Bone Cements with Dietary Fibre Additive

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Abstract: **Acrylic bone cement setting as the result of exothermic reaction of polymerization is accompanied by high temperature growth. This temperature shock may cause living tissue necrosis with subsequent implant loosening. Bioactivity lack of bone cements on the base of poly(methylmethacrylate) – methylmethacrylate also may be the reason of implant loosening. Developed bone cements on the base of poly(methylmethacrylate-2-ethylhexylmetharylate) – ethylmethacrylate-triethyleneglycol dimethacrylate as well as carboxylic groups containing cement on that base are the cements with less expressed temperature increase during polymerization. Isolated from pea beans and wheat bran dietary fibre was used as additive which was introduced into bone cement solid phase. The introduction of 20% of additive influenced bone cements setting parameters: peak temperature decreased and setting time increased. The mechanical properties of formed cements were determined from four- point bending tests and uniaxial compression. Pea beans dietary fibre introduction did not worsen mechanical properties of bone cements, whereas enhancement was noticed in some results. The introduction of the same amount of wheat bran dietary fibre caused the decrease of ultimate stress of both bone cements in bending and in compression. This additive introduction caused the decrease of apparent density of carboxylic groups containing cement what might compensate polymerizing mixture shrinkage. The changes probably were caused by difference in morphology of isolated pea beans and bran dietary fibre what was established by scanning electron microscopy. The data show that bone cement modification with pea beans and bran dietary fibre is promising for bioactivity rise of non ionogenic bone cement and bioactivity increase of carboxylic groups containing cement. Bran dietary fibre additive introduction might be proper only in small amount (3-9% in solid phase), also to diminish bone cement shrinkage.**

Keywords: **bone cement, additive, setting properties, mechanical properties, dietary fibre**

I INTRODUCTION

Bone cement ensures artificial implant fixation in the bone tissue. The cement must provide a long-term stability in the loading transfer. Also a short-term expression of the used bone cement is important, because it influences the further results of implantation in great extent.

Acrylic bone cements are usually formed by radical polymerization of methylmethacrylate (MMA) in the presence of poly(methylmethacrylate) powder [P(MMA)], its dissolution process takes place simultaneously with the start of the polymerization. MMA polymerization itself is exothermic process with intensive temperature growth. Polymer formation increases the viscosity of polymer mixture, therefore the mobility of active polymer chains is restricted and polymerization termination via active chains recombination is decreased. This causes sharp increase of polymerization rate (autoacceleration stage due to `gel-effect`), which is accompanied by temperature growth. P(MMA) powder dissolution in monomer increases the viscosity of polymerization mixture even more and autoacceleration stage starts earlier.

The temperature increase is associated with tissue thermal necrosis which can cause implant aseptic loosening [1].

Bone cement shrinkage is another factor thought to contribute to loosening of prostheses. Shrinkage of cement is reported primarily as a consequence of polymerization process however thermal shrinkage also occurs as a result of its exothermic reaction [2].

Expansion of pores can accommodate some of the reduction of material volume within its mass to yield lower overall shrinkage and hence reduce stresses. It is acknowledged that lower porosity is desirable when crack propagation is considered, however continued increase in apparent density seem to be contraindicated due to its association with enhanced crack initiation [2].

Bone cements are able to reduce the stress concentration due to the interfacing of materials which have very different stiffness. The mechanical properties of commercial bone cements were investigated by means of stress relaxation and dynamic mechanical analysis. The results showed that viscoelastic properties were strongly dependent on specimen conditioning [3].

In addition to cement shrinkage, the lack of bioactivity would be one of the factors which cause the implant loosening. P(MMA) – MMA cements do not show bone-bonding ability, i.e. bioactivity [4]. Therefore the development of bioactive bone cements is an actual problem.

The introduction of a bioactive phase, such as hydroxyapatite, to cement may permit a stronger implant by encouraging direct bone apposition rather than encapsulation of the implant by fibrous tissue [5].

Among organic additives which are introduced to cause bioactivity of bone cement chitosan may be assumed as mainly investigated. The introduction of nanoparticles of chitosan is not significantly compromised the mechanical properties of bone cement [6].

