doi:10.22306/atec.v5i1.46

Received: 11 Mar. 2019
Accepted: 26 Mar. 2019

NEW TECHNOLOGIES OF TISSUE EXPANSION - REVIEW ARTICLE

Marianna Trebuňová
Faculty of Mechanical Engineering, Department of Biomedical Engineering and Measurement, Technical University of Košice, Letná 9, 042 00 Košice, Slovakia, EU marianna.trebunova@tuke.sk (corresponding author)

Jozef Živčák
Faculty of Mechanical Engineering, Department of Biomedical Engineering and Measurement, Technical University of Košice, Letná 9, 042 00 Košice, Slovakia, EU, jozef.zivcak@tuke.sk

Radovan Hudák
Faculty of Mechanical Engineering, Department of Biomedical Engineering and Measurement, Technical University of Košice, Letná 9, 042 00 Košice, Slovakia, EU, radovan.hudak@tuke.sk

Viktória Mezencevová
Faculty of Mechanical Engineering, Department of Biomedical Engineering and Measurement, Technical University of Košice, Letná 9, 042 00 Košice and M-Science Group, s.r.o., Slovakia, EU, msciencegroup@gmail.com

Daniel Kottfer
Faculty of Mechanical Engineering - Department of Engineering Technologies and Materials, Mäsiarská 74, 040 01 Košice, Slovakia, EU, daniel.kottfer@tuke.sk

Keywords: expansion of skin, muscles and bones, tissue expander

Abstract: Currently, plastic surgeons are often challenged to reconstruct extensive and complex tissue defects in various areas of the body. Despite the availability of a variety of operative approaches in practice that are applicable in the long term for the reconstruction of tissue defects, donor and autologous transplants, skin grafts, implants, etc., the result is often not satisfactory. Restrictions of these techniques in restoring and repairing tissue serve as a driving force for the development of new techniques, the development of adipose tissue in tissue engineering. From a didactic point of view, the expansion could be divided into 3rd groups. The first group consists of physiological expansion, e.g. growth of an individual. The second group includes pathological expansion, i. skin growth over areas of tumours. The third group includes artificial expansion, which was an important part of cosmetic or ethnic adaptations for some tribes. This review article is addresses the application of tissue expansion in various types of tissues, skin, muscles and bones, as well as its localization and its side effects.

1 Introduction

Tissue expansion as a surgical method is relatively new. The clinic has been in use since 1980 and its founders are prof. Radovan, Austad and Rose. In most cases the donor tissue is expanded from the area adjacent to the defect site. The principle of tissue expansion technique is to create a hemispheric dome lobe, which does not leave any after moving respectively minimal scar on the donor side [1,2,16].

The basis of tissue expansion technique is the adaptability of tissues to changing indoor conditions. Expanding tissues has found application in many areas of reconstructive medicine due to many benefits. They can be applied in different parts of the body, even in multiple combinations with transplantation techniques. They provide tissues with a specialized sensory function, skin with almost perfect colour and texture, and minimal morbidity and scarring of the donor site are observed [3,4]. Expansion of tissues is applicable to almost all types of tissues (soft and solid tissues). It is the expansion of the skin - mechanotransduction, muscle expansion - myofibrillogenesis and bone expansion - distractional osteogenesis.

1.1 Expansion of the skin

Tissue expansion of the skin was first described in 1957 by Neumann [3,5], who used a subcutaneous rubber balloon, gradually filled with air, to spread the skin immediately adjacent to the wound. He noted that using this technique can create new, undamaged skin that could be used to cover large areas of skin injuries. In addition, the *de novo* expanded tissue-like colour and structure had identical sensory and hair bearing the missing tissue characteristics, with minimal scarring and morbidity of the donor site [3,5-7]. There is, in theory, no limit to the amount of tissue that can be generated by the expansion of the tissue, provided that the process is carried out sequentially.

1.1 Expansion of the bone

Distraction osteogenesis - this is a rapid expansion, elongation using either external devices such as bone distractor or internal devices such as ISKD (Intramedullary Skeletal Kinetic Distractor). The application of external devices stimulating distraction osteogenesis was introduced in 1951 by Russian physician Ilizarov. The

Ilizar apparatus (Figure 1) is capable of elongating the limbs in cases of congenital diseases, pathological bone loss, limb asymmetry, dwarf growth, nanism, and the like. In reconstructive and aesthetic surgery, the extension of the mandible, e.g. in cases of congenital malformations, traumas, tumours, used with a high degree of success of articulated expanders [8].

