JUSTYNA KUCIŃSKA-LIPKA*), IGA GUBAŃSKA, HELENA JANIK
Gdansk University of Technology
Faculty of Chemistry
Polymer Technology Department
Narutowicza St. 11/12, 80-233 Gdansk, Poland

Polyurethanes modified with natural polymers for medical application

Part I. POLYURETHANE/CHITOSAN AND POLYURETHANE/COLLAGEN

Summary — For over three decades polyurethanes (PUR or PU) have been reported for application in a variety of medical devices. These polymers consist of hard and soft segments, which allow for more subtle control of their structure and properties. By varying the composition of the different segments, properties of PUR can be tuned up for use in many areas of medicine. Recently, there is a great interest in modification of biomedical PUR with natural polymers making them more attractive and environmentally friendly. This group of natural polymers include chitosan and collagen. Chitosan is a crystalline polysaccharide. It is second most abundant natural polymer next to cellulose that is used in medical field. Chitosan can be applied in vastly diverse fields, ranging from waste management to food processing and medicine because of its biocompatibility, biological activity and biodegradability. Collagen is the component of tissues in nature and due to several properties it is considered for various applications in biomedical sciences. It is widely used in cosmetics surgery, healing burn wounds, orthopaedic, surgery and tissue engineering. This paper is an overview of novel achievements in medical grade PUR modifications with the use of natural polymers. Such PUR-natural polymer blends, due to their properties, may be applied as wound dressings, scaffolds in tissue engineering, tissue implants and vascular grafts.
Keywords: biomedical polyurethanes, chitosan, collagen, wound dressings, tissue scaffolds, tissue engineering, tissue implant.

POLIURETANY MODYFIKOWANE POLIMERAMI NATURALNYMI DO ZASTOSOWAŃ MEDYCZNYCH. CZ.I. POLIURETAN/CHITOZAN I POLIURETAN/KOLAGEN
Streszczenie — Artykuł stanowi przegląd literaturowy dotyczący nowych osiągnięć w zakresie modyfikacji biomedycznego poliuretanu (PUR lub PU), przy użyciu polimerów naturalnych, takich jak: chitozan i kolagen. Segmentowa budowa makrocząsteczki poliuretanu (segmenty sztywne i elastyczne) umożliwia subtelną kontrolę i sterowanie strukturą i właściwościami PUR oraz dostosowywanie ich do potrzeb w zależności od przewidywanych zastosowań. Łączenie poliuretanów z polimerami naturalnymi, tj. chitozan lub kolagen czyni je bardziej atrakcyjnymi i przyjaznymi dla środowiska. Biokompatybilny, aktywny biologicznie i biodegradowalny krystaliczny polisacharyd — chitozan — może być wykorzystywany w różnorodnych dziedzinach, począwszy od gospodarki odpadami a na medycynie kończąc. Kolagen natomiast, stanowiący budulec tkanek, ze względu na swoje właściwości może być szeroko stosowany w chirurgii kosmetycznej, w leczeniu ran oparzeniowych, stomatologii, ortopedii i inżynierii tkankowej. Poliuretany modyfikowane chitzanem lub kolagenem mogą służyć jako materiały na opatrunki, rusztowania w inżynierii tkankowej, implanty tkanek twardych i miękkich a także naczyń krwionośnych.
Słowa kluczowe: poliuretany biomedyczne, chitozan, kolagen, opatrunki, rusztowania w inżynierii tkankowej, implanty tkanek.

*) Corresponding author; e-mail: juskucin@pg.gda.pl

For over three decades polyurethanes (PUR or PU) have been reported for application in a variety of medical

devices such as intravenous catheters [1, 2], vascular grafts [3, 4], cartilage replacements [5, 6] or pacemaker lead insulation [7—9].

These polymers contain hard and soft segments which allow for more subtle control of their structure and properties. The hard, rigid segments are produced by the reaction between the diisocyanate and the chain extender, whereas polyether, polyester, or polycarbonate diol comprises the soft segments. The hard-segment content influences the degree of phase separation [10—15], which in turn affects physical and mechanical properties [16, 17] and degradation rate [18, 19]. By varying the molecular weight of polyols and the composition of the different segments, properties of PUR can be tuned up for use in many areas of medicine. In this respect, the range of mechanical and morphological properties that can be obtained with PUR is significantly larger than with commonly used medical grade polymers [20—22].

Recently, there is a great interest in modification of biomedical PUR with natural polymers making them more attractive and environmentally friendly. Natural polymers improve PURs biocompatibility and affects biodegradable properties. Moreover, they can be used as encapsules for drugs, which will release drugs and other active substances after implantation. That's why natural polymers are such important modifiers. The paper is an overview of the progress in new medical grade PUR synthesis and modifications using natural polymers.

