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GYNECOLOGIC ONCOLOGY

Biocompatibility, cell growth and clinical relevance of synthetic meshes and biological matrixes for internal support in implant-based breast reconstruction

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Abstract
Purpose Biological matrixes and synthetic meshes are increasingly used in implant-based breast reconstruction (IBBR). The objective was to test different materials used for internal support in IBBR in regards to biocompatibility and discuss possible limitations in a clinical context.
Materials and methods In vitro investigations were performed on four relevant cell lines: Normal Human Dermal Fibroblasts (NHDF), Human White Preadipocytes (HWP), Endothelial cells (HDMEC) and Skeletal muscle cells (SkMC). A titanium-coated polypropylene mesh (TiLOOP® Bra), a partially resorbable mesh (SERAGYN BR®) and a porcine derived biologic matrix (Strattice™) were investigated. Test of cytotoxicity, cell proliferation and oxidative stress was performed. Real-time cell analysis was used to determine adhesion rate. Light- and scanning electron microscopy investigated cell migration.
Results No relevant cytotoxicity was detected for any mesh or matrix. Good cell proliferation was observed in all materials with best results for NHDF and SkMC. For HWP and HDMEC decreased proliferation and adherence to the synthetic meshes and biologic matrix were observed. Real-time cell analysis of fibroblasts incubated with the corresponding material, showed increased impedance for the synthetic meshes. A morphologic cell change was observed within all materials. Scanning electron microscopy showed good cell penetration into the meshes and matrix. The material compositions did not seem to influence the clinical outcome, although the biological matrix was much thicker compared to the synthetic meshes.
Conclusion Biochemical examination showed good biocompatibility for the investigated meshes and matrix. All products seem to have their value in IBBR and can be recommended for IBBR.

Keywords Strattice · TiLOOP Bra · SERAGYN BR · Breast reconstruction · Biocompatibility · Mesh · Matrix · ADM · Internal support

Purpose

Besides autologeous breast reconstruction (BR), implant-based breast reconstruction (IBBR) gained a high level of importance during the past years. Compared to an unchanged number of autologeous procedures, the increase of immediate BR is mainly attributed to an increase in expander/implant reconstructions [1]. Long-term studies on the safety of silicone implants led to an acceptance of IBBR in patients who were not eligible or not willing to undergo an intensive autologeous reconstruction [2–5]. Using implants for BR, the need of internal support to reconstruct the inframammary fold (IMF) became of relevance and led to the introduction of acellular dermal matrices (ADM) and later synthetic meshes

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[6]. Compared to medical drugs these medical products are often implemented into clinical practice with few clinical data. Complication rates in IBBR with ADMs and meshes vary between 0 and 48.7 % and studies on biocompatibility are rare [7–9]. Not only patient selection, but also graft acceptance, inflammation and wound healing play an essential role, especially when two foreign bodies (implant and matrix/mesh) are inserted into a big mastectomy defect. Although, these medical products are increasingly used investigations regarding their biocompatibility in breast tissue are missing. A good matrix/mesh should be noncarcinogenic, antiallergic, chemically inert, have negligible foreign body reaction, resist mechanical strain and be of little risk for infections [10]. Besides the correct patient selection, biocompatibility of each implanted foreign body presents the basis for good surgical results, whereby ADMs and the surgical meshes used for reinforcement of the IMF should be comparable [11]. In clinical practice, this proves to be difficult, as no standardized instruments for comparison exists. The search for a suitable material with high functionality and biocompatibility, as well as little risk of infections is difficult. Diverse mechanical and production-linked characteristics can influence biocompatibility [12]. Prospective randomized, surgical trials are hardly feasible, as industry has little interest in conducting clinical trials with competitive products.

Since in situ assessment is nearly impossible we choose an in vitro approach, representing an acceptable strategy to obtain information on toxicity, metabolic changes and cell behavior of three different medical products used for internal support in IBBR [13]. The aim of this study was to test for differences in regards to biocompatibility of these products and evaluate possible limitations.

Materials and methods

Meshes

Two synthetic meshes, a titanium-coated polypropylene mesh (TiLOOP® Bra, pfm medical Cologne, Germany) and one partially resorbable polypropylene/polyglycol caprolactone mesh (SERAGYN BR®, Serag Wiessner KG, Naila, Germany) and one biologic porcine matrix (Strattice™, Lifecell, Brancheburg, USA) were investigated (Table 1). All meshes are approved for IBBR in Europe and applied in vitro as recommended by the manufactures in vivo use.

Preparation of cell lines

Four relevant cell lines and corresponding growth mediums were obtained from PromoCell, Heidelberg, Germany. The following cell lines were chosen due to their prevailing occurrence with in the female breast. In vitro investigations were performed on Normal Human Dermal Fibroblasts (NHDF-c adult Cat. No. 12302 using Fibroblast Growth Medium 2 Cat. No. C-23020) representing connective tissue, Normal Human White Preadipocytes (HWP-c subcutaneous Cat. No. C-12730 using Preadipocyte Differentiation Medium Cat. No. C-27436 and Adipocyte Nutrition Medium Cat. No. C-27438) representing fat