The lingering method of limb extension is expansion through intramedullary and skeletal kinetic distractors (ISKD). With this technique it is possible to obtain an extension of 12 cm, but this method of expansion is expensive, painful and time consuming (each procedure takes about 8-12 months [9].

Currently the ISKD system consists of a telescopic extension of the inner limbs, locking screws, instrumentation and an external hand-held monitor. When the patient performs small rotation oscillations of the limb, the ISKD inner limb extension gradually pulls the bone. The stretch rate depends on the level of active activity of the patient or on the manual handling of the limb. It added manually monitor, which includes a magnetic sensor. It activates a small magnet sealed inside the extender. When the stretcher stretches the tissue, the internal magnet rotates. When properly positioned over the magnet, display monitors and records the position of the magnet. With this system ISKD doctor and patient can be monitored regularly achieved by stretching the length, which can be monitored data and print. In use, the present ISKD need its full insertion into the tissue (Figure 2). The potential risk of infection is diminished as compared to extension procedures that require external pins or wires. The ISKD is designed to extend to a predetermined distance and then to stop [10].

The highest efficacy of expansion of solid tissues has been demonstrated in cases such as congenital diseases, pathological growth (nannism), asymmetry, bone loss, prolongation of bones, mandible, trauma.

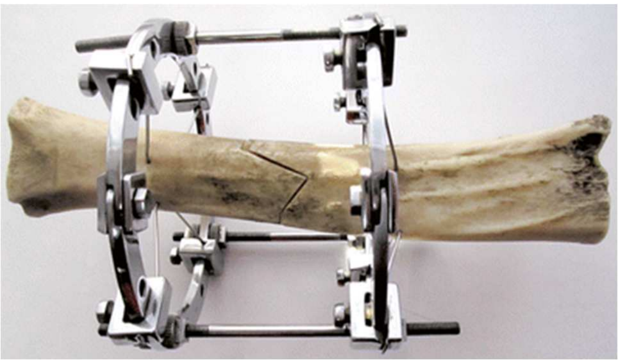

Figure 1: Ilisarov apparatus [11]

Figure 2: ISKD [10]

1.2 Expansion of muscles

Growth and increase in muscle mass under physiological conditions is proportional to muscle load and a full-fledged diet enriched with sufficient resp. excessive amounts of basic amino acid building blocks. The process of growth of muscle tissue expansion is known as myofibrillogenesis [12,13]. Targeted expansion of muscle tissue is also observed during mechanical transduction by specific techniques applied in repair and regeneration techniques through endermotherapy [14].

Tissue expanders used for muscle expansion are balloons made of silicon and filler ingredients that are molded into the preformed prosthesis. It can be filled with physiological saline through the valve system. It is either incorporated on the surface of the expander (early expanders have this structure that is not visible today) or is remote and connected by a flexible silastic filling tube to the expander (almost all expanders now have a remote valve). The greatest advantage of the remote valve and filling tube is to maintain the injection point well away from the balloon to prevent any risk of penetration of the balloon when the expander is inflated. Remote placement allows placement under the skin where it can be easily palpated [15].

Standard tissue expanders, which are available from the production companies are usually circular, rectangular or crescentic (croissant) in shape and is usually manufactured in commonly required volumes / capacities from 50 to 1000 cubic centimetres in increments of 50 to 100 cubic centimetres (Figure 3). Most of the errors can be quite satisfactorily reconstructed using standard expanders available from the manufacturer.

The expansion technique is based on regular expansion of the expander solution until the skin tissue above the expander reaches the desired size in advance. The average expiration time is 3 months. Tissue expansion is an innovative method that provides ideal tissue for reconstruction with minimal effect on the donor area. It is one of the few techniques that are satisfying both functionally and aesthetically. Attractive in its simplicity in clinical application, tissue expansion may be considered a reasonable method of manipulating the normal physiological process - i.e., for the so-called "biological dividend" [16,17].

