation.
- That the most common mechanism of burn is the flame.
- That the most common TE shape is the rectangular due to a larger surface area per volume of expansion compared to round tissue expanders for example.
- That the most common complication is infection resulting in tissue expander removal.

3. Results

We identified 35 articles complying with the required criteria. Please refer to Figure 1 for a flow diagram of the article selection process following the PRISMA 2009 statement (16).

~~Please refer to Table 1 which summarises all main details of cases in the 35 reviewed articles.~~

A total of 68 individual paediatric cases were identified. However, it is of note that a substantial number of articles which included patients of all ages were excluded as it was not possible to differentiate data from children versus adult patients. Consistent with our first hypothesis, the average age at reconstruction was 11.3 year of age (ranging 2.5 to 18), a median of 11.8 and a standard deviation of 3.7. There were 26 female, 39 males and three of non-specified gender. Of the 25 cases which specified a type of burn, 13 were by flame, 5 by grease/hot oil, 3 by chemical (acid) burn, 3 by electrical burn and 1 scald. This is consistent with our hypothesis regarding the most common type of burn. Nineteen cases reported the defect size which on average was of 207cm^2 and had a median of 189cm^2. These values were calculated from the dimensions given in the articles. Scalp alopecia was the most common indication for reconstruction in the 1980 – 1990s while neck contractures were reported more frequently in the last two decades. There were 18 patients who were reported to have undergone previous attempts at reconstruction, out of which the use of full thickness skin graft was the most common one (10/18, including full and split thickness). Other previously used reconstructive techniques included punch grafting (51) and previous or multiple tissue expansion sessions (21, 27, 34).

In 36 cases, the type of expander was mentioned, out of which 18 (the majority) are rectangular, which is consistent with one of our hypotheses. It has also been noted that there is an overall poor reporting on the exact location of the tissue expander inflation port. Seven

articles explicitly mention their port location which are all internal. These are described as being either buried (17-20), subcutaneous (21)**,** remote (22) or self-contained (23) in the tissue expander and 4 articles explained that the ports are located in separate pockets. The remaining articles do not go into detail of where the expander ports are located.

The average length of expansion is 99.7 days (median of 91 days) and ranging from 33 to 180 days. None of the articles mention the specific use of anaesthetic for the expansion or inflation process. On the contrary, the appearance of patient's discomfort is one of the methods employed to assess the tolerated volume of expansion per session. In fact, Leonard (20) describes that while inflating, the expander was palpated to note its reduced fluctuancy, which correlated with the sensation of discomfort experienced by patient. This briefly preceded the loss of capillary refill time. A small volume was withdrawn to re-store comfort and ensure appropriate circulation of the expanded flap.

The type of flap varied according to the location of the lesion, with pre-fabricated flaps having the advantage of being located further away from the defect due to availability of microsurgical anastomosis techniques. Additional or supplementary techniques were varied. These ranged from simple debulking of a flap (20) to endoscopic assisted flap insertion (26). Other included: Z-plasty (20), microsurgical anastomosis (20 – 21, 24 – 25), the use of porous polyethylene for pinna/helix reconstruction (27), full thickness skin grafts (44) and three-dimensional scanning imaging (36) to aid flap and expansion preparation.

In two occasions, authors highlighted the benefit of serial tissue expansion episodes (up to 6 cycles of tissue expansion) in order to complete the reconstruction of extensive defects (24, 25). A further third article mentioned that the patient had a previous expanded advancement flaps for the anterior chest with little improvement of function (17).

Due to the variety in reporting styles and depth of complication incidence deporting, specific data on complication rates could not be extracted and compared. Thus, a particular conclusion could not be drawn from the collated sample as most cases reported individual circumstances which are outlines on Table 1. Therefore, out final hypothesis cannot be necessarily accepted or rejected due to insufficient evidence. Of note, the cases reported in the late 1980's (50 – 51) appear to suffer more complications than recent cases.

Please refer to Table 1 which summarises all main details of cases in the 35 reviewed articles.

Case reports:

The following case reports include reconstructive surgery applying original flaps created by the senior author of this article and have not been previously published.

Case 1:

This adolescent male presented with extensive post-burn scarring affecting areas of hair growth (moustache and beard). A 700ml rectangular tissue expander was placed through a sagittal incision over the vertex. The Frontal-Rauf-Coronal-Split-Expanded (FRCSE) flap was used for moustache and beard reconstruction. Follow up at 2 and 15 years show satisfactory outcomes (Figure 2).