CHITOSAN MODIFIED POLYURETHANES (PUR-Chi)

Chitosan is a crystalline polysaccharide. It is the deacetylation form of chitin, the second most abundant natural polymer next to cellulose, which can be obtained from crustaceans or fungal cell wall. The amino groups in chitosan allow the polymer to be dissolved in acids, so chitosan films can be easily prepared from solution. The degree of deacetylation (*DD*), which determines the content of free amino groups in the polysaccharide, can influence the performance of chitosan in many aspects [23—25] (Table 1).

T a b l e 1. The application of chitosan with different deacetylation degree

Form	Chitozan type	Application
Membranes	*DD* = 75 %	Medical devices
	($\overline{M}_w$ = 1170 Da)	
	DD > 95 %	Wound dressings
Hydrogel	*DD* = 80 %, 85 %, 87 %	Wound dressings
	DD > 95 %	Catheters
Film	*DD* = 86,2 %	Implants
	Chitosan solution	Implants

Chitosan can be applied in vast number of fields. Medicine is one of them chitosan may be used as a biomedical material, because of its biocompatibility, biological activity and biodegradability [24, 26]. Chitosan carries positive charge that can interact with the microbial surface, and therefore presents good antibacterial activities [27]. Chitosan also interacts with red blood cells and possesses a homeostatic effect [24]. The degradation rate of chitosan *in vivo* is low. It depends on deacetylation degree. The higher degree of deacetylation, the slower degradation is observed [28]. The biomedical applications of chitosan include novel drug delivery such as peptide or gene delivery [29—31] as well as wound dressings and tissue engineering [32].

In 1994 Chandy *et al.* [33] described the surface modification of PUR with protamine sulfate and chitosan to significantly inhibit biomaterial calcification. Since then more papers appeared showing the use of chitosan application for the preparation of PURs for biomedical application. The proposed application of chitosan which appears in the literature is very broad and only some examples are shown below. It is worth to add that on the market soon should appear the first aid topical wound dressing under the trade mark Tromboguard (the future offer of TRICOMED S.A, Company) [34], which is the composition of chitosan, sodium alginate/calcium alginate with addition of silver salt and PUR intermediate foam thin layer [35]. It was patented in 2010 (patent application P-390 253).

Lin *et al.* (2005) showed the way of improving blood compatibility of thermoplastic polyurethane (TPUR) membrane of Desmopan® type by immobilizing water-soluble chitosan (WSC)/dextran sulfate (DS) onto the surface. Surface was activated by ozone, and then poly(acrylic acid) (PAA) was grafted on the activated surface to introduce carboxyl groups. The time needed to ozone treatment was established to be in the range of 20 minutes. The membrane/water interfacial free energy increased with PAA-grafting and WSC/DS-immobilization, indicating the increasing wettability of TPUR membrane. It was found that the WSC/DS-immobilized amount increased with pH and the molecular weight of WSC. The *in vitro* cytotoxicity test (L929 fibroplast) was accomplished for thus obtained membranes and it was shown that the TPUR-WDS/DS membranes were non-cytotoxic. The chitosan spacer conjugated with dextran sulfate not only increased the hydrophilicity and interfacial energy with water, but also increased with the DS grafting amount. When WSC/DS was immobilized to TPUR membrane and had contact with blood the coagulation time was considerably prolonged, and platelet adhesion and protein adsorption were effectively reduced. Furthermore, TPUR-WSC/DS membranes exhibited higher cell viability than native TPUR membrane. Overall the results demonstrated that the WSC/DS immobilization was a promising method to improve the blood compatibility of TPUR membrane, while maintaining the superior cytocompatibility for clinical applications [36].

In another paper of Lin *et al*. low temperature plasma (LTP) surface treatment of TPUR membrane was applied

instead of ozone. Than the TPUR membrane (0.15 thick Tecophilic™ type membrane) was grafted with PAA, followed by the grafting of water-soluble chitosan (WSC) and heparin (HEP). TPUR Tecophilic™ was made of hydrogenated 4,4'-methylene diphenyl diisocyanate, poly(tetramethylene ether glycol) (PTMEG), and butane-1,4-diol (BD). The surface was characterized with static contact-angle and XPS [37]. The results showed that the surface densities of peroxides and PAA reached a maximum when treated with LTP for 90 s. A higher pH of the reacting solution led to higher graft densities of WSC and HEP. After WSC and HEP grafting, the hydrophilicity of the TPUR membrane increased. The adsorption of proteins on HEP-grafted TPUR membranes was effectively curtailed. In addition, HEP grafting also reduced platelet adhesion, elevated thrombin inactivation, and prolonged the blood coagulation time. According to the L929 fibroblast cell growth inhibition index, the HEP-grafted TPUR membranes exhibited non-cytotoxicity. The overall results demonstrated that the WSC/HEP immobilization on TPUR would be promising to improve the *in vitro* hemocompatibility of a TPUR membrane [37].

