S53P4 Bioactive Glass - an Alternative Treatment of Bone Defects

CRISTIAN TRAMBITAS[1], TUDOR SORIN POP[2]*, ALINA DIA TRAMBITAS MIRON[3], DORIN CONSTANTIN DOROBANTU[4], KLARA BRINZANIUC[1]

[1]Medicine and Pharmacy University of Tirgu-Mures, Department of Anatomy and Embryology, 38 Gheorghe Marinescu Str., 540136, Tirgu Mures, Romania

[2]Medicine and Pharmacy University of Tirgu-Mures, Department of Orthopedics, 38 Gheorghe Marinescu Str., 540136, Tirgu Mures, Romania

[3]Ortopedul Tau SRL-D, 2 Margaretelor Str., 547530, Sangeorgiu de Mures, Romania

[4]Medicine and Pharmacy University of Tirgu-Mures, Department of Plastic Surgery, 38 Gheorghe Marinescu Str., 540136, Tirgu Mures, Romania

A challenging problem in orthopedic practice is represented by bone defects may they occur from trauma, malignancy, infection or congenital disease. Bioactive Glasses have a widely recognized ability to foster the growth of bone cells, and to bond strongly with both hard and soft tissues. Upon implantation, Bioactive Glasses undergoes specific reactions, leading to the formation of an amorphous calcium phosphate or crystalline hydroxyapatite phase on the surface of the glass, which is responsible for its strong bonding with the surrounding tissue. This phenomenon sustains a more rapid healing of bone defects and presents great antibacterial properties. In this paper we report on a clinical study that uses S53P4 Bioactive Glass to successfully treat bone defects and testify of the good compatibility of this material with human tissues.

Keywords: Bioactive Glasses, biocompatible synthetic materials, bone cysts

A challenging problem in orthopedic practice is represented by bone defects may they occur from trauma, malignancy, infection or congenital disease. Clinically, these defects can be reconstructed through the use of various grafts such as autografts, allografts and biocompatible synthetic materials [1,2]. As such, more than 2.2 million bone graft procedures are performed annually worldwide to ease fracture healing or to fill defects.

After Hench discovered the 45S5 bioactive glasses in 1971 [3] the later has been frequently considered as scaffold materials for bone repair [3-6]. Bioactive glasses have a widely recognized ability to foster the growth of bone cells [7,8], and to bond strongly with both hard and soft tissues [3,4]. Upon implantation, bioactive glasses undergo specific reactions, leading to the formation of an amorphous calcium phosphate (ACP) or crystalline hydroxyapatite (HA) phase on the surface of the glass, which is responsible for their strong bonding with the surrounding tissue [4]. Several studies have reported on properties of the Bioactive Glass (BAG) such as ions releasing that activate expression of osteogenic genes [9-11] or stimulation of angiogenesis [11-14]. It is also shown in [15-21] that the Bioactive Glass has antibacterial, osteoconductive and angiogenic properties, that makes it a perfect candidate for treating bone defects in infections.

Another important advantage of the BAG is the ease in controlling its chemical composition, thus its rate of degradation which makes it attractive as scaffold material. The structure and chemistry of Bioactive Glasses can be tailored over a wide range by changing either composition, or thermal or environmental production conditions. Therefore, it is possible to design glass scaffolds with variable degradation rates closely matching those of bone ingrowth and remodeling [22].

So far, a limiting factor in the common use of Bioactive Glass scaffolds for the repair of defects in load-bearing bones has been their low strength [5,6, 23]. However, there are studies [24,25] showing that by slightly varying the composition and the fabrication conditions, bioactive glass scaffolds can be created with strength comparable to human trabecular and cortical bones, having predesigned pore architectures.

To our knowledge, in Romania there is limited scientific work involving the Bioactive Glass and the existing approaches are mainly in vitro experiments such as [26-28]. So far, the only Romanian clinical initiative of treating bone infections using the Bioactive Glass has been recently reported by [29] with promising results. However, the clinical work involving Bioactive Glass implants for treating bone defects and especially defects in load-bearing bones is far from mainstream in Romanian hospitals. This motivated our clinical trial and via our results we intend to encourage the update of the treatment protocol for bone cysts not only institutional wide but also country wide.