Acrylic bone cement on the base of poly(methylmethacrylate-n-hexylacrylate) – ethylmethacrylate-triethyleneglycol dimethacrylate has been modified by the introduction of chitosan to get bioactive and biodegradable material. The introduction of 10% and 20% chitosan into solid phase of bone cement influenced little its mechanical parameters [7].

In present study the results of bone cement modification with materials of polysaccharide nature (dietary fibre isolated from pea beans and wheat bran) have been reported. The modification has been done using developed bone cements based on acrylic system poly(methylmethacrylate-2-ethylhexylmethacrylate)-ethylmethacrylate-triethyleneglycol dimethacrylate [P(MMA-EHMA)-EMA-TEGDMA], as well as functionalized with carboxylic groups of acrylic acid , i.e. poly(methylmethacrylate-2-ethylhexylmethacrylate)-ethylmethacrylate-acrylic acid - triethyleneglycol dimethacrylate [P(MMA-EHMA)-EMA-AA-TEGDMA].

The influence of additive introduction into cement solid phase on their setting parameters, mechanical properties and apparent density has been under consideration.

II MATERIALS AND METHODS

EMA and AA were purified by vacuum distillation; MMA, TEGDMA, EHMA (all ALDRICH) and other reagents were used as received.

P(MMA-EHMA) copolymer was synthesized by suspension polymerization, the content of EHMA being 8%. After washing and drying spherical beads of copolymer were sieved, and fraction less than 100 µm being collected as working fraction. The content of polymerization initiator benzoyl peroxide was 1% in solid phase.

The content of cross-linking agent TEGDMA in liquid phase was 8% for P(MMA-EHMA)-EMA-TEGDMA bone cement (ABC-8) and 6% for P(MMA-EHMA)-EMA-AA-TEGDMA cement (ABC-6-3A). The content of AA was 3 vol % in liquid phase of cement ABC-6-3A. Hydroquinone was added to liquid phases of both cements for stabilization during storage. Activator N,N-dimethyl-p-toluidine content was 1%.

To prepare bone cement specimens solid and liquid phases were mixed in proportion 2 g : 1 ml. 20% of additives (or another amount) were introduced instead of the same amount of copolymer powder.

Setting temperature was measured in polyethylene mould using Checktemp 1 (HANNA Instruments), resolution 0.1^0C, accuracy $\pm 0.3^0$C. Setting time was determined as in [1].

The mechanical tests (in bending and in compression) were carried out using INSTRON 4301. Using four-point flexural tests and uniaxial compression the ultimate strength and elastic modulus of material were found from stress - strain relationship. Bone cement specimens were formed as rectangular bars for bending tests and as cylinders for tests in compression. Before testing in bending specimens were stored for 6 days in 0.01M phosphate buffer solution containing 0.14 M NaCl and having pH 7.3. Tests in compression were done after storage of samples for 24 h in dry condition [1].

Bone cement apparent density (g/ml) was measured via increase of water volume in 10 ml cylinder after commitment of specimen of known weight.

Bone cement morphology was studied using Tescan Mira//LMU Schottky type electron microscope (SEM).

Dietary fibre was isolated from pea beans (PDF) and wheat bran (BDF) by treatment with petrol ether, 0.5 N NaOH, 0.5 N HCl solutions, and hot water. The absence of water soluble organics was controlled by permanganate oxidation. The non-soluble material was dried, grained and sieved. The fraction size of PDF was <90µm, and of BDF - <300µm.

III RESULTS

Additives which are used in present study are biopolymers of mainly polysaccharide structure. The composition of isolated from pea beans and wheat bran dietary fibre (fibril polymers) is complicate. Dietary fibre nowadays is defined as food material, particularly plant material, that is not hydrolyzed by enzymes secreted by the human digestive tract but that may be digested by microflora. Dietary fibre may include non-starch polysaccharides such as celluloses, some hemi-celluloses, gums and pectins, as well as lignin, resistant dextrins and resistant starches [8, 9].

The influence of additive introduction on setting parameters of developed cements has been estimated.