Yang J.-M. *et al.* (2008) prepared thermosensitive PUR membranes for medical application by take advantage of the thermosensitive behavior of poly(*N*-isopropyl acrylamide) [poly(NIPAAm)]. Polybutadiene (HTPB) and MDI, BD and dibutyl tin dilaurate PUR solution was prepared. The PUR solution was modified with *N*-isopropyl acrylamide and UV to get thermosensitive membrane (PUR/NIPAAm). Then chitosan was impregnated onto the PUR/NIPAAm surface. In order to evaluate the biocompatibility of these membranes, a cytotoxicity test and cell adhesion and proliferation assay were conducted in cell culture [38].

The results showed that these thermosensitive PUR/NIPAAm-Chi membranes exhibited very low cytotoxicity and could support cell adhesion and growth. 3T3 fibroblast cells not only remained viable but also proliferated on the surface of these various PUR/NIPAAm-Chi membranes. The morphology of 3T3 fibroblast cells on PUR/NIPAAm-Chi membranes is similar to that of control material (polystyrene). The result demonstrated that PUR/NIPAAm-Chi membranes could support the growth of 3T3 fibroblasts and can be easily stripped off from the skin. As the antibacterial ability and the values of WVTR and permeability of the PUR/NIPAAm-Chi membranes are comparable to the commercial. In this case the PUR/NIPAAm-Chi material may be considered for wound dressing [38].

Some papers present the use of chitosan as a gel to modify PUR properties. The example is the paper of Yang S.-H. *et al.* (2007). The authors reported a four-step surface modification method to create a thin lubricious layer of chitosan/poly(vinyl alcohol) (PVA) hydrogel on the segmented PUR Biomer® (SPUR) catheter. Modification steps included oxidation of the SPUR surface, functionalities modification, carbodiimide reaction and hydrogel crosslinking. Chitosan in the hydrogel could provide antimicrobial activity, which take place when it stayed on the catheter surface. Hydrogel coating SPUR samples eluded into the infected urinary tract, showed also significant antibacterial effects in this study. In summary, the four-step modification method developed in this study provided a simple and effective way to coat the surface of SPUR catheters with a chitosan/PVA blending hydrogel that could help to minimize the risk of complications related to the use of urethral catheters [39].

The chitosan/PVA blending hydrogel can help to minimize the risk of complications related to the use of urethral catheters, including urethral trauma, encrustation, and infection [39].

Another example of PUR modification is adding a dry chitosan as a powder contrary to previous presented examples where chitosan was added in solution or as a gel form. Zuo D.-Y. *et al.* (2009) prepared, by immersion precipitation (phase inversion method), a novel kind of asymmetric blend membranes with superfine chitosan powder (SCP) and biomedical PUR (Pellethane 2363-80AE) to investigate effects of different SCP content on the morphology and properties of the biomedical membranes [40]. With an increment of SCP content, the pore diameter and porosities of blend membranes increased firstly, and decreased subsequently. However, the water absorption rate and the water vapor transmission rate (WVTR) enhanced remarkably with SCP content increasing, which resulted from SCP strong hydrophilicity. WAXD (wide-angle X-ray diffraction) results revealed that the aggregated structure of SCP was not destroyed and amorphous region of PUR increased. The mechanical testing results indicated that with the increase in the ratio of SCP to PUR, mechanical properties presented a downtrend, whereas all blend membranes exhibited the good elasticity.

Zuo *et al.* (2012) also investigated effects of polyvinylpyrrolidone (PVP) as a pore-forming agent on the structure and performance of the SCP/PUR composite scaffolds. They used the same composition of SCP/PUR for the investigation as in the paper [41]. The morphology and structure of the composite scaffolds were verified *via* SEM, X-ray diffraction, and porosity measurement. The result showed that all SCP/PUR scaffolds were asymmetric with a skin layer near the top surface and a porous supporting solid matrix. The porosity and average pore size of SCP/PUR scaffolds exhibited a maximum value at 5 wt. % PVP. The crystallinity and the lamellar thickness (*L*) of composite scaffolds decreased with increasing PVP content from 0 to 8 wt. %. Consequently, through adjusting PVP content, SCP/PUR scaffolds prepared by immersion precipitation phase transformation could be a potential material that could be applied in skin tissue engineering [41].