Table 1 Physical data of the investigated materials

	TiLOOP® Bra extralight	SERAGYN BR®	Strattice™
Material	100 % PP titanium coated (30–50 nm)	Resorbable polyglycol acid—caprolacton and non-resorbable polypropylene	Acellular xenogenic matrix (porcine derived)
Filament	Monofilament	Monofilament	–
Base weight (g/m^2)	16		–
Before resorption	–	85	
After resorption	–	28 (resorbable within 90–120 days)	
Pore size (mm)	≥1.0		3
Resorbable part	–	2	(Pores were manually punched into the mesh using a sterile hole-punch machine)
Non-resorbable part	–	4	
Strength (mm)	0.2	0.5 (before resorption)	–
		0.2 (after resorption)	
Filament diameter	65 µm	0.15 mm	Matrix thickness: 1–2 mm
Tensile strength (grab test)	37 N	67 N/cm (before resorption)	128 N/cm
	–	41 N/cm (after resorption)	–
Physiologic elasticity at 16 N	23 %	Lengthwise: 14 %/ crossways 50 % (before resorption)	–
		Lengthwise: 25 %/ crossways 69 % (after resorption)	

PP polypropylene, *nm* nanometer, *g* gram, *m* meter, *N* Newton, *cm* centimeter, *mm* millimeter

tissue, Normal Human Dermal Microvascular Endothelial Cells (HDMEC-c adult Cat. No. C-12212 using Endothelial Cell Growth Medium MV Cat. No. C-22020) representing vascular tissue and Normal Human Skeletal Muscle Cells (SkMC-c Cat. No. C-12530 using Skeletal Muscle Growth Medium KIT Cat. No. C-23160) representing muscle tissue. All cell lines were cultivated over several passages using 25 and 75 cm^2 cell culture flasks (BIOCHROM AG, Berlin, Germany). Cell transfer from one flask dimension to another took place, when cells reached a confluency of at least 90 %. Fully differentiated cells were plated at an initial density of 1×10^5 cells/cm^2 on the fixed matrix/meshes of 1 × 1 cm in size (24 well-plates). Cells and matrix/meshes were incubated for 12 weeks under constant sterile conditions (incubator 37 °C, 5 % CO_2, saturated atmosphere). Growth medium with cells alone served as control. Medium change was performed every 48 h using the specific growth medium for each cell line supplemented with 1 % penicillin/streptomycin and 0,5 % amphotericin (PAA GmbH, Cölbe Germany).

Measurement of cytotoxicity and cell proliferation

LDH test (Cytotoxicity Detection Kit (LDH), Roche Diagnostics, Germany, Cat. No. 11644793001) was used for determination of cytotoxicity after cultivation of cells on the meshes/matrix for 48 h. High control for determining the maximum of LDH release was performed by incubation of cells with 1 % Triton X-100 (Ferak, Berlin, Germany) as detergent diluted in Dulbecco's Modified Eagle's Medium (DMEM). Spontaneous LDH release (low control) was determined by measurement of LDH in supernatants of untreated cell cultures. Immunodetection was performed in accordance to the manufacture's instruction. Briefly, after incubation cell-free supernatant was carefully removed and transferred into a 96-well microplate. Supernatants were mixed 1:1 with freshly prepared reaction mixture. Afterwards solution was incubated for 30 min at room temperature and protected from light. Principle of the assay is based on a LDH/diaphorase coupled reaction with creation of a purple colored formazan. Finally, absorbance was measured at 490 nm using a microplate reader (Model 680, BioRad, Hercules, CA, USA). After subtraction of low control values the percentage of cytotoxicity was calculated in relation to the high control result. Values >70 % were regarded as a significant degree of cytotoxicity.

BrDU test (Cell Proliferation ELISA, BrdU, Roche, Mannheim, Germany, Cat. No. 11647229001) was used for measuring cell proliferation. After cell culturing, labeling of cells with BrdU (10 μmol/L) for further 4 h was performed according to the manufacture's instruction under cell culture conditions. After removal of cell culture medium the cells were fixed by incubation with the ready-to-use FixDenat solution for 30 min at room temperature. FixDenat solution was removed and anti-BrdU-POD working solution was added. Afterwards, cells were washed three times with PBS and substrate solution was added. As soon as sufficient color development was observed the reaction was stopped with 1 M H_2SO_4, and absorbance was measured at 450 nm using the microplate reader. Untreated cells served as control.

Oxidative stress

Hydrogen peroxide Assay Kit (BIOVISION, Mountain View, CA, USA, Cat. No. K265-200) was used for determination of oxidative stress (free radicals). The assay was performed according to the manufacture's instructions. Briefly, after incubation of cells for 48 h cell culture supernatants were collected, centrifuged at $1000 \times g$ for 15 min and filtered through a 10 kDa MW spin filter (BIOVISION, Cat. No. 1997-25) for removing of all proteins. Subsequently, content of H_2O_2 was quantified by addition of the OxiRed™ substrate solution in the presence of horse reddish peroxidase. After incubation for 10 min at room temperature the amount of the colored product was measured at 570 nm using the microplate reader. Levels of hydrogen peroxide were calculated using a standard curve.

Real-time cell analysis

Bionas Discovery™ 2500 System for bioenergetics and impedance and the metabolic chip Bionas Discovery™ SC1000 were used in cooperation with Bionas GmbH, Rostock, Germany for real-time cell analysis. The system continuously detects physiologic parameters of cell lines (NHDF cells) to monitor acute changes in the cellular metabolism. Differences are represented in percentage change.

In the first instance all meshes were incubated for 4 weeks at 37 °C in Bionas running medium. Before the measurement started, pH values were adjusted to 7.4 and the osmolality was determined. The exposition on the cells was 24 h, followed by 4 h of measurement with medium lacking the extract to investigate regeneration. As a positive control, 10 mM phenol was used.