Figure 3: Different types of tissue expanders [15]

1.3 Indication of tissue expansion

The most frequent indications of tissue expansion are: mastectomy (breast reconstruction, implant), scars, keloids, burns, trauma, postoperative condition, previous surgery, congenital melanocytic nerve, scalp reconstruction, genital and urethral reconstruction, eye microsurgery, etc. [3,4,18,19].

1.4 Localisation of tissue expanders

The use of tissue expanders has limitations that are particularly related to the location of the expander. Optimal expansion is achieved when the process is performed on a hard surface (e.g. bone), while expansion is more complicated when done against other soft tissues (e.g. neck, abdomen).

In the latter case, it is necessary to closely monitor the process of tissue expansion. Expansion itself can also create new edges of tissue, sometimes hard, that need to be addressed during the final surgery. Due to the high annual increase in tumour diseases, especially breasts, tissue expansion is most commonly used in breast tissue reconstructive surgery [20].

Other sites for expander placement are individual regions of the body where the tissues are expanded mono or bilaterally (Figure 4).

1.5 Expansion of other tissues

1.5.1 Expansion of the scalp, hairline

The tissue expansion induced by the mechanical effect of increasing the volume of tissue expander has been the subject of research by scientists and surgeons since 1957 [6]. The ability of almost unlimited expansion, with all its original features and properties, has long been used in cases of fibrotic scarring of the head and face due to previous surgery, trauma, etc., after the removal of the tumours, where as a result of the occurrence in the hair part of the alopecia, after the excision of the tumours, in the correction of the defects of the cranial cover (Figure 7) [21-23].

The tissue expanders are located near the defect in the cranial area. Percutaneously replenishing once or twice a week increases the volume until the expanded scalp is 20% larger than the size of the wound to be covered by the expanded tissue. The duration of the expansion varies depending on the clinical application, usually in the range of 4 and 8 weeks [23].

1.5.2 Expansion of the iris

In 2008 Dr. David F. Chang, MD used the 5-0 polypropylene Malyugin pupil expansion device by patients with intraoperative floppy-iris syndrome (IRIS) having cataract surgery. He was evaluated it in 30 eyes from 21 patients. This Malyugin ring maintained a constant 6.0 mm pupil diameter throughout surgery (Figure 8). Result was that all eyes achieved a best corrected visual acuity of at least 20/25 [24]. This expander device is increasingly used in such and similar visual operations, sometime with small modification [25-27].

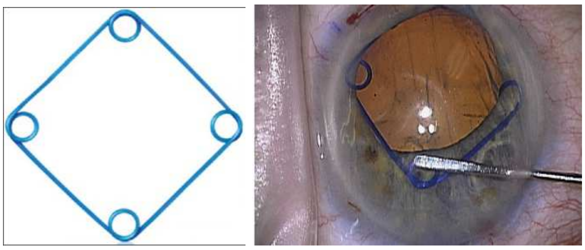

Figure 8: Malyugin ring and its use [24,28]

1.5.3 Genital and urethral expansion

Expansion techniques have almost unlimited possibilities of application in the reconstruction of soft tissues. Barbagli et al. [29-31] belong to pioneers of genital and urethral reconstruction. They work with a high success rate, perform the surgical reconstruction of male genitalia via the tissue expansion method, even in the case of a foreskin recovery technique that is usually inoperable, applying external tension using specialized devices to replace the cut tissue with new cells [32].

1.6 Complications of tissue expansion

Despite the many benefits of expansion reconstruction in the treatment of extensive tissue defects, significant problems have been noted limiting the clinical applicability of tissue expansion. The incidence of post-expansion complications was in the range of 11 to 39% [6,33-39].

Pisarski et al. [38] and Antonyshyn et al. [40] reported as the most common complications following the application of expanders: inflammation, infection, extrusion, wound dehiscence, serum, hematoma, necrosis, capsular contract, and implant rupture. Each of these complications may lead to the expulsion of the expander, the premature elimination, the hospitalization, the newly induced trauma of the patient, the increase of undesirable economic parameters and the separation of the tissue reconstruction itself.