Case 2:

A 15 year old male patient presented with a left sided temporal alopecia. An incision at the edge of the alopecia served for insertion of the rectangular 100ml tissue expander. The flap was raised at the subgaleal plane combining the elements of transposition, advancement and rotation in a single flap, the Gulraiz, Advanced, Transposition Expanded (GATE) flap. At two months following reconstruction, the patient shows a satisfactory outcome (Figure 3).

5. Discussion

Tissue expansion has become important in secondary burn reconstruction. Addressing alopecia of the scalp secondary to burn is one of the most successfully managed burn complications by tissue expansion. The expander can be placed under the galea aponeurotica. The expansion allows for redistribution of the existing hair follicles on the scalp. A 50% cut-off of scalp alopecia is commonly considered for appropriate reconstruction. This is the case because if the scalp tissue needed to expand more than double the spread of the hair follicles may be unsatisfactory or unacceptably thin (5). We note from our review that alopecia is the most common indication (15 cases), particularly between 1987 and 1998.

Another major indication for post-burn tissue expansion reconstruction is neck scar contractures. These were reported in 13 cases particularly from 1990 onwards, however one might argue that those with reduced range of neck movement are due to neck scar contractures.

Given the apparent bimodal evolution between alopecia and neck contractures as indications for surgery, it would be interesting to compare these incidences throughout the years to those of adult age.

Complications in tissue expansion reconstruction include major complications, in which the expander needs to be removed, and minor complications, which do not necessarily hault the reconstruction. As described in a review by Bozkurt, Groger (6), minor complications include haematoma, seroma, delayed wond healing, bone moulding, neuropraxia, whereas major complications include infection, dislocation, leakage and deflation, exposure, wound dehiscence, skin necrosis, extrusion etc. Bozkurt reviewed 102 expander cases reporting a

complication rate of 28% with 7% resulting in failure of the procedure (when a procedure had to be abandoned due to a complication). Other previous studies noted on this review indicate a wide range of complication rates which varied according to site of expander as well as indication. For example, the lower limb appeared to have a complication rate between 20% - 80% owing the higher complication rate to the thinner protective overlying tissue. In contrast to the head and neck whose complication rates ranged from 1% - 32%. Bozkurt noted that volume and anatomical location of the expander affected the failure rate whereas other factors e.g.: age, gender, expander quantity per patient and shape of expander appeared to have no statistical correlation to the failure rate (6).

A large study of the complications arising from tissue expansion in burn paediatric patients involving a 10-year follow up (from 1996 to 2006) reviewed 240 patients. The analysis classified complications as absolute (e.g.: premature expander loss leading to further operations or halting of the reconstructive plan) or relative (poor pre-operative judgement causing a partial completion of surgical reconstructive plan). Results indicate that the absolute complication rate was 14% and the relative one 10%, with the most common anatomical site being the scalp. Authors noted that skin prepared with betadine was linked to a reduction of 10% complications related to infection. Furthermore, factors like the patient's age or surgeon were not related to higher complication rates (52).

A recent study (53) from 2015 reviewed 202 tissue expansion procedures out of which 119 were paediatric (considered age <16). Complication rates between adults and children were compared: children have a rate of 20% of complications whereas adults a rate of 13%. However, neither the difference between the two cohorts nor the difference between various anatomical sites (including head and neck with a 7.1% complication rate in adults and 12% in children, torso nil complications in adults whereas 19% in children, etc.) was found to be statistically significant. The most common complication rate in paediatric procedures was

infection (9.9%) followed by expander exposure (6.4%) whereas in adults 8.9% (5 cases) had infections followed by a single seroma case and a single expander deflation case. The study concludes that in spite of the high complication rates, tissue expansion is a good reconstructive approach as in the majority of cases, even those affected by complications, it is possible to proceed with the final reconstructive procedure (53).

The only article about surgical complications which fulfilled the 4 main criteria of this review was written by Hudson (25) in 2001 in which 70 TEs were assessed. He found that 20 % (14 expanders) had a major complication, infection, requiring removal of the TE and that 14% had a minor complication which did not require removal of the expander, e.g.: extrusion at full expansion, exposure of filler dome.

More recently in 2016, Duclert-Bompaire, Sallot (54), published the experience with tissue expansion reconstruction in 45 children where 39% of cases (20) were due to burn pathology throughout the body. It was noted that 53% of the burn cases developed complications. When assessing the overall outcome which included an assessment between the surgeon, the parents and the patient, 15 out of 20 cases were classed as excellent or satisfactory results (54).