Habib *et al*. (2011) combined urethane prepolymer with a chitosan gel (ChitoHeal) to be used as tissue adhesives. The aim of such a combination was twofold, first, to

exploit the properties of PUR in order to achieve good tissue adhesion, and second to manipulate the biocompatibility and healing properties of chitosan. Habib used isophorone diisocyanates (IPDI) and castor oil to obtain medical PUR. To confirm presence of urethane bonds he carried out the FT-IR analysis. To examine morphology of the urethane prepolymer and that of the final tissue adhesive SEM was used and the cytotoxic effect of the tissue adhesive was determined based on the growth and viability of cells (according to ISO 10993-5) [42]. They prepared a tissue adhesive to replace sutures in wound closure. Achieved tissue adhesive was biocompatible, with acceptable adhesion and accelerated tissue regeneration properties. Considering the enhanced biocompatibility of the adhesive using chitosan gel, it appears that, unlike cyanoacrylate adhesives, its degradation product does not present any toxicity and unlike fibrin-based glues, it would adhere to the tissue even in the presence of water with acceptable adhesion strength [42].

Xu D. *et al.* (2008) prepared in two steps a series of novel block polymers of waterborne polyurethane (PUR) and chitosan for medical application. The first step was the preparation of PUR prepolymer, obtained from polytetramethylene oxide glycol (PTMO, $\overline{M}_n$ = 1000), IPDI, and 2,2′-dimethylolpropionic acid (DMPA), followed by ionizing PUR prepolymer with triethylamine (TEA). The second step involves PUR chain-extension by water-soluble chitosan of low molecular weight ($\overline{M}_n$ = 5000) by self-emulsion polymerization method [43]. The sizes of the latex particles, morphology, and copolymer architecture have been characterized by dynamic light scattering (DLS), general tensile test, IR, surface contact angle measurement and TEM. Furthermore, it shows that the addition of chitosan remarkably increases anticoagulative property of PUR elastomers confirmed by the recalcification time. These polymers showed great potential in blood contacting implantable devices [43].

The cell (HUVECs) culture experiments in further studies showed that films exhibited very low cytotoxicity and supported cell adhesion and growth. Protein (BSA) adsorption significantly decreased. Furthermore, the results of prothrombin time (PT) and activated partial thromboplastin time (APTT) indicated that antithrombogenicity of the materials were effectively improved [44].

The remarkable advantage of this structure was to combine the biological and mechanical properties of Chi and PUR. The Chi-immobilized PUR films favored cells adhesion and growth, reduced plasma protein adsorption, and improved hemocompatibility, whilst good mechanical properties were reserved. Hence, PUR-Chi materials could provide a new candidate for implantable materials [44].

Lin Y.-H. *et al.* (2007) synthesized waterborne PUR, based on MDI, poly(butylene adipate), and chain extender *N*-methyldiethanolamine (MDEA) that provided tertiary amine groups. The PUR-Chi blends can be dissolved in the acetic acid and cast into films [45].

The mechanical properties (tensile strength and elongation), as well as the water absorption and thermal properties of the PUR-Chi films were evaluated to estimate their properties for medical application like better mechanical properties and biocompatibility. The tensile strength increased with the increased amount of chitosan, but the elongation decreased accordingly. The chitosan in the blends promoted the water absorption. Chitosan was more thermally-stable than PUR and also had higher crystallinity, as demonstrated by DSC. The blends were partially compatible mixtures, based on the data obtained from DMTA. Biocompatibility test was conducted utilizing immortalized rat chondrocytes (IRC). After IRC were seeded onto the PUR/CS films for 1.5 and 120 h, the number of cells was counted and the morphology of cells was observed by light microscopy and SEM. Blends containing 30 % chitosan had more cells attached initially. However, the blends containing more than 70 % chitosan appeared to promote the cell proliferation. Overall, PUR/CS films with more chitosan had better mechanical properties as well as biocompatibility. Authors claim that further exploration of PUR/CS films will allow to use them in cartilage repair [45].

The blends of PUR and chitosan were also in the interest of Janik team [46]. They modified PUR derived from HDI, PCL and BD having different amount of hard segment content. Chitosan obtained from Baltic krill with the degree of deacetylation equal 72 wt. % was added *in situ* at the second stage of PUR synthesis in the amount of 0.1—0.5 wt. %. Contact angle and surface profilometry showed that hydrophilicity is increasing after chitosan modification more for PUR having higher amount of HS and that the trend is stronger than in the case of collagen modification [46—48].

Interesting paper is of Barikani *et al.* (2009) who used chitosan as a chain extender to synthesize biodegradable PUR elastomers with potential for biomedical and industrial applications. PUR was obtained by the reaction of PCL and IPDI, extended with different mass ratio of chitosan and BD. Incorporation of chitosan into PUR backbone caused improvement in thermal stability and thermal degradation rate. The crystallinity and hydrophilicity of the prepared polymers were also examined by X-ray and contact angle measurements. The results showed that hydrophilicity decreased and crystallinity increased with increasing of chitosan content in PUR backbone [49, 50].