One of the most common complications of surgical wound healing is dehiscence, premature wound margins that are caused by a wound healing disorder due to wound infection, wound haemorrhage and hematoma, or aseptic necrosis of the wound environment caused by insufficient blood flow. Serum, accumulation of fluid in the confined space that gives rise to a tumour-like feature belongs to the concomitant complications of infection, inflammation and dehiscence. Chang et al. [41] in their studies of the incidence of risk factors following immediate tissue expansions confirmed the incidence of wound dehiscence at 4.1% and necrosis in 4.9% of the 246 cases of breast reconstruction. The most significant risk parameter, up to 95% of all cases were BMI (body mass index). Due to the necessity of applying tissue expansion and increasing its rate of success without causing undesirable factors, preventive solutions have been sought. Egeland and Cederna [42] proposed a way of preventing endoscopic tissue expansion by mini-invasive approaches.

Despite the many advantages of reconstructing large and complex soft tissue defects with tissue expanders, there are several significant problems that limit their clinical usability.

Extra cut: If open access is used to place the tissue expander, the rupture must be close to the tissue expanding bag to allow visualization of the bag during subsequent manipulation. Dehiscence of the wound: Unfortunately, this approach creates a wound near the tissue expansion pocket, which increases the risk of wound dehiscence when the tissue spreads during expansion.

Expansion Delay: To reduce the risk of wound dehiscence, physicians usually wait a few weeks after the surgical site of the tissue expander to allow wound healing before tissue expansion begins. However, the wound reaches only 70% of its original strength after 6 weeks of treatment, so the onset of tissue expansion 6 weeks after surgery does not exclude the risk of wound dehiscence. Techniques have also been proposed that try to make minor incisions and thus reduce the risk of wound dehiscence, but this has occurred at the cost of poor visibility and increasing difficulty in achieving haemostasis [43]. Although a number of surgical approaches have been suggested to reduce as much as possible this risk, surgical wound dehiscence remains a significant problem in using open techniques.

Overall, the extent of complications in the reconstruction of the tissue expander is disproportionately high; the authors report complications ranging from 11 to 39% in individual studies [36-38,40].

In the case of the use of tissue expansion in the reconstruction of the limbs, an even higher degree of complication was observed, more than 50% of the cases. The most frequently cited complications are infection, hematoma, serum, extrusion, wound dehiscence, and tissue expander exposure, each of which may require removal of the expander, hospitalization of the patient and / or delay in the completion of the reconstruction [38,40], the expander may fail at any stage of reconstruction, including at the time of the tissue expander placement or during the expansion process.

In the case of some injuries, the soft tissue loss is so extensive that skin margins cannot be approximated; in such cases, application of skin grafts or FLAP clamps is necessary for closure. (Flap surgery is a technique in plastic and reconstructive surgery where any type of tissue is lifted from a donor site and moved to a recipient site with an intact blood supply [34]. Full grain skin grafts contain the epidermis and the total dermis thickness from the recipient region. The split-thickness grafts contain the epidermis and the variable thickness of the dermis. Grafts with a higher dermis thickness change on the wound bed and provide more durable coverage. Thin grafts have the advantage of faster revascularization, so they are more likely to be successful. Thin grafts, however, tend to provide less durable coverage [35]. This high rate of complications associated with decreasing reimbursement for the operation alone has reduced the usability of the tissue expanders themselves in the current medical environment even despite the large amount of procedures. Therefore, it has become a necessity to design a technique that would reduce this complication while maintaining the effectiveness of the reconstruction technique, significantly improving the clinical utility of tissue extension [37,44-48]. These objectives have been achieved in many surgical areas using endoscopic approaches to performing routine procedures. Based on this assumption, surgeons have begun to use endoscopic approaches to the performance of tissue expander placement in the hope that the complication can be reduced without minimizing the effectiveness of the reconstruction technique.

Conclusion

The main objectives of Plastic, Reconstructive and Aesthetic Surgery is especially perfect replacement of damaged tissue, in terms of functional and aesthetic. The technique of tissue expansion is based on the observation that living tissues respond to mechanical stimulus dynamic manner. Tissue expansion has become a preferred technique in many reconstruction techniques, but its preferences are currently under discussion due to dissatisfaction with the post-operative state and the need for subsequent reoperation to achieve aesthetic and functional satisfaction. Nowadays tissue expanders are used only for expansion of the skin and some muscle. Methods expansion of other tissues are currently in the experimental stage.

Acknowledgment
This article was supported by the state grant KEGA 069TUKE-4/2017 of the Ministry of Education of the Slovak Republic and APVV-17-0258.