Experimental part

Our study of using Bioactive Glass for treating bone defects was conducted between 2011 and 2016, by a well prepared team of orthopedics surgeons. The Bioactive Glass BonAlive [31] (S53P4) was used to fill the defects resulted after the debridement of bone cysts. The study was conducted on 4 patients (2 male, 2 female) with an age range of 17 to 67 years, with a mean age of 32 years and a male/female ratio of 1:1. None of the patients had any contraindication neither for the surgery nor for this technique.

The physical examination of all 4 patients showed pain in the area of the cysts. The active and passive mobility of the affected limb was restricted due to algic defense. The diagnosis of bone cysts was confirmed radiologically. Figure 1 shows the Rx images of two of the treated defects.

The surgical intervention consisting of debridement of bone cysts and filling the defects with Bioactive BonAlive Glass was performed by the same team of surgeons. We used BonAlive granules sized 2.0-3.15 mm on all patients, with a composition of 53% SiO_2, 23% Na_2O, 20% CaO, 4% P_2O_2 [31].

* *email: sorintpop@yahoo.com; Phone: 0744527203*

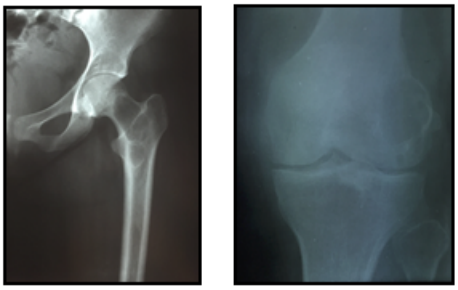

Fig. 1. Pre operatory Rx images of two of the patients included in the study

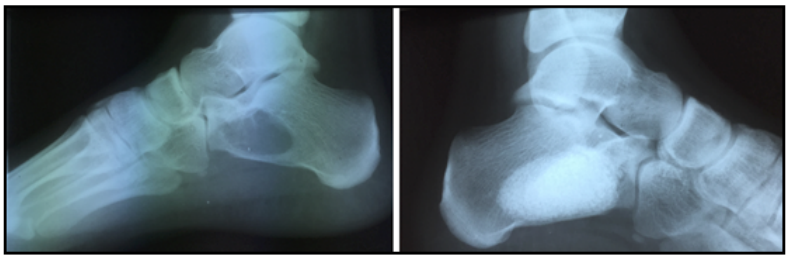

Fig. 2. Mirror images showing the initial calcaneus defect (left side) and the post-operatory results where the defect is filled with Bioactive Glass (right side)

Patient	Age	Sex	Cyst localization	Treatment
1	17	F	Proximal femoral epiphysis	Debridment+BonAlive
2	18	F	Left calcaneus	Debridment+BonAlive
3	26	M	Proximal femoral epiphysis	Debridment+BonAlive
4	67	M	Medial femoral condyle	Debridment+BonAlive

Table 1
DETAILS ON THE PATIENTS INCLUDED IN THIS STUDY

The patients were clinically and radiologically evaluated (Rx exams) after the surgery at 2 weeks, 1 month and 12 months. Figure 3 shows a selection of the post-operatory images of the treated areas.

Results and discussions

After surgery all patients followed the same recovery program. 2 weeks they had no weight bearing restrictions (walk with crutches). Between 2-4 weeks they could progressive start loading walking. No restrictions on movements after 2 months.

We performed physical examination of the patients to determine the range of motion and the level of pain. For all patients the pain decreased between 2 to 4 weeks after surgery and they were able to return to their normal activities after the recovery program. At the 1 and 12 months' evaluations all the patients showed good bone substitute integration, with no signs of ostheolysis on the Rx. None of the patients experienced post operatory complications. Figure 3 illustrates the Rx results on two patients at 12 months' evaluation exam.