Incorporation of chitosan into PUR backbone was also the subject of interest of Janik *et al.* They obtained crosslinked systems from IPDI, PCL, BD and chitosan. Contact angle did not change after modification. Hexane and water extracts were in the range of Farmacopea demands. The system was very stable during sterilization at 120 °C for 30 min or after treating with 15 MGy. The chitosan modified PUR had better extensibility and comparable tensile strength in comparison to unmodified PUR and could be considered as material for heart valves [46—48].

COLLAGEN MODIFIED POLYURETHANES (PUR-Col)

Collagen is the major insoluble fibrous protein in the extracellular matrix and in the connective tissue. In fact, it is the single most abundant protein in the animal kingdom. There are the least 16 types of collagen, but 80—90 percent of the collagen in the body consists of types I, II, and III [51]. These collagen molecules pack together to form long thin fibrils of similar structure. Collagens due to several properties are considered for various applications in biomedical sciences. Collagen is used widely in cosmetic surgery, wound healing of burn patients, dentistry, for reconstruction of bone, orthopedic and surgical purposes and in tissue engineering. It has the capacity to absorb large amounts of tissue secretions, leads to smooth adherence to the wet wound and maintain a low-moisture climate in the wound and shields against mechanical harm and secondary bacterial infection. Collagen has been used as implantable carriers for bone inducing proteins and has been used as bone substitutes due to its osteo-inductive activity. Collagen films may be used as gene delivery carriers for osteoinduction and collagen sponge may be used for bone related protein carriers [52].

Van Wachem *et al.* (2002) assumed that collagen-immobilization on PUR surface will improve the tissue integration. They characterized foreign body reactions to collagen-immobilized polyurethane (PUR-Col) films during subcutaneous implantation in rats. They compared the properties of bare PUR (non-modified PUR), polyurethanes modified with an acrylic acid (PUR-AA), and PUR modified with AA and collagen (PUR-AA-Col). 2363-55D Pellethane was used as a medical grade PUR to be modified. Bare PUR had a flat surface, whereas both PUR-AA and PUR-AA-Col displayed a slightly roughened surface. PUR-AA-Col induced early after implantation a far more intense foreign body reaction than PUR and PUR-AA. This reaction consisted of increased presence of fibrin, granulocytes and macrophages. Roughening of the surface as with PUR-AA induced only a small increase in fibrin formation and cellular migration. These results show that collagen-immobilization of PUR increased the early tissue reaction and therefore the tissue integration. The results showed that PUR-AA-Col can be successfully used in biomedical field [53].

Li Y. *et al.* (2006) reported a safe, easy, effective, and one-step process to introduce a collagen layer onto a poly(ester-urethane) surface for improving its biocompatibility and reducing acute inflammatory reaction. Collagen gel was spread onto the plasma-treated polyurethanes type SCU-PUR-25 (PUR) film to make PUR-Col composite film by lyophilization [54]. In this process, collagen on the interface was covalently immobilized to PUR surface. Density of immobilized collagen molecules was examined to find the optimal experiment condition. The surface properties of the collagen-immobilized film were characterized by ATR IR and XPS. The results indicated that collagen chains had been grafted on PUR surface because of plasma activation. To see if collagen modification can deduce acute inflammatory reaction and improve tissue guide regeneration, PUR and PUR-Col composite films were implanted subdermally in rats to analyze the effect of collagen immobilization. The reaction interface of PUR-Col composite film and rat's tissue was observed by TEM; unmodified PUR film was used as control. The result showed that acute inflammatory reaction induced by PUR-Col composite film had vanished gradually after 7 days and the material was embedded by tissue, almost forming a capsule. The capsule's wall thinned out gradually in the following days. Although the control group's inflammatory reaction did not vanish in 1 month and PUR film embed in rat's tissue incompletely, PUR implant migrated easily from the implant site. As a result, PUR-Col composite film had most advantage in tissue guide regeneration and compatibility [54].

Another way and more complicated to introduce the collagen to the surface of PUR was suggested by He *et al.* (2012). At first they synthesized by prepolymer method a biodegradable PUR composed of l-lysine ethyl ester diisocyanate (LDI), PCL-diol and 1,4:3,6-dianhydro-d-sorbitol (isosorbide). Then amino groups were introduced onto the surface of the PUR membrane by an amination reaction with 1,3-propanediamine to produce polycationic substratum. After the preparation in this way of the PUR surface, type I collagen and chondroitin sulfate (CS) were deposited alternately on the polycationic substratum through layer-by-layer (LBL) assembly technology. The hydrophilicity of the PUR membrane was greatly enhanced through the modification of LBL assembly. The PUR modified through the adsorption of Col/CS may be a potential application for cartilage tissue engineering due to its created mimicking chondrogenic environment [55].