References

[1] ABEDRABBO, N., POURBOGHRAT, F., CARSLEY, J.: Forming of AA5182-O and AA5754-O at elevated temperatures using coupled thermo-mechanical finite element models, *International Journal of Plasticity*, Vol. 23, No. 5, pp. 841-875, 2006.
[2] PATRICK, CH.W.: Engineering Adipose Tissue for regenerative and Reparative Therapies, *Seminars in Plastic Surgery*, Vol. 19, No. 3, pp. 207-215, 2005.
[3] WAGH, M.S., DIXIT, V.: Tissue expansion: Concepts, techniques and unfavourable results, *Indian Journal of Plastic Surgey*, Vol. 46, No. 2, pp. 333-348, 2013.
[4] STADELMAN, W.K.: *Skin Tissue Expansion*, [Online], Available: https://emedicine.medscape.com/article/1822400-overview [17 Jan 2019], 2016.
[5] NEUMANN, CH.: The expansion of an area of skin bz progresive distention of a subcutaneous baloon, *Plastic and Reconstructive Surgery*, Vol. 19, No. 2, pp. 124-130, 1957.
[6] CUNHA, M.S., NAKAMOTO, H.A., HERSON, M.R., FAES, CH.C., GEMPERLI, R., FERREIRA, M.C.: Tissue expander complications in plastic surgery. a 10-year experience, *Revista do Hospital das Clínicas*, Vol. 57, No. 3, pp. 93-97, 2002.
[7] RADOVAN, C.: Tissue expansion in soft-tissue reconstruction, *Plastic and Reconstructive Surgery*, Vol. 74, No. 4, pp. 482-92, 1984.
[8] ÇAKMAK, M., ŞEN, C., ERALP, L., BALCI, H. I., CIVAN, M.: *Basic Techniques for Extremity Reconstruction: External Fixator Applications According ti Iliyarov Principles*, (eBook), [17 Jan 2019], 2018.
[9] LASHEEN, A. E., SALIM, A., HEFNY, M. R., AL-BAKLY, E.: External Tissue Expansion Successfully Achieved Using Negative Pressure, *Surgery Today*, Vol. 34, No. 2, pp. 193-6, 2004.
[10] ORTHOFIX, http://web.orthofix.com/sites/Country/Intl/Products/Pages/ISKD.aspx?catid=29 [17 Jan 2019], 2019.
[11] https://media.springernature.com/original/springer-static/image/art%3A10.1007%2Fs00264-013-1935-0/MediaObjects/264_2013_1935_Fig2_HTML.gif [17 Jan 2019], 2019.
[12] DE DYNE, P. G.: Application of Passive Stretch and Its Implications for Muscle Fibers, *Journal of the American Physical Therapy Association*, Vol. 81, No. 2, pp. 819-827, 2001.
[13] KAMIKAWA, Y., IKEDA, S., HARADA, K., OHWATASHI, A., YOSHIDA, A.: Passive Repetitive Stretching for a Short Duration within a Week Increases Myogenic Regulatory Factors and Myosin Heavy Chain mRNA in Rats' Skeletal Muscles, *ScientificWorldJournal*, Vol. 2013, No. May, pp. 1-6, 2013.
[14] MEZENCEVOVÁ, V., TREBUŇOVÁ, M., ŽIVČÁK, J., KLUKA, T.: Endermológia®LPG® mechano-transdukcia v praxi, *Plastická chirurgia 2016 : odborná príloha časopisu Bedeker zdravia*, Vol. 7, No. 5, pp. 18-19, 2016. (Original in Slovak)
[15] MILIND, S. WAGH, VARUN DIXIT: Tissue expansion: Concepts, techniques and unfavourable results, *Indian Journal of Plastic Surgery*, Vol. 46, No. 2, pp.333-348, 2013.
[16] VARGOVČÁK, M.: *Využitie tkanivových expanderov v rekonštrukčnej chirurgii*, http://www.zone.sk/viamedica/expandery.html [08 Mar 2019], 1999. (Original in Slovak)
[17] TIMED, http://www.timed.sk/produkty/zdravotnicke-pomockypre-nemocnice/plasticka-chirurgia/silikonove-implantaty [08 Mar 2019], 2019. (Original in Slovak)
[18] ESPOSITO, G., DI CAPRIO, G., ZICCARDI, P., SCUDERI, N.: Tissue expansion in the treatment of pressure ulcers, *Plastic and Reconstructive Surgey*, Vol. 87, No. 3, pp. 501-508, 1991.
[19] ZOLLNER, A.M., TEPOLE, A.B., GOSAIN, A.K., KUHL, E.: Growing skin: Tissue expansion in pediatric forehead reconstruction, *Biomechanics and Modeling in Mechanobiology*, Vol. 11, No. 6, pp. 855-867, 2012.
[20] WAGH, M.S., DIXIT, V.: Tissue expansion: Concepts, techniques and unfavourable results, *Indian Journal of Plastic Surgery*, Vol. 42, No. 6, pp. 333-48, 2013.
[21] FLEMING, M., TINTLE, S.M., DAVILA, J.: *Soft Tissue Care About the Knee in High-energy War Injuries*, https://www.researchgate.net/publication/216739912_Soft_Tissue_Care_About_the_Knee_in_High-energy_War_Injuries/figures?lo=1 [17 Jan 2019], 2010.
[22] GÜRLEK, A., ALAYBEYOĞLU, N., DEMIR, C.Y., AYDOĞAN, H., BILEN, B.T., OZTÜRK A.: Aesthetic Reconstruction of large scalp defects by sequential tissue expansion without interval, *Aesthetic Plastic Surgery*, Vol. 28, No. 4, pp. 245-250, 2004.
[23] MEDICA MAGAZINE, https://www.medica-tradefair.com/cgi-bin/md_medica/lib/pub/tt.cgi/Self-inflating_Tissue_Expanders_for_Plastic_Surgery_Ophthalmology_and_Dental.html?oid=40073&lang=2&ticket=g_u_e_s_t [17 Jan 2019], 2012.
[24] CHANG, D.F.: Use of malyugin pupil expansion device for intraoperative floppy-iris syndrome: results in 30 consecutive cases, *Journal of Cataract & Refractive Surgery*, Vol. 34, No. 5, pp. 835-841, 2008.
[25] ZAREI-GHANAVATI, S.: Stabilizing the capsular bag and expanding the pupil with a pupil expansion