Preparation of NHDF cells

Culture medium consisted of DMEM + 10 % FCS + Penicillin/Streptomycin. Medium for extraction and measurement of NHDF cells consisted of Bionas running medium (DMEM, sodium bicarbonate free) + 0.1 % FCS + Penicilin/Streptomycin. The total amount of medium needed for the extraction and for the

measurement was calculated in advance and pH and osmolality were adjusted (7.4 and 330 mOsmol/kg). The pH value of all media and the extraction solutions were controlled and adjusted to pH 7.4 with NaOH (1 M) (Riedel–de–Haen, Cat No.35256), if necessary. Osmolality of all media was also controlled and adjusted to 340 mOsmol/kg H_2O for one of the two stored medium control conditions. This was done, as the osmolality of the extraction media was out of the normal range of measurement. To investigate possible effects of the osmolality, one control condition (incubated medium) was adjusted. Human dermal fibroblasts cells were plated on chips at a density of 70,000 cells per chip. Just before the measurement started chips with cultured cells were checked microscopically and photographed for documentation.

Morphologic investigations

Light microscopy (LM) has been used as semi-quantitative method to investigate morphologic cell changes. Scanning electron microscopy (SEM) served as qualitative method for endpoint determination to measure cell adherence in regards to the different meshes.

Results

Cytotoxicity

The highest levels of cytotoxicity were observed for the TiLOOP® Bra with 22 % in NHDF. No cytotoxicity greater 70 %, as threshold value for biological relevant cytotoxicity was observed (Fig. 1).

Cell proliferation

Generally rates of cell proliferation were lower in treated cells compared to untreated controls (Fig. 2). Degree of inhibition was lowest in NHDF. Within this cell line the resorbable part of the SERAGYN® BR exceeded the cell proliferation compared to the control with cells in medium alone. The remaining three materials had comparable proliferation rates. In SkMC the TiLOOP® Bra revealed the lowest proliferation rate with about 40 %. Comparable results with rather low proliferation rates compared to NHDF and SkMC were seen in HWP and HDMEC for all meshes/matrix.

Oxidative stress

Analysis of oxidative stress showed different levels of hydrogen peroxide release in the investigated cell lines (Fig. 3). With a maximum of 4 pmol/L all results were far below the manufacture's threshold of 40 pmol/l indicating a significant oxidative stress. Lowest levels of hydrogen peroxide were observed in HWP cultured on synthetic meshes. The outliner of the biological matrix in this cell line is unclear and might be contributed to singleton performance of the tests. Second lowest levels of oxidative stress were observed equally distributed between the meshes/matrix in SkMC followed by NHDF. In HDMEC oxidative stress was higher than in all other cell lines but in range or lower than the control. Generally, stress levels of treated cell lines were in the range of the controls, except for the Strattice™ matrix in HWP.

Real-time cell analysis (adhesion rate)

During the period of measurement a decrease of impedance was observed for the biologic matrix (stored extraction medium 1 and 2) and the control medium (stored control medium 1 and 2) by about 20 %, indicating a change in adherence, respectively, morphologic cell changes (Fig. 4). The fresh control medium showed no change in impedance in contrast to phenol, where a constant decrease was observed. Phenol served as control. All synthetic meshes showed only a minor decrease of impedance at the beginning of the measurement with quick recovery indicating decreased morphologic cell changes as observed for the biologic matrix (Fig. 5). Phenol served as control.

Morphologic investigations

Light microscopy showed only a low cell growth on all meshes after 2 weeks. The lowest growth rates were observed for HWP and HDMEC (see figure, Supplemental Digital Content 1–8, which demonstrates the in vitro findings). The best cell growth was observed for fibroblasts and SkMC after 12 weeks (Fig. 6, 7, 8, 9, 10, 11, 12, 13). Scanning electron microscopy revealed a cell layer in all meshes for NHDF and SkMC.

Discussion

Our in vitro investigations showed only minor differences in regards to biocompatibility for the synthetic meshes and the biological matrix. The clinical impact of the increased cytotoxicity for TiLOOP® Bra in NHDF seems to be negligible, as the value of 22 % was far below the manufactures threshold for cytotoxicity of 70 %. The low levels of oxidative stress observed in NHDF support this finding. Nevertheless, it is an approximately 10 times increase in cytotoxicity compared to the other tested materials. Oxidative stress itself is an important parameter for material-stimulated leukocyte activation indicating inflammation.