Bone cement setting parameters define exploitation properties of formed cement in great extent. Polymerization thermodynamics is decisive for the reaction result. The value of polymerization peak temperature, which accompanies the exothermic process of acrylic monomer polymerization, is the expression of the process thermodynamics. Polymerization peak temperature depends greatly on heat capacity of whole system, including polymerizing mixture itself and surrounding medium.

Bone cement modification with additives influences heat capacity of a system and, therefore, may influence bone cement setting process. Really, the introduction of 20% of PDF and BDF into cement solid phase instead of the same amount of P(MMA-EHMA) dispersion caused the change of bone cement setting profiles. Polymerization peak temperature of modified cements was lower but setting time was longer in comparison with non-modified cement for both ABC-8 (Fig.1) and ABC-6-3A cements (Fig.2).

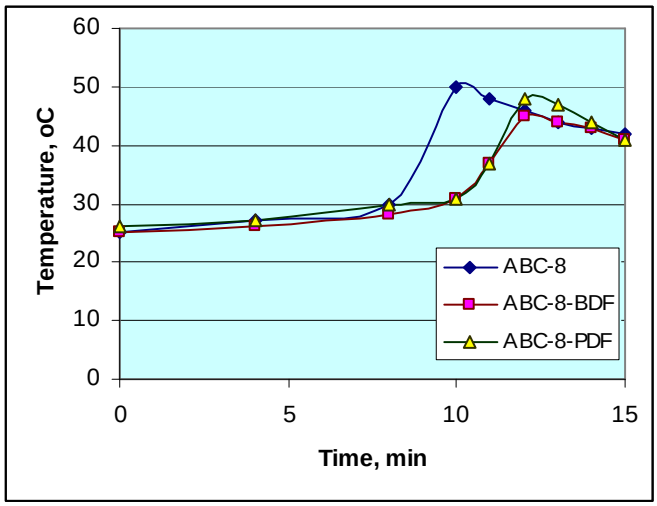


Fig.1. Setting profiles of modified and non-modified bone cements on the base of P(MMA-EHMA)-EMA-TEGDMA

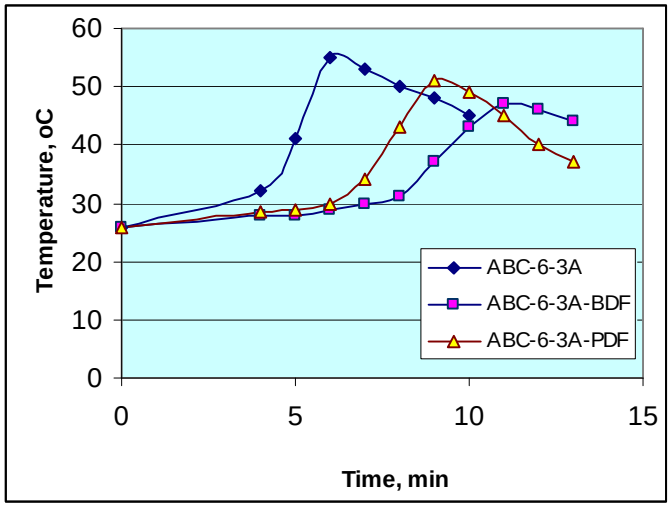


Fig.2. Setting profiles of modified and non-modified bone cements on the base of P(MMA-EHMA)-EMA-AA-TEGDMA

Bone cement formation is known to be accompanied by shrinkage of polymerized material. Specific density increase might be compensated in some extend by micropores formation during polymerization. This, in its turn, may alternate mechanical properties of the material.

In frames of the used measuring method, apparent density of bone cements with PDF additives was found to differ little from density of plane bone cements, but BDF introduction aroused large decrease of this parameter when the amount of additives was equal (20% in solid phase) (Fig.3). Apparent density decrease was noticed when the amount of introduced BDF was only 3% in solid phase.

The used native additives differ essentially in their morphology and size of grains (Fig.4).