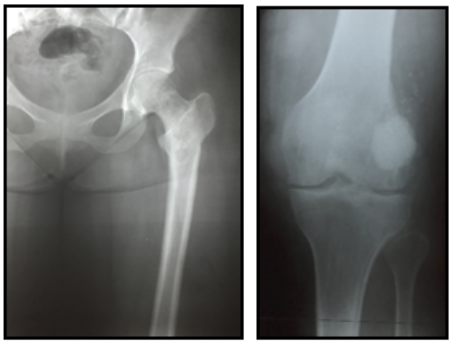

Fig. 3. 12 months Rx images of two of the patients included in the study

From a biological point of view, the Bioactive Glass is a promising solution for filling post-osteomyelitis, traumatic or other bone defects [29]. It has anti-microbial, osteoconductive and angiogenic properties [9, 12, 17, 29]. In contact with body fluids bioactive glass works by leaching out ions (in our study BonAlive generates Na, Ca, Si and P ions) leading to an alkaline environment (high *p*H) and increased osmotic pressure. This mechanism has been shown to effectively inhibit bacterial growth.

Also, bioactive glass has been demonstrated [9,12] to stimulate release of angiogenetic growth factors and to promote angiogenesis. The bioactive glass surface is not only conductive but also osteoproductive in promoting migration, replication, and differentiation of osteogenic cells and their matrix production. Using an in vitro model [18] demonstrated that the presence of 45S5 Bioglass scaffold in a fibroblast-conditioned medium stimulated the development of complex networks of interconnected tubules and increased the tubules branching. These are essential elements for angiogenesis, cell migration, cell proliferation, vessel branching and anastomosis.

All those properties make the Bioactive Glass an excellent candidate for solving bone defects in orthopedic practice. In this direction our current clinical study proved that the bioactive glass can be successfully used for treating cysts in load-bearing bones and that it permits a more rapid recovery than the conventional therapy protocol.

In the future we intend to extensively study and test several new generations of mesoporous bioactive glasses configurations (MBGs) [22] tailored at the nanometer scale through the incorporation of structure-directing agents to the solgel synthesis. These new glasses exhibit the fastest in vitro bioactivity observed up to date. The real clinical significance and the resulting palette of implications is still unknown, as the ordered mesoporous structure could allow incorporating osteogenic agents, osteoclasts inhibitors, antitumoral drugs, etc., thus providing an excellent potential for the treatment of bone diseases. Also the morphology and the size of the implanted granules are critical parameters for an optimal colonization of bone cells and formation of blood vessels. In this sense, rapid prototyping techniques and additive preparation methods allow the control of the implants macro-architecture and are called to play a very important role in regenerative therapies [22].

Conclusions

This clinical study confirms that bioactive glass is an excellent bone substitute that can be used as a replacement of autografts in several particular scenarios. In particular, great candidates for bioactive glass implants are patients with minimal access to the defect and minimal exposure of the bone. In this specific configuration, patients are protected from infections, excessive bleeding and are expected to have a faster recovery.