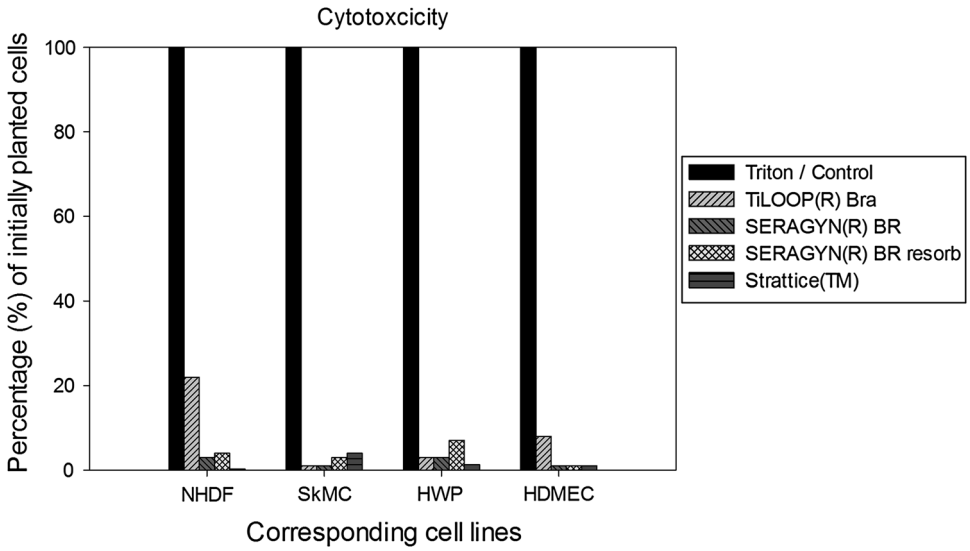

Fig. 1 Cytotoxcity using LDH test

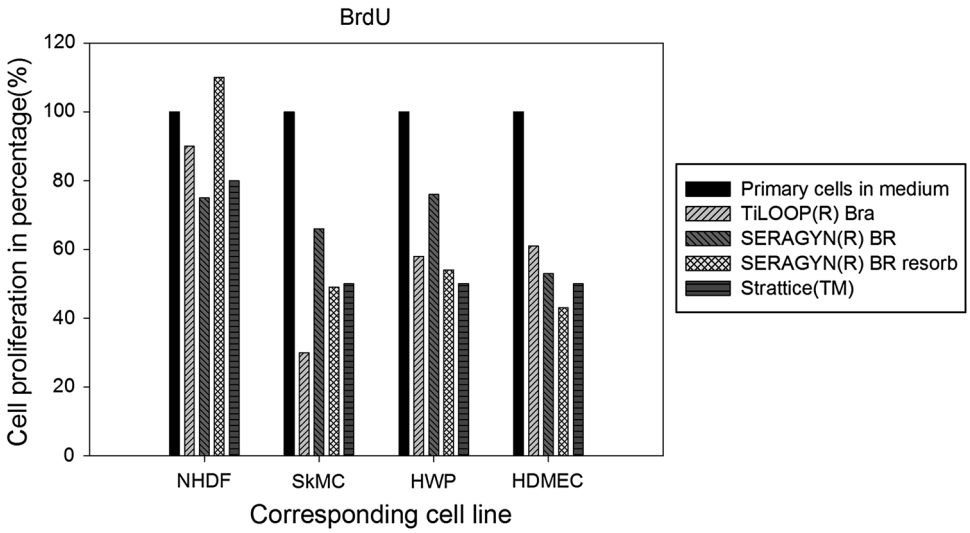

Fig. 2 Cell density measured by cell proliferation in percentage (BrdU test)

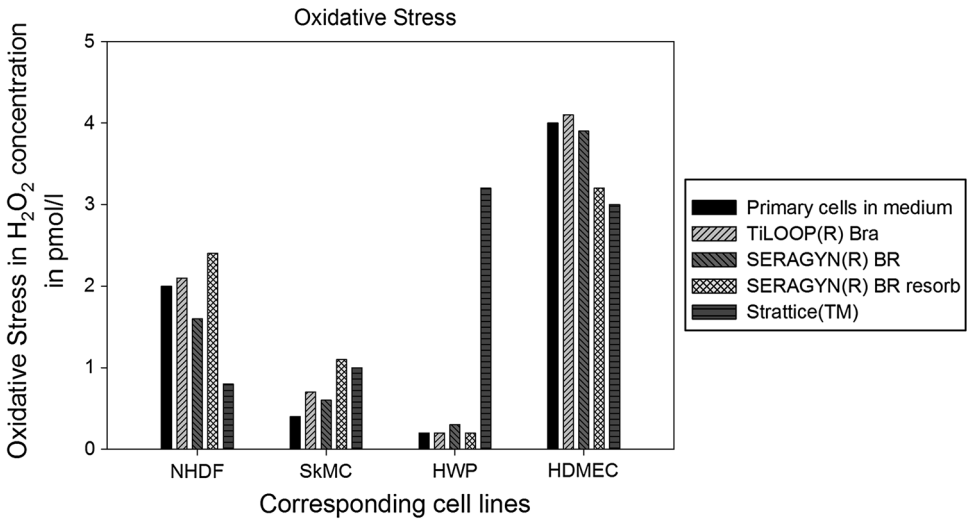

Fig. 3 Oxidative stress measured in the H_2O_2 concentration

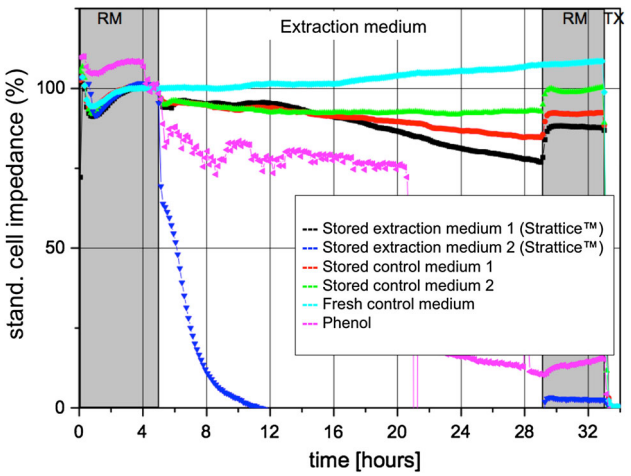

Fig. 4 Impedance/adherence of NHDF cells and the biologic mesh (Stored extraction medium 1 and 2 corresponding to Strattice™). (After 21 h a disturbance of the impedance sensor occurred (presumably air bubble), that caused a change of impedance for phenol. Correspondingly one control medium (*dark blue curve*) showed a decrease in impedance without recovery to the end of the measurement. *RM* running medium, *TX* termination of experiment)