Furthermore, McCullough, Roubard (55) in her review of 88 paediatric patients (with 150 expanders) who underwent tissue expansion of facial defects, described a complication rate of 43% and highlighted an 11% rate (10 cases) of ectropium of which nine were managed with canthoplasty and one conservatively (55).

A recent single surgeon case series analysis of complications in Paediatric Tissue expansion reconstructions revealed a complication rate of 23% of the total number of expanders (65 of 282 expanders) which involved 39 of the 94 patients. These included major complications such as exposure, rupture and migration requiring removal of tissue expander, and minor complications such as expander migration and port malfunction in which the expander was

preserved (56). The author highlighted the importance of avoiding the use of incorporated ports due to the risk of thinning of the skin overlying the port in tight areas. Additionally, this could avoid potential expander puncture in the case of an uncooperative patient.

There are many advantages to having external ports during tissue expansion, these include the reduced dissection and requirement for soft tissue coverage, quicker expansion, reduced risk of rupture or puncture, and reduced pain and emotional stress to patient (57, 58). These offer a great benefit particularly in paediatric tissue expansion where pain may be less tolerated. However, there are concerns regarding a higher infection risk for external ports versus internal ports. Azadgoli's (59) assessment states that the literature results contradict this by obtaining infection rates from 5 – 6.5% with the use of internal ports compared to the 6 – 8.8% when using external ports, but, this study does not state if these differences are statistically significant. In fact, the articles identified in our review do not appear to favour the external port placement. Furthermore, externalising an internal port has been a technique highlighted to salvage an infected expander (60). A further finding in Azadgoli's (59) study was that a higher number of tissue expanders placed in particular anatomical location contributed further to infection than the use of external ports itself.

Furthermore, it has been highlighted that subsequent episodes of expansion cycles, though required where there is a large defect, could increase the risk of complications in a way such that the complication rate is 50% by the 3rd and 5th round of expansion and 100% by the 5th round (56). This is comparable to the finding in Gil's study (41) in which the patient went through 5 cycles of tissue expansion without complications but developed one in the 6th session having an expander exposed in a suture line breakdown. The second article in this review which also carried out multiple cycles of tissue expansion was (25). However, the complication rate did not appear to have an obvious relation to the number of expansion

cycles: the major complication rates were: 21%, 25% and 14% and the minor complication rates were 7%, 8% and 7% for the 1st, 2nd and 3rd expansion cycles respectively. Furthermore, one of the drawbacks of repeated scalp expansion is the likelihood of visible reduction in hair follicle density, however, in Gill's case, in spite of 6 expansions, the hair-bearing scalp density was deemed acceptable.

The versatility of tissue expansion can be increased when combined with other techniques for reconstruction, Fernandes and Driscoll (61) published a review of thirteen children (average age nine) with alopecia and external ear defects secondary to burn. They described the concomitant use of subgaleal tissue expansion to reconstruct the post-burn alopecia together with Medpor® (Stryker, Kalamazoo, MI, USA) as a porous polyethylene implant to reconstruct the structure of the external ear using a temporo-parietal fascial flap. This study reported no complications from the expansion process. The combination of both techniques was described as the preferred method for managing such external ear defects in children as it offered good cosmetic outcomes, high satisfaction and low morbidity (61). Additionally, Driscoll has highlighted the possibility of "reducing waste" by employing the scarred hairless scalp skin to reconstruct the pinna (35) as the cases in our review highlighted.

Tissue expansion may not be the treatment of choice in certain circumstances, for example, if the hospital implementing the treatment lacks from monetary, infrastructural or human resources, for instance as seen in the Department of Reconstructive Surgery in Pristina, Kosovo. Their article highlights the fact that burn injuries are a very frequent occurrence in Kosovo. In this particular study, they reported 188 patients (out of which 73% were children) who suffered from burn injuries in sites throughout the body, reporting 14% of those being the head and neck. Nevertheless, due to the cost of such extensive technique, it was not used frequently, only in 8% of cases (62).

Tissue expansion reconstruction has shown to offer the best match of skin colour and texture and has offered solutions to reconstructions that may have appeared to be impossible with other reconstructive techniques. It must be born in mind that careful patient selection together with a satisfactory availability of resources is required. This will help reduce incidences such as that highlighted by Calobrace (46) in which the patient was lost to follow up, had the TE fully expanded on his scalp for 15 months and then returned with a deformed skull, which fortunately spontaneously remodelled without major consequence described.