Plasma (P) surface preparation like in chitosan was tested as well for PUR-Col modification. Li Y.-H. *et al.* (2007) showed how to enhance cell adhesion and growth on medical polyurethane (SCU-PUR-25) surface. They immobilized type I collagen on the oxygen plasma treated PUR (P-PUR-Col) by a safe, easy, effective and one-step process. Tests results indicated that plasma treatment and collagen immobilization could improve hydrophilicity of P-PUR-Col. Moreover, HeLa cells were cultured on the surface of PURs to evaluate cell compatibility. The results showed that P-PUR-Col had higher cell adhesion and cell growth state compared to untreated PUR. The process in the paper can be a promising way to enhance biocompatibility of medical PUR [56].

Also electrospinning like in the case of chitosan modification of PUR was tested for collagen. Chen R. *et al.* (2010), produced successfully collagen functionalized TPUR Tecoflex EG-80A/nanofibers (TPUR/collagen), by coaxial electrospinning technique with a goal to develop biomedical scaffold. The coaxial electrospun nanofibers were further investigated as a promising scaffold for

PIECs culture. The results demonstrated that coaxial electrospun composite nanofibers had the characters of native extracellular matrix and may be used effectively as an alternative material for tissue engineering and functional biomaterials [57].

Collagen derived peptides were tested for modification of polyurethane-urea by Benhardt H. *et al.* (2011). They used poly(ester urethane)-ureas (PUU) derived from poly(ethylene glycol) (PEG), PTMEG, hexamethylene diisocyanate (HDI) and those mentioned peptides. The obtained modified PUU enables cellular release of proteases to dictate degradation rate whereas in typical poly(ester urethanes) degradation is controlled by hydrolysis that occurs independently of tissue regeneration. It is hypothesized that this cell-responsive design of the material will facilitate load transfer from the biodegradable scaffold to neo-tissue at a rate that promotes proper tissue orientation [58].

Recently, appeared the papers in which hybrid modification of medical grade PUR are suggested with the use of both collagen and chitosan modifiers. Huang Ch. *et al.* (2011) designed that modification as a novel kind of scaffolds for blood vessel and nerve repairs. Random and aligned nanofibrous scaffolds based on collagen-chitosan-TPUR Tecoflex EG-80A (TPUR) blends were electrospun to mimic the componential and structural aspects of the native extracellular matrix, while an optimal proportion was found to keep the balance between biocompatibility and mechanical strength. The scaffolds were crosslinked by glutaraldehyde (GTA) vapor to prevent them from being dissolved in the culture medium. The analysis with the use of SEM, AFM and FT-IR showed that the three-component system exhibits no significant differences before and after crosslinking, whereas pore size of crosslinked scaffolds decreased drastically. The mechanical properties of the scaffolds were found to be flexible with a high tensile strength. Cell viability studies with endothelial cells and Schwann cells demonstrated that the blended nanofibrous scaffolds formed by electrospinning process had good biocompatibility and aligned fibers could regulate cell morphology by inducing cell orientation and might be a potential candidate for vascular repair and nerve regeneration [59].

CONCLUSION

The number of polyurethane modification with natural polymers for medical application is still increasing. Natural polymers influence PURs biocompatibility and improve biodegradable properties. They are also used as encapsules for drugs, which will release drugs and other active substances after implantation. That's why natural polymers are such important modifiers. The least explored PUR natural polymer combinations are those with cellulose and starch while the most investigated are the compositions in which the use of chitosan is described. A very popular approach is activation of PUR surface with ozone or plasma and then modification with PAA to introduce carboxyl groups that can be farther used for particular reactions. The preparation of polymer blends or polymer composites is popular as well. Less popular but very interesting from chemical point of view is using the functional groups of natural polymers to incorporate them straight to PUR backbone as chain extenders or crosslinking agents. The most popular application of PUR modified with natural polymers in medicine is wound dressings and tissue engineering. Electrospinning technology for fabrication of the PUR/natural polymers compositions for medical application is very popular.

REFERENCES

[1] Bach A., Bohrer H., Motsch J., Martin E., Geiss H. K., Sonntag H. G.: *J. Antimicrob. Chemomether.* 1994, **33**(5), 969. [2] Hoffmann K. K., Weber D. J., Samsa G. P., Rutala W. A.: *JAMA* 1992, **15**, 2072. [3] Khorasani M. T., Shorgashti S.: *J. Biomed. Mater. Res. B* 2006, **76B**, 41. [4] Detta N., Errico C., Dinucci D., Puppi D., Clarke D. A., Reilly G. C., Chiellini F.: *J. Mater. Sci. Mater. Med.* 2010, **21**(5), 1761. [5] Chetty A., Steynberg T., Moolman S., Nilen R., Joubert A., Richter W.: *J. Biomed. Mater. Res. A* 2008, **84**, 475. [6] Eglin D., Grad S., Gogolewski S., Alini M.: *J. Biomed. Mater. Res.* 2010, **92**, 393. [7] Lelah M., Cooper S.: „Polyurethanes in medicine", CRC Press, Boca Raton, FL 1986. [8] Gogolewski S., Galletti G., Usia G.: *Colloid. Polym. Sci.* 1987, **265**, 971. [9] Tienen T. G., Heijkants R. G., de Groot J. H., *et al.*: *J. Biomed. Mater. Res. B* 2006, **72**, 389. [10] Tocha E., Janik H., Petrovic Z., Vancso J.: *J. Macromol. Sci. Phys.* 2002, **B41**, 1291.