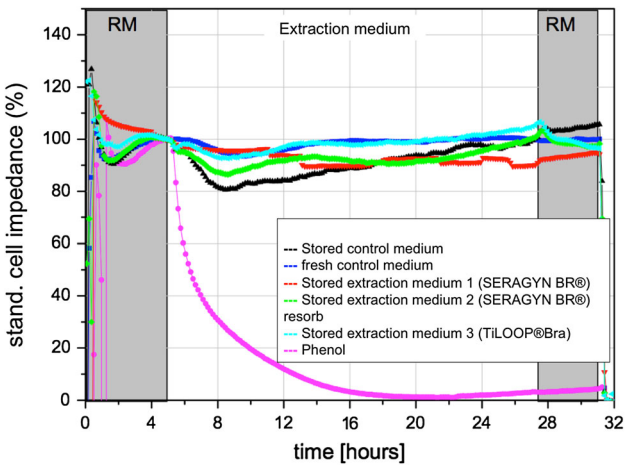

Fig. 5 Impedance/adhesion of NDHF cells and the synthetic meshes (Extract 1: SERAGYN® BR; Extract 2: SERAGYN BR® resorb; Extract 3: TiLoop®) *RM* running medium, *TX* termination of experiment

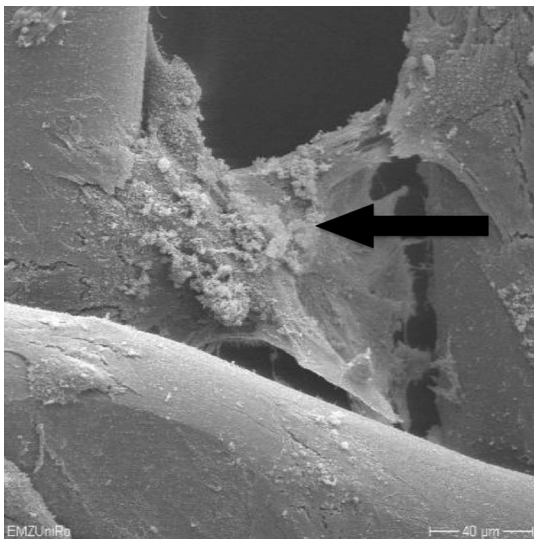

Fig. 6 Morphologic results after 12 weeks of in vitro cultivation. Scanning electron microscopy of fibroblasts and the TiLOOP® Bra mesh showing good adherent cells

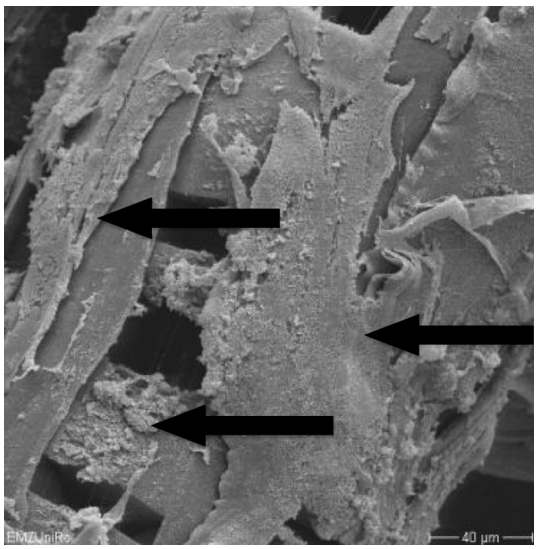

Fig. 7 Morphologic results after 12 weeks of in vitro cultivation. Scanning electron microscopy of fibroblasts and the SERAGY BR® mesh showing good adherent cells

The higher the oxidative stress the higher the inflammatory potential. Although we observed different levels of oxidative stress, these differences did not influence biocompatibility and are explained by the different intracellular metabolic processes of each cell line. The observed levels of oxidative stress within each cell line and the corresponding meshes/matrix were always in the range of the control with primary cells in medium alone. This indicates no additional stress for the cells when incorporated with any of the investigated materials. With a maximum of 4.1 pmol/L oxidative stress was low in our investigations in general. The outliner seen in HWP and Strattice™ is unclear and might be due to the single determination of our experiments. Our findings are supported by investigations of Bryan et al. on reactive oxygen species (ROS) as a marker to predict the behavior of biological graft materials, in regards to material-mediated leukocyte activation. Their results showed, above all for Strattice™, release profiles of ROS below that of the no material control, compared to the synthetic mesh group [11]. Strattice™ was found to be the only material associated with ROS quenching characteristics resulting in decreased leukocyte activation, decreased

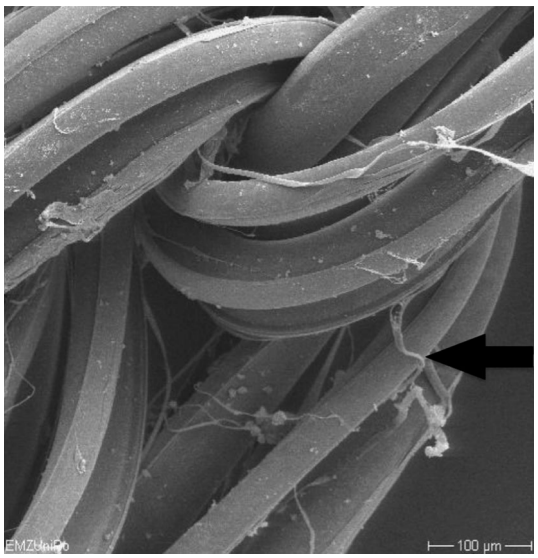

Fig. 8 Morphologic results after 12 weeks of in vitro cultivation. Scanning electron microscopy of fibroblasts and the SERAGY BR® (resorbable part) mesh showing decreased adherence patterns compared to the non-resorbable part of the SERAGY BR® mesh