Measures have been taken to try to minimise some of the challenging aspects of tissue expansion. These issues include the numerous visits to hospital which may result difficult to the patient and relatives in terms of taking time off school or work. Another difficulty includes the risk of puncturing the expander when injecting the isotonic solution during the serial expansion. In order to try and minimise the above issues, self-expanders have been manufactured.

The creation of self-inflating expanders originated almost 40 years ago by Austad and Rose who made a hypertonic solution filled expander, this was later abandoned due to the necrosis occurring on the overlying tissue secondary fluid leakage (63). In 1999 Osmed presented a new version of self-inflating tissue expanders which absorbed the surrounding fluid to grow in size over six to eight weeks. This expander was made of a material which included hydrogel. However, this first generation caused pressure necrosis on the overlying tissue and therefore required to be optimised. A second generation of self-inflating expanders was born by including a silicon cover with pores allowing the resorption of fluid. These expanders resulted in an improved outcome. Nevertheless, the disadvantages of uncontrolled tissue expansion which starts the moment it is placed in the subcutaneous pocket persists and is something the surgeon needs to carefully take into account (64). A study with second generation Osmed tissue expanders including seven children with lesions in various parts of

the body, concluded that these expanders were more convenient for children due to being less painful and having less visits to a medical centre for serial expansion (65). This appears to have a promising potential, particularly in children, however, to our knowledge there were no self-inflating expanders in the cases we reviewed.

Endoscopic assisted tissue expansion is a new approach to the tissue expansion technique. As'adi, Salehi (66) described a study of 42 patients who underwent neck tissue expansion following this approach. Advantages include: minimal incisions placed at a greater distance from the tissue to be expanded, magnified field view leading to an improved haemostasis. Additionally, reduced length of expansion, attributed to the sooner initiation of expansion given the smaller incisions as well as a larger intraoperative expansion (reported to be between 25% to 30% of the expander). Furthermore, this approach was associated with a lower complication rate as well as a reduced hospital stay and operative time (66). Only one article described endoscopic assisted TE insertion in our review (34) with satisfactory outcomes.

Limitations of this review include the fact that many reconstructions carried out in paediatric cases but published as a mixed adult and paediatric reconstruction review had to be excluded as a consequence of having pooled data. Conclusions regarding complications for example were difficult to analyse due to previous analyses being done in a mixture of adults and children, mixture of indications for tissue expansion or mixture of body sites of reconstruction (14, 67). Also, information regarding a number of aspects of the reconstructive technique, for example complication rates, remains inconsistent throughout the published literature (53). Further literature reviews focussing on the aesthetic and functional outcome as well as patient satisfaction with tissue expansion reconstruction will provide further information regarding the impact of these procedures other than the technical information.

4. Conclusions

In conclusion, tissue expansion reconstruction offers a versatile reconstructive technique to address post-burn reconstruction of the head and neck (as well as other areas of the body) in the paediatric population. Benefits of the technique include the ability to optimise the matching of skin colour and texture when replacing the defect with the expanded tissue. Additionally, this gives the major advantage of being able to redistribute hair follicles into regions which may have lost them as a consequence of scars secondary to burn injuries. Naturally, no technique is free of disadvantages. The seemingly bearable but high complication rates as well as the long process which includes an additional but temporary disfigurement may prevent patients from opting for this technique. However, complication rates are not reported consistently and further specific studies will be required to ascertain these and classify them according to indication, location in body, age, number of expansion sessions if more than one etc. in order to gain a deeper understanding and prevention strategies.

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FIGURE CAPTIONS ONLY:

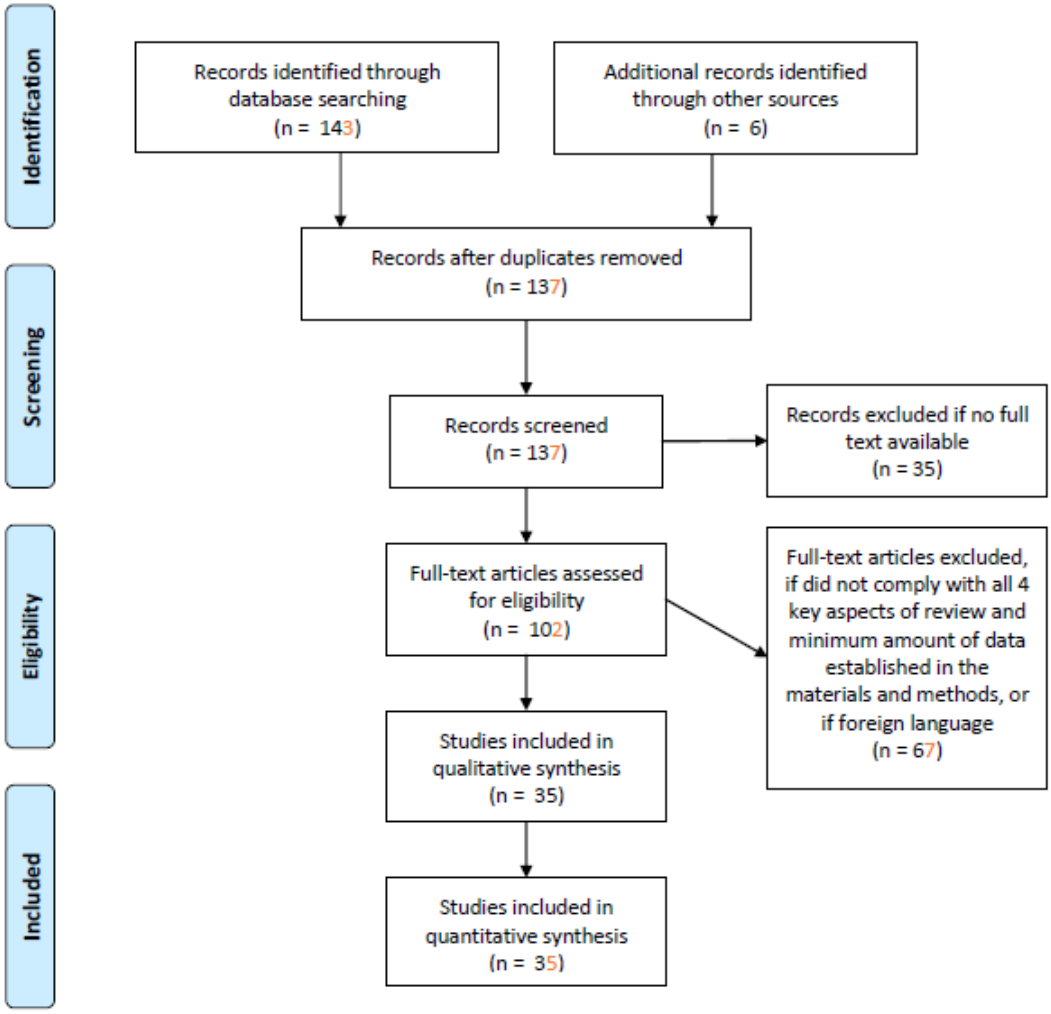

Figure 1 – PRISMA guidelines flow diagram showing process of article selection for systematic literature review.

Figure 2 - Tissue expansion reconstruction of an adolescent male with extensive post-burn scarring (A) Frontal view. No potential for hair growth in moustache and beard areas. (B) Following tissue expansion of frontal scalp with a 700 ml rectangular tissue expander placed through sagittal incision over the vertex. (C) Frontal view – after further expansion. (D) FRCSE flap (Frontal-Rauf-Coronal Split Expanded Flap) for moustache and beard reconstruction. The defects over both temples were reconstructed three weeks later (at the time of division of pedicles) with excess tissue from flap pedicles. (E) Two years and (F) 15 years post reconstruction. Images courtesy of Mr Khawaja Gulraiz Rauf.

Figure 3 - Tissue expansion reconstruction using the GATE flap (Gulraiz Advanced Transportation Expanded Flap) (A) 15 year old male patient with left temporal alopecia. (B) Incision at edge of alopecia patch for insertion of rectangular 100 ml tissue expander. (C) Injection port placed under patch of alopecia. (D) Patient towards the end of expansion process continuing social activities. (E) Flap raised in subgaleal plane. (F) Undersurface of flap. (G) Splitting (arrow) of the rotation flap to

accommodate a triangular flap (*) thus combining elements of transposition, advancement and rotation in a single flap. (H) Final closure. (I) Two months post reconstruction. (J) Diagrammatic representation of incisions – superior view of scalp: Patch alopecia 5.5cm x 4cm (orange circle). Length of incision from point a to point b is 12cm. An incision was made at middle of rotation (point c) to accommodate triangular flap (*). Images courtesy of Mr Khawaja Gulraiz Rauf.