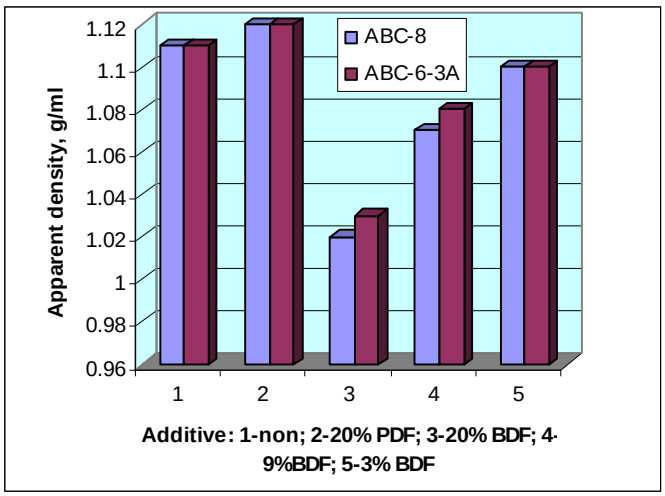


Fig.3. Apparent density of non-modified and modified cements ABC-8 and ABC-6-3A

From the SEM images of used additives follows that PDF grains are compacter than BDF grains. The last have many voids which probably were not filled with polymer during bone cement setting. This fact leads to decrease of cement apparent density. On the other hand highly expressed heterogeneity of BDF grains facilitates close interconnection between the two materials – polymer and polysaccharide.

The influence of polysaccharide containing additives on morphology of cement ABC-8 (Fig.5) and ABC-6-3A (Fig.6) fracture was adequate to their surface property.

The largest change of cement fracture morphology had been noticed when cement was modified with BDF. It can be mentioned that the grain size of PDF and BDF was different.

Mechanical tests showed that introduction of 20% PDF into cement solid phase practically did not influence flexural properties of bone cement ABC-8. Mechanical parameters in pressure had larger values in the case of samples modified with this additive: ultimate stress increased 1.2 times but modulus of elasticity 1.5 times. On the contrary, the introduction of 20% BDF caused the decrease of mechanical strength of bone cement ABC-8, particularly in bending.

The results showed the increase of flexural ultimate stress in the case of ABC-6-3A cement modification with 20% PDF in solid phase. Ultimate stress in compression was influenced little. 20% BDF introduction caused the decrease of ultimate stress of ABC-6-3A bone cement similarly to influence on ABC-8 cement. The decrease of ultimate stress was noticed when only 3 % of BDF was introduced into solid phase of ABC-6-3A cement. Modulus of elasticity in compression increased with BDF introduction.

As it emerged from dietary fibre definition, it consists of biocompatible and biodegradable components. Therefore the use of this additive may facilitate bone cells formation instead of biodegraded material. All biological processes are known to take place in presence of water solution. Therefore some increase of water uptake by bone cement might be considered as desirable phenomenon. Hydrophilic PDF additive introduction into bone cements increased their water uptake (Fig.7). The influence of BDF introduction on water uptake was less noticeable. Moreover, as it was shown earlier, PDF and BDF contain carboxylic groups in their structure [10, 11] which may be responsible for bioactivity rise in ABC-8 bone cement and bioactivity increase in ABC-6-3A cement.