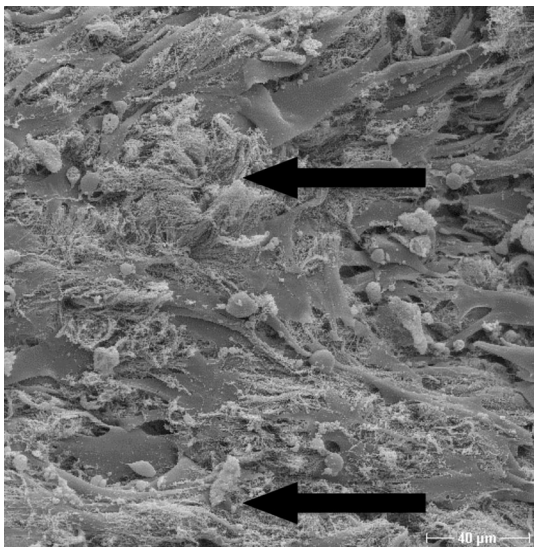

Fig. 9 Morphologic results after 12 weeks of in vitro cultivation. Scanning electron microscopy of fibroblasts and the Strattice™ mesh showing good adherent cells

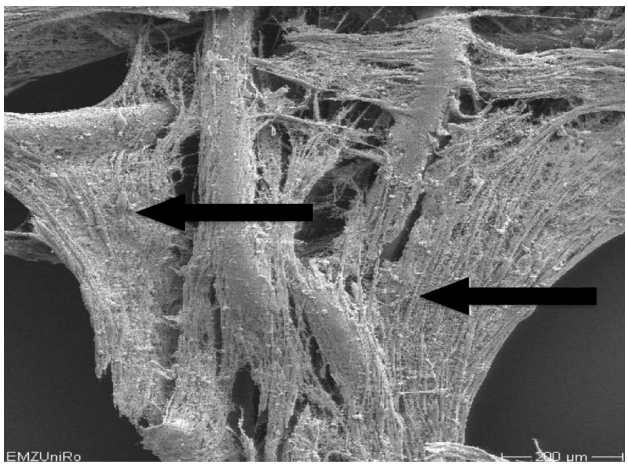

Fig. 10 Morphologic results after 12 weeks of in vitro cultivation. Scanning electron microscopy of skeletal muscle cells and the TiLOOP® Bra mesh showing good adherent cells

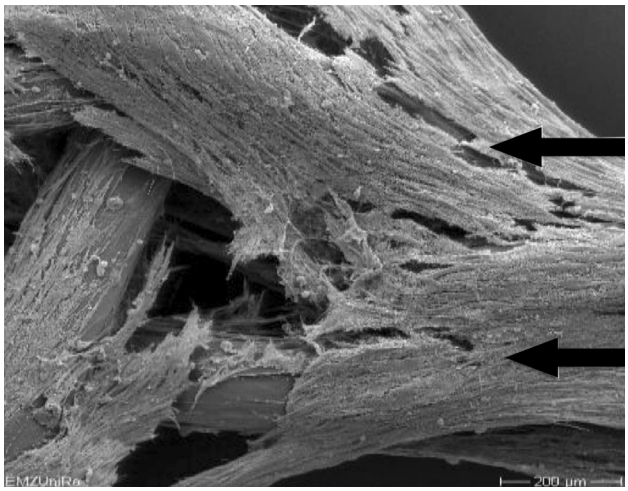

Fig. 11 Morphologic results after 12 weeks of in vitro cultivation. Scanning electron microscopy of skeletal muscle cells and the SERAGY BR® mesh showing good adherent cells

inflammatory reaction and potentially low risk for complications. A decrease in oxidative stress or cytotoxicity for the TiLOOP® Bra compared to the SERAGYN® BR mesh due to its Titanium coating could not be observed, as stated in previous investigations [14]. Although cytotoxicity and oxidative stress were low, cell proliferation was not increased compared to primary cells in medium in any cell line and for any material. As expected, best cell proliferation was observed for NHDF and SkMC what might be attributed to stroma differences including various growth factors increasingly seen in fibroblasts and skeletal cells compared to HWP and HDMEC [15].

Cell proliferation showed, that cells are influenced in their growth, when getting in contact with a foreign material. Therefore, good biocompatibility does not necessarily come along with good cell growth. Real-time cell analysis supports theses findings, as a change in impedance was observed after adding the meshes/matrix to the cell extract indicating a morphologic cell change. This cell change is reflected in decreased proliferation rates compared to the primary cells in medium. Reason for a better cell adhesion in synthetic meshes observed in real-time cell might be explained by the different surface structures. Synthetic meshes are rather rough, allowing good cell impedance. Biological matrixes have a smooth surface,