Table 1 – Table summarising most relevant aspects of Tissue Expansion head and neck burn reconstruction of paediatric cases. Where qualitative data was not sufficient, a description of the most salient points has been added.

Article		Pt			Defect			Expansion							
No	Author, y	A & G	BA	Sx/FE	Area (cm^2)	Site	Prev Recon	S # TE	TE size (ml)	T vol (ml)	Expansion time (d)	Flap location/ Type	Flap area (cm^2)	Other technique /comments	Outcome +/- complications	f/u
1	Hu, 2017 (26)	17 F, 14 M, 12 M, 16 F	B					Sq 1	150/150 / 150/150 / 150/150	220 / 260 / 160 / 320			72 / 108 / 48 / 112		Very good	
2	Tian, 2016 (27)	8 M	C-A	De		Face, cheeks		Ro 2	200 / 281	267 /	91	B/L cervicoperiauricular	67.5 /71.25		Satisfactory	
3	Zhang, 2015 (28)	11 F	E	De, Co	23 0	Lower face, nasal dorsum, perioral, chin, neck.	Skins grafts	4	200 / 300 /	150 / 150 / 150 / 150		Neck / left face / right face / neck		Transfer of parietotemporal fascia to neck	Good colour and texture	

							1 0 0 / 2 0 0 0							
	14 M		Co,	37 8	Neck		E 1	8 0 0		56	Scapular	MA, Debulking	Hypertrophic scar	Good match, no contractures. 1 y
	9F		RRO M	16 0	R neck and upper chest			4 0 0		56	Scapular	Full thickness platysma transection, MA, Z-plasty		
4	Song, 2015 (29)	30 6 / 18 10 F / 17 F / 13 F/ 19 F / 11 F	B	Sc	9 / / 13 3 / 18 9 / / 15 3	Neck		1				None / Debulking / None / Debulking / Z-plasty	No complications	

		11.8* 1F:3M		Co				3 2 5*	103 1.6*								
		13M	B	RRO M	R neck	Previous expansion	3 2 5	103 1.6	180	Superficial cervical artery	300	Pedicled flap	Excellent ROM	2 y
5	Li, 2015 (17)	12M	Fl	RRO M			3 2 5	103 1.6	160	Superficial cervical artery flap, L back	350	MA Free flap circumflex scapular artery to left facial artery/vein	Good flap survival, correction of defects, ROM	2 y
6	Grishkevich, 2015 (30)	6M	B		Cheeks uni/bilat					Cervico-periauricular flaps		Split neck flap	Good match colour, sensate.	5 y
7	Yang, 2014 (31)	16F	B	Co, RRO M		Tangential excision and STSG	1	8 0	940	L cervico acromial region	368	Flap rotation 180 degrees without pedicle isolation	100% flap survival, donor site closed with STSG, good	2 y

													match, ROM improved.		
		9F	B	Co, LL	Cervical contracture						204	MA, thoracodorsal artery perforator (flap) to facial		1.5 y
		8F	Fl	Co, LL							336	MA, thoracodorsal artery perforator (flap) to facial	Good match colour, texture	2 y
8	Wang, 2014 (32)	15 F / 12 M / 10 M									187 / 368 / 187				
9	Acarturk, 2014 (33)	15 M	Fl	Co, RROM, LL	Anterior neck (shoulders and arms)	R e 1	1 0 0	120	90	Anterolateral thigh flap		MA, vascular lateralis perforators to superior thyroid artery/IJV	Full lateral movement.	2 y
10	Elsha er, 2011 (34)	13 F	B		Cheek	R e 1	5 0	100	35			EA TE insertion	No complications		
		14	B		Forehead	R	2	75	56	Advance		EA TE			

		F				o 1	5			ment rotationa l flap	insertion		
		17 F	B		Neck	R o 1	1 5 0	150	56		EA TE insertion		
		7 (1 0 m)	C - A	De	R temporal region and hairline	Scalp expansi on					PPE for helix reconstru ction		
		10 (1) F	Fl		R temporal region and ear.	2	1 0 0 0 / 6 0 0				PPE for helix reconstru ction		
1 1	Drisc oll, 2010 (35)	17 (1 5)	C - A		Ear						PPE construct with scarred alopecic skin tissue and temporop arietal fascial flap		3 y +
1 2	Ridg way, 2009 (36)	14 M	E	Chro nic wou nd, exp osed		2	2 0 0 / 3 2		135	Adjacent to wound defect		None	