References

1. GIANNOUDIS, P.V., DINOPOULOS, H., TSIRIDIS, E., Int. J. Care Injured, **36**, 2005, p. 20–27

2. LAURENCIN, C., KHAN Y., EL-AMIN, S.F., Expert Rev. Med. Devices, **3**, 2006, p. 49
3. HENCH, L.L., SPLINTER, R.J., ALLEN, W.C., GREENLEE, T.K., J Biomed Mater Res, **2**, 1971, p. 117–141
4. HENCH, L.L., J. Am. Ceram. Soc., **81**, 1998, p. 1705–1728
5. RAHAMAN, M.N., BROWN, R.F., BAL, BS., DAY, D.E., Semi Arthrop., **17**, 2006, p. 102–112
6. YUNOS, D.M., BRETCANU, O., BOCCACCINI, A.R., J. Mater. Sci., **43**, 2008, p. 4433–4442
7. WHEELER, D.L., STOKES, K.E., PARK, H.M., HOLLINGER, J.O., J. Biomed. Mater. Res., **35**, 1997, p. 249–254
8. WHEELER, D.L., STOKES, K.E., HOELLRICH, R.G., CHAMBERLAND, D.L., MCLOUGHLIN, S.W., J. Biomed. Mater. Res., **41**, 1998, p. 527–533
9. XYNOS, I.D., EDGAR, A.J., BUTTERY, L.D.K., HENCH, L.L., POLAK, J.M. Biochem. Biophys. Res. Commun., **276**, 2000, p. 461–465
10. XYNOS, I.D., EDGAR, A.J., BUTTERY, L.D.K., HENCH, L.L., POLAK, J.M., J. Biomed. Mater. Res., 2001, p. 151–157
11. QI FU, SAIZ, E., RAHAMAN, Md.N., TOMSIA, A.P., Materials Science and Engineering, **31**, 2011, p. 1245–1256
12. HENCH, L.L., POLAK, J.M. Science, **295**, 2002, p. 1014–1016
13. LEU, A., LEACH, J.K., Pharm. Res., **25**, 2008, p. 1222–1229
14. GORUSTOVICH, A.A., ROETHER, J.A., BOCCACCINI, A.R., Tissue Eng. B Rev., **16**, 2010, p. 199–207
15. HU, S., CHANG, J., LIU, M., NING, C., J Mater Sci Mater Med, **20**, 2009, p. 281–286
16. LEPPARANTA, O., VAAHTIO, M., PELTOLA, T., ZHANG, D., HUPA L, HUPA, M., YLÄNEN, H., SALONEN, J.I., VILJANEN, M.K., EEROLA, E., J Mater Sci Mater Med, **19**, 2008, p. 547–551
17. RAHAMAN, M.N., DAY, D.E., BAL, B.S., FU, Q., JUNG, S.B., BONEWALD, L.F., TOMSIA, A.P., Acta Biomaterialia, **7**, 2011, p. 2355–2373
18. DAY, R.M., Tissue Eng, **11**, 2005, p. 768–777
19. ARKUDAS, A., BALZER, A., BUEHRER, G., ARNOLD, I., HOPPE, A., DETSCH, R., NEWBY, P., FEY, T., GREIL, P., HORCH, R.E., BOCCACCINI, A.R., KNESER, U., Tissue Eng Part C Methods, **19**, 2013, p. 479–486
20. VÄLIMÄKI, V.V., ARO, H.T., Scand J Surg, **95**, 2006, p. 95–102
21. CORAÇA-HUBER, D.C., FILLE, M., HAUSDORFER, J., PUTZER, D., NOGLER, M., J Orthop Res, **32**, 2014, p. 175–182
22. VALLET-REGI, M., SALINAS, A.J., ARCOS, D., International Journal of Applied Glass Science, **7**, 2016, p. 195–205
23. REZWAN, K., CHEN, Q.Z., BLAKER, J.J., BOCCACCINI, A.R., Biomaterials, **27**, 2006, p. 3413–3431
24. FU, Q., SAIZ, E., TOMSIA, A.P., Adv. Funct. Mater., **21**, 2011, p. 1058–1063
25. LIU, X., RAHAMAN, M.N., FU, Q.A., Acta Biomater., **7**, 2011, p. 406–416
26. GERGELY, I., ZAZGYVA, A., MAN, A., ZUH, S., POP, T., Acta Microbiologica et Immunologica Hungarica, **61**, 2014, p. 145-160
27. OPRITA, E.I., MOLDOVAN, L., CRACIUNESCU, O., ZARNESCU, O., 1, Central European Journal of Biology, **3**, 2008, p. 31–37
28. STANCIU, G.A., SANDULESCU, I., SAVU, B., STANCIU, S.G., PARASKEVOPOULOS, K.M., CHATZISTAVROU, X., KONTONASAKI, E., KOIDIS, P., 1, Journal of Biomedical & Pharmaceutical Engineering, **1**, 2007, p. 34-39
29. LUPESCU, O., NAGEA, M., MARCOV, N., JINESCU, G., POPESCU, G.I., Rev. Chim. (Bucharest), **67**, no. 12, 2016, p.2541
30. GEURTS, J., VRANKEN, T., ARTS, J.J.C., Jacobus J.C. Arts, **23**, 2016, p. 37-41
31.*** http://www.bonalive.com

Manuscript received: 16.12.2016