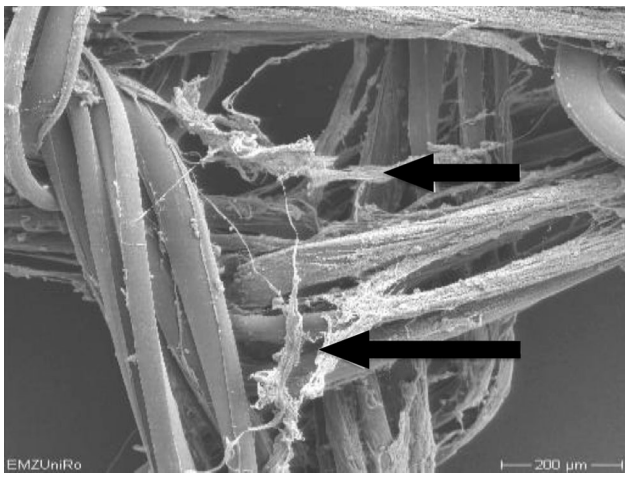

Fig. 12 Morphologic results after 12 weeks of in vitro cultivation. Scanning electron microscopy of skeletal muscle cells and the SERAGY BR® (resorbable part) mesh showing decreased adherence patterns compared to the non-resorbable part of the SERAGY BR® mesh

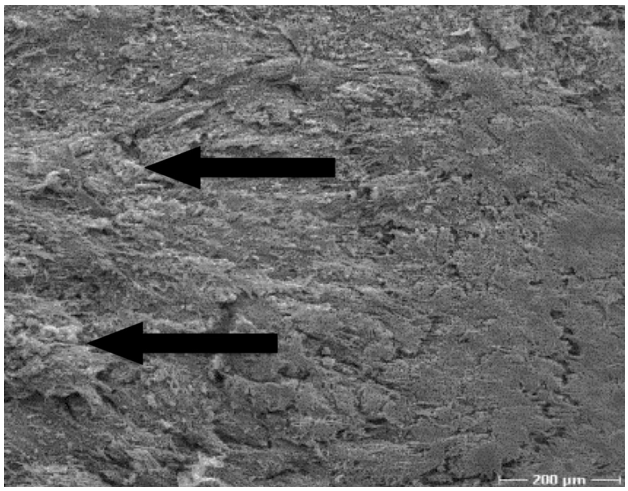

Fig. 13 Morphologic results after 12 weeks of in vitro cultivation. Scanning electron microscopy of skeletal muscle cells and the Strattice™ mesh showing good adherent cells

which might be more challenging for the cells to adhere to the surface structure. How far this affects clinical practice is unclear and might be of minor concern.

Correlating our in vitro findings with available clinical data implies good in vivo growth patterns for TiLOOP® Bra and Strattice™, with incremention of capillaries and cell populations into both materials [16, 17]. Most clinical data are available for TiLOOP® Bra and Strattice™. Complication rates vary between 17.7 and 29.0 % for TiLOOP® Bra and 2.7–47.6 % for Strattice™, where as complications after IBBR without additional internal support are stated in about 15 % [18–23]. For SERAGYN® BR, data on complication rates cannot be discussed. Except for an abstract of 23 patients with a complication rate of 15.6 % no clinical data are available [24].

Whilst comparable biocompatibility was observed for all materials, the clinical judgment of the soft tissue condition is decisive to decide which material to use. First clinical results show increased complications rates in patients undergoing secondary IBBR using TiLOOP® Bra [25]. In these secondary cases poor soft tissue conditions are frequently found. Besides the biologic features, Strattice™ has a thicker structure compared to synthetic meshes. From a clinical point of view Strattice™ is rather suitable in patients with inferior/thinner soft tissue conditions, often seen in patients undergoing secondary BR. Synthetic meshes should primarily used in patients with good soft tissue conditions, seen in immediate IBBR. Although biologic matrixes can be used in primary cases as well, they are more expensive. With good biocompatibility, the learning curve and patient selection are basic prerequisites in reducing mesh/matrix-associated complications. In vitro no restrictions were found limiting the use of any of the investigated materials in IBBR. For long lasting clinical results longer follow-ups are necessary than presented in the discussed studies.

Future projects are anticipated and focus on in vitro behavior of these meshes/matrix in combination with textured or smooth silicon implants. A recent mouse-model investigated the influence of different surfaces of silicone implants on the formation of capsular contraction [26]. Hereby, no advantage was observed for smooth silicone implants covered by TiLOOP® Bra compared to textured implants alone in regards to capsular formation. A limitation of our study is that the experiments were only performed once, due to limitations of resources. No standard deviations could be calculated and data need to be interpreted carefully. The effect of phenol, as positive control for the biologic mesh, could not be measured due to a signal disturbance of the impedance sensor. An effect on the biocompatibility testing did not arise thereby. One control medium showed a permanent decrease until the end of the measurements during real-time cell analysis for the biologic mesh. A biological explanation did not exist, as all cells were nicely adherent to the sensor chip (See Figure, Supplemental Digital Content 9, showing a picture of the biochip with the adherent cells). Our in vitro results can only be interpreted for the investigated meshes/matrix alone. How far changes in biocompatibility will appear when investigating these products in combination with different silicone implants is not yet clear and should be part of upcoming studies.

Conclusion

Comparable biocompatibility was observed for all tested materials and all can be recommended to be used for

internal support in IBBR. Cell proliferation was highest in NHDF and SkMCs. Which material to be applied in clinical practice is depended on the patient's soft tissue conditions and surgeons experience.

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Conflict of interest None of the authors has a financial interest in any of the products, devices, or drugs mentioned in this manuscript.