				bon e				5/ 4 0 0									
13	Liu, 2009 (37)	5	M	B	Sc			R e 3	2 0		75	Neck: Temporo parietal transposi tion fascial flap transferr ed to the cervical region.	42	Pre-fabricated temporof ascial flap.	100% flap surviv al, match ed well		
14	Bey, 2009 (38)	13	M	Fl	Sc, Co		R subme ntal FTSG.					Deltopec toral flap			No flap failure , Hypert rophic neck scar noted.		
15	Xianji e, 2008 (39)	4	M	B	Sc	49	4	2	4 5 0 / 2			Bilateral deltopec toral regions			Facial conto ur satisfa ctory, neck ROM restor ed.		
16	Ulric h, (8)	10	M	B	RRO M		Anterior neck	STSG	R e	5 0	650	56	Pedicled trapezius	243		100% flap	6 m

6	2008 (18)	M				1	0			musculocutaneous flap				survival, good outcome, ROM improved
17	Pallua, 2008 (40)	11 M	B			Re 3	250 Left 500/40 0/40 0/10 0 (x 2)	320	84	Supraclavicular artery island flap	192			
18	Gil, 2008 (41)	16 (1.5) F	B	Al	L occipical and nuchal areas	6 expansion sessions	C, C, C, C + C, Re, Re	0 0 (x 2)	105 / 119 / 91 / 126 / 98 / 63					6th (last) session: exposure of implant due to suture breakdown. Required removal of expander.

											/ 1 0 0 (x 2)							
19	Ninkovic, 2004 (42)	14 F	B	Co, RRO M	27	Face, neck, upper chest, middle and lowe back, arms and thighs	Tangential excision and STSG			7 0 0	Pre-expanded free scapular flap		275	MA	Nil donor or reconstruction site issues but required minor debulking.	7 y
20	Ji, 2002 (43)	14 M	B	Co		Face, dorsum of nose and scalp	STSG	2	4 0 0	60	L side of head			3D scanning	Immediately, nil issues. POD 12d: 44% flap shrinkage. At 6m: nill issues, pt satisfied with	

																		outcome.	
21	Hudson, 2001 (25)		B															20 % (14 expanders) had a major complication, infection, requiring removal of TE. 14% had a minor complication which did not require removal of the expander, e.g.: extrusion at full expansion, exposure of filler dome.	
22	Silfen, 2000 (44)	5 (2)	M	Fl	Al 70%, Co, behavior changes	Scalp	Silicone sheets, pressure, physiotherapy	R e 2	17 5 / 15 0	190 / 140		Temporo-parietal / occipital		Frontal hairline and behaviour improved. Expander deflated, replaced and then extruded - removed.	1 y
23	Fan, 2000 (45)	8	M	Fl	Co, RROM				30 0	350	35	Submuscular pocket of forehead	160	Excellent	
24	Chun, 1998 (19)	2.5	M	G	Al 90	Vertex of scalp		C 2	70 / 25 0	227 .5 / 484	135	anteriorly - advancement of hairbearing scalp		No complications	

														/ posterior		
25	Calobrace, 1997 (46)	5 (2) M	B	Al 40%			C	3 0 0	265	150	Subgaleal plane advancement flap				Patient lost to follow up, kept TE expanded for 15m. Severe calvarial depression and ridging, 3cm depth. 6m post reconstruction, nearly complete remodelling of the skull with minimal visual deformity.	
26	Riaz, 1995 (47)	11 (5) M	B	22 4	Lower face, neck, chest and R thigh.	Tangential excision and skin graft. Co release x2	1	7 0 0	102	60	R scapular	350	Flap was passed through triangular space and delivered without tension to the neck.	100% flap survival. Hypertrophic scars. Z-plasties required. Debulking of flap under the chin.		
27	Neale, 1993	14 M	Fl	Sc	R cheek						Cephalad advancement			Unsatisfactory		

	(21)											flap			outcome. Scar widened.
		Ten F	B			Anterior chin and anterior madibular border	STSG	hyperpigmented			120	Advancement of neck flap			Scar widening and slight ectropion of left lower lip
		16 F	Fl	Sc		R lower cheek and mandibular border						Posterior neck flap			New anterior neck scar
		12 M	B	Co		L neck						Advancement flap			
28	Spence, 1992 (48)	10 M	Fl	Sc		L cheek and forehead		Re				Shoulder as donor for expanded FTSG	Expanded FTSG (+/- allograft wound delay)		100% take of grafts
29	Ortega, 1990 (49)	14 (2.5) M	G	Al 35%	90	R parieto-occipical scalp	Serial excisions	R e 1	6 8 0			Bi-pedicled flap R parieto-occipical segment.	Near total correction NB: RTA caused scalp avulsion while expander was in. Then reconstructed. Atelectasis post-op		
3	Laitu	15	B	Co		Lower	Skin	R	1	140	70	R	360	End to	Satisfa