[11] Janik H., Palys B., Petrovic Z.: *Macromol. Rapid Commun.* 2003, **24**, 265. [12] Kozakiewicz J., Janik H., Kwiatkowski R., Włochowicz A.: *Polym. Adv. Technol.* 2000, **21**, 82. [13] Janik H., Foks J.: in „Advances in Urethane Science & Technology" (Ed. Frisch K. C., Klempner D.), Technomic Publ. Lancaster Based 1992, **11**, pp. 137—172. [14] Foks J., Janik H., Russo R.: *Eur. Polym. J.* 1990, **26**, 309. [15] Król P., Pilch-Pitera B.: *Eur. Polym. J.* 2003, **39**, 1229. [16] Chen K. S., Leon Yu. T., Chen Y. S., *et al.*: *J. Polym. Res.* 2001, **82**, 9920. [17] Ioan S., Grigorescu G.: *Eur. Polym. J.* 2002, **38**, 2295. [18] Tang Y. W., Labow R. S., Santerre J. P.: *J. Biomed. Mater. Res.* 2001, **56**(4), 516. [19] Takahara A., Tashita J., Kajiyama T., *et al.*: *J. Biomed. Mater. Res.* 1985, **19**, 13. [20] Cleries L., Fernandez Pradas J. M., Morenza J. L.: *Biomaterials* 2000, **2**, 1861.

[21] Tanzi M. C., Fare' S., Petrini P., Tanini A., Piscitelli E., Zecchi Orlandini S., *et al.*: *J. Appl. Biomater. Biomech.* 2003, **1**(1), 58. [22] Bonzani I. C., Adhikari R., Houshyar S., Mayadunne R., Gunatillake P., Stevens M. M.: *Biomaterials* 2007, **28**(3), 423. [23] Struszczyk M. H.: *Polimery* 2002, **47**, 396. [24] Lee K. Y., Ha W. S., Park W. H.: *Biomaterials* 1995, **16**, 1211. [25] Struszczyk M. H.: *Polimery* 2002, **47**, 619. [26] Bernkop-Schnürch A., Kast C. E.: *Adv. Drug Deliv. Rev.* 2001, **52**, 127. [27] Rhoades J., Roller S.: *Appl.*

Environ. Microbiol. 2000, **66**, 80. [28] Chatelet C., Damour O., Domard A.: *Biomaterials* 2001, **22**, 261. [29] Aiedeh K., Gianasi E., Orienti I., Zecchi V.: *J. Microencapsul* 1997, **14**, 567. [30] Giunchedi P., Genta I., Conti B., Muzzarelli R. A., Conte U.: *Biomaterials* 1998, **19**, 157.

[31] Miyazaki S., Ishii K., Nadai T.: *Chem. Pharm. Bull.* 1981, **29**, 3067. [32] Mi F. L., *et al.*: *Biomaterials* 2001, **22**, 165. [33] Chandy T., Kumar B. A., Sharma C. P.: *J. Appl. Biomater.* 1994, **5**(3), 245. [34] www.tricomed.com/kontakt [35] Kucharska M., Struszczyk M. H., Niekraszewicz A., Ciechańska D., Witczak E., *et al.*: *Prog. Chem. Appl. Chitin.* 2011, **16**, 121. [36] Lin W. C., Yu D. G., Yang M. C.: *Colloid Surf. B-Biointerfaces* 2005, **44**, 82. [37] Lin W. C., Tseng C. H., Yang M. C.: *Macromol. Biosci.* 2005, **5**, 1013. [38] Yang J. M., Yang S. J., Lin H. T., Wu T.-H., Chen H.-J.: *Mater. Sci. Eng. C-Biomimetic Supramol. Syst.* 2008, **28**, 150. [39] Yang S.-H., Lee Y.-S. J., Lin F.-H., Yang J.-M., Chen K.-S.: *J. Biomed. Mater. Res. Part B* 2007, **83B**, 304. [40] Zuo D.-Y., Tao Y.-Z., Chen Y.-B., Xu W.-L.: *Polym. Bull.* 2009, **62**, 713.