References

1. Albornoz CR, Bach PB, Mehrara BJ et al (2013) A paradigm shift in U.S. Breast reconstruction: increasing implant rates. Plast Reconstr Surg 131:15–23
2. Hammond DC, Migliori MM, Caplin DA et al (2012) Mentor Contour Profile Gel implants: clinical outcomes at 6 years. Plast Reconstr Surg 129:1381–1391
3. Stevens WG, Harrington J, Alizadeh K et al (2012) Five-year follow-up data from the US clinical trial for Sientra's US Food and Drug Administration-approved Silimed(R) brand round and shaped implants with high-strength silicone gel. Plast Reconstr Surg 130:973–981
4. Maxwell GP, Van Natta BW, Murphy DK et al (2012) Natrelle style 410 form-stable silicone breast implants: core study results at 6 years. Aesthet Surg J 32:709–717
5. Stafford N (2011) FDA finds breast implants to be safe but calls for better follow-up. BMJ 343:d5664
6. Dieterich M, Gerber B (2011) Patient selection and technical considerations in nipple-sparing and areola-sparing mastectomy. Curr Breast Cancer Rep 3:79–87
7. Newman MI, Swartz KA, Samson MC et al (2011) The true incidence of near-term postoperative complications in prosthetic breast reconstruction utilizing human acellular dermal matrices: a meta-analysis. Aesthetic Plast Surg 35:100–106
8. Chun YS, Verma K, Rosen H et al (2010) Implant-based breast reconstruction using acellular dermal matrix and the risk of postoperative complications. Plast Reconstr Surg 125:429–436
9. Dieterich M, Reimer T, Dieterich H et al (2012) A short-term follow-up of implant based breast reconstruction using a titanium-coated polypropylene mesh (TiLoop (R) Bra). Eur J Surg Oncol 38:1225–1230
10. Shankaran V, Weber DJ, Reed RL 2nd et al (2011) A review of available prosthetics for ventral hernia repair. Ann Surg 253:16–26
11. Bryan N, Ashwin H, Smart N et al (2012) The innate oxygen dependant immune pathway as a sensitive parameter to predict the performance of biological graft materials. Biomaterials 33:6380–6392
12. Wintermantel E, Suk-Woo H (2009) Life Science Engineering, Interdisziplinarität, Biokompatibilität, Technologien, Implantate, Diagnostik, Werkstoffe, Business. Medizintechnik (ISBN 978-3-540-93935-1)
13. Pizzoferrato A, Vespucci A, Ciapetti G et al (1985) Biocompatibility testing of prosthetic implant materials by cell cultures. Biomaterials 6:346–351
14. Scheidbach H, Tannapfel A, Schmidt U et al (2004) Influence of titanium coating on the biocompatibility of a heavyweight polypropylene mesh. An animal experimental model. Eur Surg Res 36:313–317
15. Sadlonova A, Novak Z, Johnson MR et al (2005) Breast fibroblasts modulate epithelial cell proliferation in three-dimensional in vitro co-culture. Breast Cancer Res 7:R46–R59
16. Dieterich M, Dieterich H, Timme S et al. (2012) Using a titanium-coated polypropylene mesh (TiLOOP® Bra) for implant-based breast reconstruction: case report and histological analysis. Arch Gynecol Obstet 286(1):273–276
17. Daly KA, Stewart-Akers AM, Hara H et al (2009) Effect of the alphaGal epitope on the response to small intestinal submucosa extracellular matrix in a nonhuman primate model. Tissue Eng Part A 15:3877–3888
18. Cordeiro PG, Snell L, Heerdt A et al (2012) Immediate tissue expander/implast breast reconstruction after salvage mastectomy for cancer recurrence following lumpectomy/irradiation. Plast Reconstr Surg 129:341–350
19. Petersen A, Eftekhari AL, Damsgaard TE (2012) Immediate breast reconstruction: a retrospective study with emphasis on complications and risk factors. J Plast Surg Hand Surg 46:344–348
20. Spear SL, Sinkin JC, Al-Attar A (2013) Porcine acellular dermal matrix (strattice) in primary and revision cosmetic breast surgery. Plast Reconstr Surg 131:1140–1148
21. Salzberg CA, Dunavant C, Nocera N (2013) Immediate breast reconstruction using porcine acellular dermal matrix (Strattice): long-term outcomes and complications. J Plast Reconstr Aesthet Surg 66:323–328
22. Evgeniou E, Cain H, Amonkar S et al (2013) Complications in immediate breast reconstruction using Strattice™. Eur J Plast Surg 36:301–306
23. Kiechle M, Klein E, Paepke D et al (2012) Use of acellular dermal matrix (Strattice™) in problematic cases of breast reconstructive surgery. Euro J Cancer 48:S177
24. Paepke S, K. E., Dittmer S, Ohlinger R, Kiechle M (2012) Einsatz des teilresorbierbaren Zweikomponenten-Polypropylen-Vicryl-Meshs (SERTAGYB ® BR) als Gewebeinterponat in der plastisch-rekonstruktiven Mammachirurgie—Erste Erfahrungen. Abstract, Kongressbeitrag Senologiekongress 2012
25. Dieterich M, Paepke S, Zwiefel K et al (2013) Implant based breast reconstruction using a titanium-coated polypropylene mesh (TiLOOP Bra®): a multicenter study of 231 cases. Plast Reconstr Surg 132(1):8e–19e
26. Bergmann PA, Becker B, Mauss KL et al (2014) Titanium-coated polypropylene mesh (TiLoop Bra®)— an effective prevention for capsular contracture? Eur J Plast Surg 37:339–346