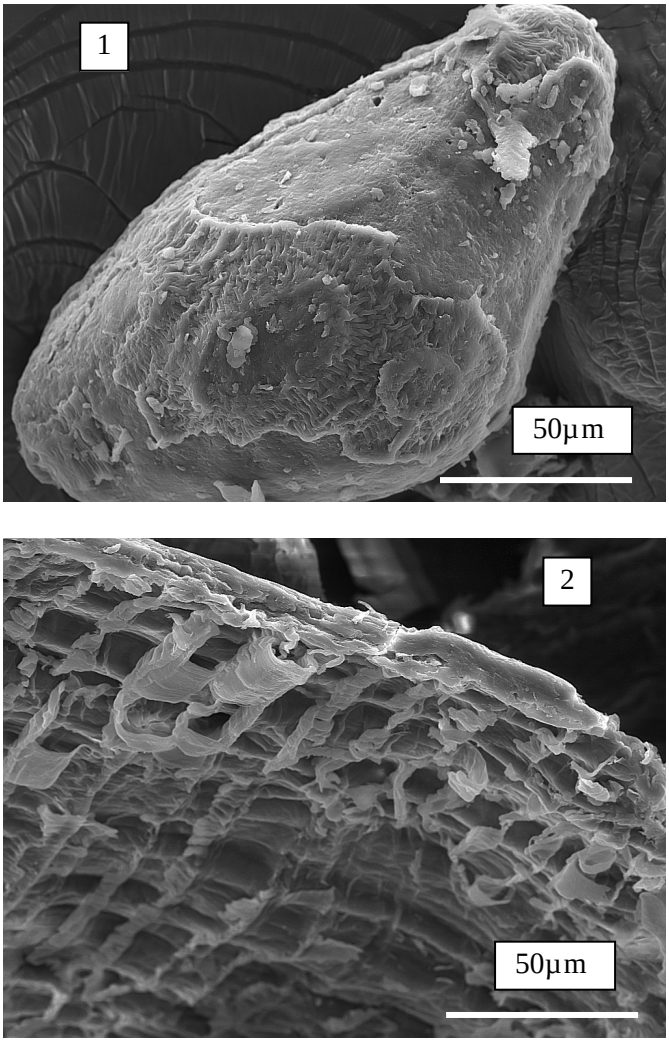
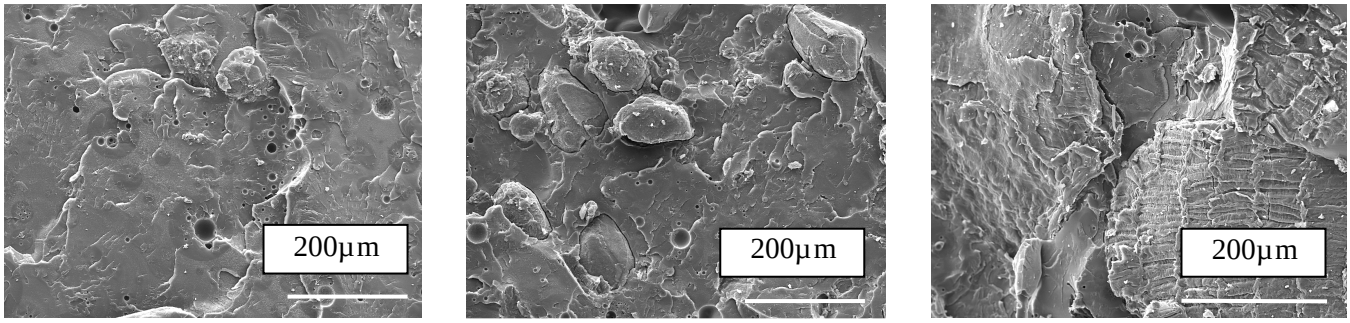
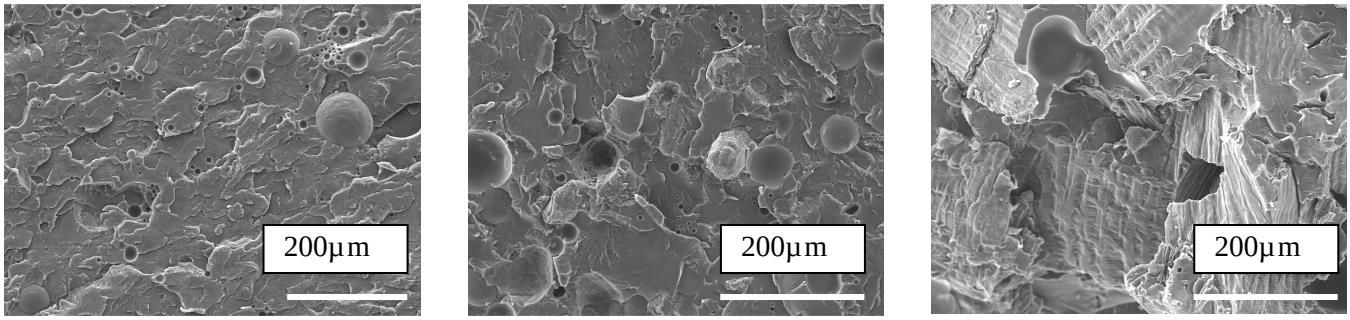