device, *Journal of Cataract & Refractive Surgery*, Vol. 41, No. 9, pp. 1801-1803, 2015.

[26] MALYUGIN, B.: Small pupil phaco surgery: a new technique, *Annals of Ophthalmology*, Vol. 39, No. 3, pp. 185-193, 2007.

[27] KIM, E.J., BERG, J.P., WEIKERT, M.P., KONG, L., HAMILL, M.B., KOCH, D.D., YEN, K.G.: Scleral-fixated capsular tension rings and segments for ectopia lentis in children, *American Journal of Ophthalmology*, Vol. 158, pp. 899-904, 2014.

[28] MALYUGIN, B.: Cataract surgery in small pupils, *Indian Journal of Ophthalmology*, Vol. 65, No. 12, pp. 1323-1328, 2017.

[29] BARBAGLI, G., BALÒ, S., SANSALONE, S., LAZZERI, M.: One-stage and two-stage penile buccal mucosa urethroplasty, *African Journal of Urology*, Vol. 22, No. 1, pp. 11-17, 2016.

[30] BARBAGLI, G., MONTORSI, F., SANSALONE, S., LAZZERI, M.: Reconstructive Management with Buccal Urethroplasty, *European Urology Supplements*, Vol. 15, No. 1, pp. 17-23, 2016.

[31] BARBAGLI, G., PELLEGRINI, G., CORRADINI, F., MONTORSI, F., SANSALONE, S., BUTNARU, D., LAZZERI, M.: One-stage Penile Urethroplasty Using Oral Mucosal Graft and Glue, *European Urology*, Vol. 70, No. 6, pp. 1069-1075, 2016.

[32] BRANDES, S.B., MOREY, A.F.: *Advanced Male Urethral and Genital Reconstructive Surgery*, 2nd ed., Humana Press, (eBook), [17 Jan 2019], 2014.

[33] http://www.dailyadvent.com/index.php/tag/china/ [17 Jan 2019], 2019.

[34] SONG, D.H., GINARD, H., RUSSELL, R. REID, WU, L.C., WIRTH, G., DORAFSHAR, A.H.: *Chapter 2: Grafts and Flaps*, Plastic Surgery: Essentials for Students, *Plastic Surgery Education Foundation* [17 Jan 2019], 2019.