0	ng, 1990 (50)	F			border of mandible to sternum	graft releases	o 2	1 0 0	0	scapular region (subcutaneous)	end MA	ctory release of contracture. Ecchymosis which resolved			
3 1	Cooper, 1990 (23)	9 (8)	Fl	Al	R frontotemporoparietal scalp		1	3 7 5 to 8 0 0	500	Subgalea l plane in L temporoparietal region free flap	End to side MA	Majority of burned scalp removed and replaced with hair bearing skin.	1 2 m		
3 2	Da Matta, 1989 (24)	14 F	B	Al	27 2		R e 3	2 5 0		Transposition expanded flap (L) and a rotation advancement flap (R).	2nd expansion, advancement of occipital expanded flap + rotation and adanceme nt of expanded flap (on				

												right side).
6			M	B	Al	33	0	Frontotemporoparietal scalp	C / Re	5 0 0 / 2 5 0	Rotation and advancement flaps	Further improvement can be obtained from reconstruction of sideburns and hairlines
8	F		B	Al				Temporoparietal occipital regions	C / Re	3 0 0 / 2 5 0	Transposition and advancement flap	
7	(10 m)	M	G	Al		R / L scalp	STSG	2	R e	6 8 0 / 2 5 0	42	Multiple flaps	Full coverage of alopecia and frontal hairline
3	3	Zuker, 1987 (51)	6 (1 m)	F	Fl	Al		Central scalp	STSG. At 4 y: rotation flap on left scalp, but residual alopecia	2	®	2 0 0 (L), 1 0 0	63	Sub galeal plane, beneath prev rotation flap, for a transposition flap	TE recon initially delayed due toopen fontanelles. L expanded scalp reconstructed hairline, R expanded scalp covered defect created by transposition flap. Excellent results.

						a.						from the L expanded scalp.	
		16 (14)	M	E		R Temporoparietal scalp, R upper limb, and lower limbs	STSG	2	25 0 + 14		35	Subgalea l plane over apex of skull + post to apex	Transposition flaps to cover alopecia and reconstruct the hairline. Exposed posterior expander 1d before reconstruction
34	Geter, 1987 (22)	9	M	Fl	Al	R parietal and frontal scalp.				880	90	Subgalea l plane of L scalp	2d pre-op infection/collection, drained, irrigated. 8d later, infection sx resolved and the reconstruction took place, burnt scalp was excised. Hair growth adequate
		8 (2)	M	B	Al	31		R e 2		235 / 75		2 x rotation flaps	Normal hair growth achieved
35	Leonard, 1986 (20)	9 (2)	M	G	Al	22 5		R e / R o		450 / 750		Advancement and rotation flap	9d after TE insertion: haematoma. Drained. 3w: expander eroded through scalp. Covered by transposition flap.

										Then, expansion was started. After reconstruction: Dog ear in the centre of the flap - excised Excision of small areas of alopecia within the hairbearing scalp, prior to insertion of expanders.
12 (4) M	S c	Al	90	Punch grafting	Ro / Re	274 / 90	Advancement flap	90		
9 (3) M	G		70		Re 2					Seroma + infection. TE removed. At the time of the article publication, 4/12 post op, expansion had commenced with a new TE.

*Abbreviations: Sx: N: article number, Pt: patient demographics, A&G: age at surgery/y and (injury), BAe: Burn aetiology, y: years, m: months, d: days, M: male, F: female, B: burn not specified, Fl: flame, G: grease, C: chemical, A:acid, Sc: scald, E: Electrical, Sx: Symptoms/Signs, FE: functional effect, S: scar, Co: contracture, Al: alopecia, De: deformity, LL: lower lip deformity, R:right/right hand side, L: left/left hand side, S#TE: number of tissue expanders, TE: tissue expander, RROM: reduced range of movement, Sq: square, Re: Rectangular, Ro: round, C: crescent, El: elliptic, MA: microsurgical anastomosis, EA: Endoscopically assisted, PPE: porous polyethylene, FTSG: full thickness skin graft, STSG: split thickness skin graft, B/L: bilateral, POD: post-operative day, *:average for 4 patients, T: total, f/u: follow*