Fig.4. SEM images of PDF (1) and BDF (2) grains



ABC-8 ABC-8-PDF ABC-8-BDF

Fig.5. SEM images of ABC-8 fractures



ABC-6-3A ABC-6-3A-PDF ABC-6-3A-BDF

Fig.6. SEM images of ABC-6-3A fractures

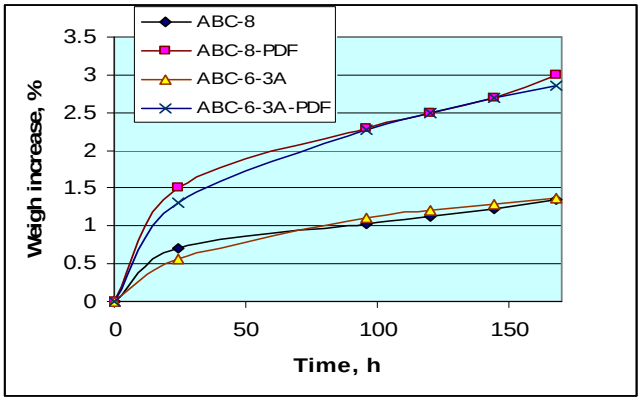


Fig. 7. Water uptake of bone cements with and without PDF additive

TABLE 1

MECHANICAL PROPERTIES* OF BONE CEMENTS ON THE BASE OF P(MMA-EHMA)-EMA-TEGDMA AND P(MMA-EHMA)-EMA-AA-TEGDMA

Bone cement	Flexural tests		Uniaxial pressure	
	Ultimate stress, MPa	Modulus of elasticity**, MPa	Ultimate stress, MPa	Modulus of elasticity**, MPa
ABC-8	54.99±10.61	1670±189	75.16±1.53	877±17
ABC-8-PDF	54.89±10.92	1954±221	90.43±13.55	1324±304
ABC-8-BDF	34±1.11	1298±77	68.16±0.39	858±20
ABC-6-3A	56.85±2.10	1612±500	106±1.00	800±298
ABC-6-3A-PDF	70.22±25.49	1747±527	90.02±10.07	1369±298
ABC-6-3A-BDF	38.09±3.05	1412±21	81.19±1.75	1375±69
ABC-6-3A-BDF-9 %	50.62±9.35	1671±411	73.88±7.73	1012±145
ABC-6-3A-BDF-3 %	50.64±8.05	1647±51	78.55±9.32	1068±180

*- mean±STD; **- between stresses 10-20MPa

IV CONCLUSIONS

Polysaccharide nature additives – pea beans dietary fibre and wheat bran dietary fibre – have been introduced into bone cement P(MMA-EHMA)-EMA-TEGDMA and having carboxylic groups P(MMA-EHMA)-EMA-AA-TEGDMA cement. The introduction of studied additives in the amount of 20% into solid phase of the cements influenced the setting parameters of the cements: polymerization peak temperature decreased and setting time increased.

P(MMA-EHMA)-EMA-TEGDMA bone cement modification with pea beans dietary fibre did not worsen mechanical parameters of the cement, whereas ultimate stress and modulus of elasticity in compression even increased .

The introduction of pea beans dietary fibre into P(MMA-EHMA) –EMA-AA-TEGDMA cement increased ultimate stress in bending, but influenced little ultimate stress in compression.

Wheat bran dietary fibre introduction decreases ultimate stress of both bone cements in bending and in compression. This additive introduction causes the decrease of P(MMA-EHMA)-EMA-AA-TEGDMA cement apparent density and noticeable change morphology of cement fracture.

The data show that bone cement modification with pea beans dietary fibre is promising for bioactivity rise in P(MMA-EHMA)-EMA-TEGDMA bone cement and bioactivity increase in P(MMA-EHMA)-EMA-AA-TEGDMA cement.

Wheat bran dietary fibre additive introduction might be proper only in small amount (3-9% in solid phase), also to diminish bone cement shrinkage.