[35] https://en.wikipedia.org/wiki/Tissue_expansion, [17 Jan 2019], 2018.

[36] CUNHA, M.S., NAKAMOTO, H.A., HERSON, M.R., FAES, J. C., GEMPERLI, R., FERREIRA, M.C.: Tissue expander complications in plastic surgery: a 10-year experience, *Revista do Hospital das Clinicas da Faculdade de Medicina da Universidade de Sao Paulo*, Vol. 57, No. 3, pp. 93-7, 2002.

[37] MANDERS, E.K., SCHENDEN, M.J., FURREY, J.A., HETZLER, P.T., DAVIS, T.S., GRAHAM, W.P. 3rd: Soft-tissue expansion: concepts and complications, *Plastic and Reconstructive Surgery*, Vol. 74, No. 4, pp. 493-507, 1984.

[38] PISARSKI, G.P., MERTENS, D., WARDEN, G.D., NEALE, H.W.: Tissue expander complications in the pediatric burn patient, *Plastic and Reconstructive Surgery*, Vol. 102, No. 4, pp. 1008-1012, 1998.

[39] AGRAWAL, K., AGRAWAL. S.: Tissue regeneration during tissue expansion and choosing an expander, *Indian Journal of Plastic Surgery*, Vol. 45, No. 1, pp. 7-15, 2012.

[40] ANTONYSHYN, O., GRUSS, J.S., MACKINNON, S.E., ZUKER, R.: Complications of soft tissue expansion, *British Journal of Plastic Surgery*, Vol. 41, No. 3, pp. 239-50, 1988.

[41] CHANG, C.W., TAI, H.C., CHENG, N.C., LI, W.T., LAI, H.S., CHIEN, H.F.: Risk factors for complications following immediate tissue expander based breast reconstruction in Taiwanese population, *Journal of the Formosan Medical Association*, Vol. 116, No. 1, pp. 57-63, 2017.

[42] EGELAND, B.M., CEDERNA, P.S.: A minimally invasive approach to the placement of tissue expanders, *Seminars in Plastic Surgery*, Vol. 22, No. 1, pp. 9-17, 2008.

[43] CORBAN, J., SHASH, H., SAFRAN, T., SHEPPARD-JONES, N., FOUDA-NEEL, O.: A systematic review of complications associated with direct implants vs. tissue expanders following Wise pattern skin-sparing mastectomy, *Journal of Plastic, Reconstructive & Aesthetic Surgery*, Vol. 70, No. 9, pp. 1191-1199, 2017.

[44] MASSER, M.R.: Tissue expansion: a reconstructive revolution or a cornucopia of complications, *British Journal of Plastic Surgery*, Vol. 43, pp. 344-348, 1990.

[45] LEYNGOLD, M.M., STUTMAN, R.L., KHIABANI, K.T., SHAH, H., FONG, E., HO, CH.-H., ZAMBONI, W.A.: Contributing variables to post mastectom tissue expander infection, *The Breast Journal*, Vol. 18, No. 4, 2012. https://onlinelibrary.wiley.com/doi/full/10.1111/j.1524-4741.2012.01253.x [17 Jan 2019], 2012.

[46] STRAKA, M., MALINDZAKOVA, M., TREBUNA, P., ROSOVA, A:, PEKARCIKOVA, M., FILL, M.: Application of extendism for improvement of production logistics´ efficiency, *International Journal of Simulation Modelling*, Vol.16, No. 3, pp. 422-434, 2017.

[47] KYZIOL, K., OCZKOWSKA, J., KOTTFER, D., KLICH, M., KACZMAREK, L., KYZIOL, A., GRZESIK, Z.: Physicochemical and biological activity analysis of low-density polyethylene substrate modified by multi-layer coatings based on DLC structures, obtained using RF CVD method, *Coatings*, Vol. 8, No. 4, pp. 1-14, 2018.

[48] KYZIOŁ, K., KOPER, K., KACZMAREK, L., GRZESIK, Z.: Plasmochemical modification of aluminum-zinc alloys using NH3-Ar atmosphere with anti-wear coatings deposition, *Materials Chemistry and Physics* 189, pp.198-206, 2017.

Review process

Single-blind peer review process.