[41] Zuo D.-Y., Yan-Wang Xu W.-L., Liu H.-T.: *Adv. Polym. Technol.* 2012, **31**, 310. [42] Habib F. N., Kordestani S. S., Afshar-Taromi F., Shariatinia Z.: *Int. J. Polym. Anal. Charact.* 2011, **16**, 609. [43] Xu D., *et al.*: *J. Appl. Polym. Sci.* 2008, **109**, 240. [44] Xu D., *et al.*: *Polymer* 2010, **51**, 1926. [45] Lin Y. H., *et al.*: *J. Appl. Polym. Sci.* 2007, **104**, 2683. [46] *PL pat. appl.* A1 391 140 (2010). [47] Gibas I., Szypcio M., Janik H.: „Polyurethanes modification with collagen and chitosan for medical application" in „The Proc. After Conference on Modified Polymers — State and perspectives" (Eds. Steller R., Zochowska D.), Wroclaw University of Technology, Wroclaw 2009, pp. 179—182. [48] Litwa P., Janik H., Gibas I.: „Cast segmented polyurethanes modified with chitosan for medical application", BioMedTech Conference, Silesia 2011, Zabrze 18.03.2011. [49] Barikani M., Honarkar H., Barikani M.: *J. Appl. Polym. Sci.* 2009, **112**, 3157. [50] Barikani M., Honarkar H., Barikani M.: *Mon. Chem.* 2010, **141**, 653.

[51] Lodish H., Berk A., Zipursky S. L., *et al.*: „Molecular Cell Biology", 4th edition, Freeman W. H., NY, 2000. [52] www.news-medical.net/health/Collagen-Medical-Uses.aspx [53] Van Wachem P. B., *et al.*: *Biomaterials* 2002, **23**, 1401. [54] Li Y. H., Huang Y. D.: *J. Appl. Polym. Sci.* 2006, **99**, 1832. [55] He X., Wang Y., Wu G.: *Appl. Surf. Sci.* 2012, **258**, 9918. [56] Li Y.-H., Huang Y.-D.: *Surf. Coat. Technol.* 2007, **201**, 5124. [57] Chen R., Ke K. E. Q., Mo X.: *AATCC Rev.* 2010, **10**, 59. [58] Benhardt H., Sears N., Touchet T., Cosgriff-Hernandez E.: *Macromol. Biosci.* 2011, **11**, 1020. [59] Huang C., *et al.*: *Colloid Surf. B-Biointerfaces* 2011, **82**, 307.

Received 12 II 2013.

W kolejnym zeszycie ukażą się m.in. następujące artykuły:

— *B. Marciniec* — Wprowadzenie

— *B. Mossety-Leszczak, M. Włodarska, H. Galina, M. Dutkiewicz* — Właściwości termiczne i dielektryczne silseskwioksanów z azowymi ugrupowaniami mezogenicznymi

— *M. Przybylak, H. Maciejewski, B. Marciniec* — Synteza i charakterystyka silseskwioksanów o strukturze niecałkowicie skondensowanych klatek

— *K. Szwarc-Rzepka, M. Walkowiak, M. Osińska-Broniarz, M. Dutkiewicz, H. Maciejewski, T. Jesionowski* — Otrzymywanie i zastosowanie funkcjonalizowanych napełniaczy hybrydowych SiO_2/F-SF POSS w żelowych elektrolitach polimerowych

— *M. Heneczkowski, M. Oleksy, R. Oliwa, M. Dutkiewicz, H. Maciejewski, H. Galina* — Zastosowanie sferokrzemianów do modyfikacji żywic epoksydowych

— *M. Szołyga, M. Dutkiewicz, B. Marciniec, H. Maciejewski* — Synteza reaktywnych żywic siloksanowo-silseskwioksanowych

— *M. Zaborski, A. Strąkowska, A. Kosmalska, H. Maciejewski, M. Dudkiewicz* — Związki POSS jako modyfikatory i dodatki do kompozytów elastomerowych

— *K. Pielichowski, M. Jancia, E. Hebda, J. Pagacz, J. Pielichowski, B. Marciniec, A. Franczyk* — Poliuretany modyfikowane funkcjonalizowanym silseskwioksanem — synteza i właściwości

— *E. Andrzejewska, A. Marcinkowska, D. Prządka, A. Kloziński, P. Jakubowska* — Polimerowe materiały hybrydowe i kompozytowe zawierające funkcjonalizowane poliedryczne oligomeryczne silseskwioksany (POSS)

— *M. Barczewski, D. Czarnecka-Komorowska, J. Andrzejewski, T. Sterzyński, M. Dutkiewicz, B. Dudziec* — Właściwości przetwórcze termoplastycznych tworzyw polimerowych modyfikowanych silseskwioksanami (POSS)