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Valentīna Krilova, Visvaldis Vītiņš. Kaulu cementi ar šķiedrvielu piedevu.
Kaulu cementu sacietēšanu metilmetakrilāta ekzotermiskās polimerizācijas rezultātā pavada nozīmīgs temperatūras paaugstinājums. Šāds temperatūras šoks var izraisīt dzīvo audu nekrozi ar tālāku implanta atslābināšanu. Bioaktivitātes trūkums, kas piemīt kaulu cementiem uz poli(metilmetakrilāta) - metilmetakrilāta bāzes arī var būt par iemeslu implanta fiksācijas atslābināšanai. Izstrādātam cementam uz poli(metilmetakrilāta-2-etilheksilmetakrilāta) – etilmetakrilāta-trietilēnglikoldimetakrilāta bāzes, kā arī akrilskābes karboksilgrupu saturošam cementam piemīt zemāka temperatūras pacelšana sacietēšanas laikā. Izdalītie no zirņu pupiņām un kviešu klijām šķiedrvielas tika ievadīti cementu cietā fāzē. Doto piedevu ievadīšana cementu cietā fāzē 20% daudzumā izraisīja sacietēšanas maksimālas temperatūras pazemināšanu un sacietēšanas laika palielināšanu. Cementu mehāniskās īpašības noteiktas pēc četrpunktu lieces un vienass spiedes testiem. Zirņu šķiedrvielas piedevas ievadīšana neizraisa kaulu cementu mehānisko īpašību pasliktināšanās, turpretim, novērojama dažu radītāju izlabošana. Līdzīga daudzuma kliju šķiedrvielas ievadīšana izraisīja abu cementu graujošā sprieguma samazināšanu kā uz lieci, tā arī uz spiedi. Karboksilgrupu saturoša kaulu cementa modificēšana ar kliju šķiedrvielu pieveda pie cementa blīvuma samazināšanas, kas var kompensēt cementa polimerizējošās masas sarukumu. Izraisītas izmaiņas saistītas acīmredzot ar piedevu morfoloģijas atšķirībām, konstatētām pēc skenējošās elektronu mikroskopijas. Akrila kaulu cementu modificēšana ar zirņu un kliju šķiedrvielām var uzskatīt par perspektīvo ar mērķi pielikt bioaktīvitāti nejonoģēnam cementam un to palielināt karboksilgrupu saturošam cementam. Kliju šķiedrvielas ievadīšana vat būt pamatota tikai nelielos daudzumos (3-9%), arī kaulu cementa sarukuma samazināšanai.

Валентина Крылова, Высвалдис Витыньш. Костныые цементы с добавкой клетчатки.
Отвердевание акриловых костных цементов в результате экзотермической реакции полимеризации метилметакрилата сопровождается высоким подъёмом температуры. Такой температурный шок может вызвать некроз живой ткани с последующим ослаблением контакта импланта и костной ткани. Отсутствие биоактивности костных цементов на основе поли(метилметакрилат) - метилметакрилат также может являться причиной ослабления фиксации импланта. Разработанный цемент на основе поли(метилметакрилат-2-этилгексилметакрилат) - этилметакрилат-триэтиленгликольдиметакрилата, а также содержащий карбоксильные группы акриловой кислоты в своём составе, отличаются меньшим подъёмом температуры в процессе отвердевания. Введение добавок растительного происхождения –выделенной клетчатки гороха и пшеничных отрубей – в состав твёрдой фазы костных цементов в количестве 20% вызвало снижение максимальной температуры и увеличение времени затвердевания костных цементов. Механические свойства цементов определены по четырёхточечному изгибу и одноосному сжатию. Введение добавки клетчатки гороха не вызывает ухудшения механических свойств костных цементов, а по отдельным показателям наблюдается даже улучшение. Введение того же количества

клетчатки отрубей вызвало снижение разрушающего напряжения обоих цементов как на изгиб, так и на сжатие. Модифицирование клетчаткой отрубей привело также к снижению кажущейся плотности костного цемента, содержащего карбоксильные группы, что может компенсировать усадку полимеризующейся цементной массы. Вызванные изменения обусловлены, по-видимому, различиями в морфологии выделенной клетчатки гороха и отрубей, выявленными с помощъю сканирующей электронной микроскопии. Модифицирование акриловых костных цементов клетчаткой гороха и отрубей представляется перспективным с целью придания биоактивности неионогенному костному цементу или её повышению у цемента, содержащего карбоксильные группы акриловой кислоты. При этом введение клетчатки отрубей может быть обоснованным только в небольших количествах (3-9%), также и для уменьшения усадки костного цемента.