



Case report

CALCANEAL RECONSTRUCTION WITH A LARGE BONY DEFECT WITH THE AID OF BIOACTIVE GLASS – CASE STUDY

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ABSTRACT

Bone defect reconstruction is a critical component of orthopedic surgery, aiming to restore bones' structural integrity and functionality after injury. Recent developments in biomedical technology have brought forward several advancements in this field, particularly in the development and application of bone graft substitutes.

These materials are engineered to mimic the biological and mechanical properties of the bone, thereby facilitating new bone growth and integration without the limitations and morbidity associated with traditional bone grafts.

Bioactive glass is an example of such innovation in bone graft substitutes. Composed primarily of silicon dioxide, along with calcium oxide and phosphate, it is designed to undergo a chain of reactions to form a layer of hydroxyapatite that is chemically and structurally similar to human bone.

Bioactive glass (BAG) has already found its place in maxilla-facial and spine surgery. However, it is surprising that limited data exist on the use of BAG in trauma patients.

We present a case of a 42-year-old male who arrived at the emergency department following a high-energy trauma to the calcaneus after a fall from 4-5 meters onto his left foot. CT imaging revealed a bone deficit in the affected calcaneus due to the impact trauma. The patient underwent open reduction and internal fixation (ORIF) with bioactive glass (BAG), which was used as an alternative to traditional bone grafting.

Keywords: Bone grafts and substitutes, bioglass, calcaneus fracture,

INTRODUCTION

Bone substitute use in the treatment of fractures has increased in recent years, as has the trend of less invasive surgical protocols [1, 2]. Nowadays, biomaterials' development and improved biomechanical stability provide a case to consider synthetic grafts over auto and allografts [1, 2, 3].

Bioactive glass (BAG) was developed and described by Prof. Larry Hench in the early 1970s. Over the next 50 years, it was extensively studied and developed [4]. Today, BAG is used in regenerative medicine, dentistry, bone infection treatment, and bone reconstruction surgery [5, 6].

Few clinical trials have explored the use of bioactive glass (BAG) in bone regeneration and reconstruction. In a randomized controlled trial (RCT), Heikkila et al. (2011) compared the use of BAG with autogenous bone transplants in a population with depressed lateral tibia plateau fractures [7]. After a one-year follow-up, they found no significant differences in clinical outcomes or the redepression of the articular surface between the two groups [7].

Calcaneal fractures are among the most common and challenging injuries encountered in foot trauma, predominantly resulting from high-energy impacts such as falls from height [8]. Though relatively uncommon, representing around 1-2% of all fractures, they nevertheless represent potentially debilitating trauma. Having a crucial role in weight bearing, gait, and foot biomechanics, fractures in this area significantly affect mobility and quality of life, and proper reconstruction of the bone is thus required [9].

PRESENTATION OF CASE

A 42-year-old male was admitted to the emergency department in University Hospital – Pleven following a fall from a height of 4 to 5 meters, landing on his legs. He presented with severe left ankle pain, rating it 8 out of 10 on the visual analogue pain scale, and was not able to bear weight on the affected limb. Clinical examination

revealed a visible hematoma and severely restricted active and passive ranges of motion (AROM and PROM) due to the pain.

Following careful neurovascular assessment and lateral radiographic examination, the decision to perform a computer tomography (CT) scan with 3-dimensional reconstruction was made. This allowed for better visualization and understanding of the fracture's state.

Fig. 1. Patient pre-operative lateral x-ray.



Fig. 2a) b). Calcaneus 3-dimensional reconstruction.

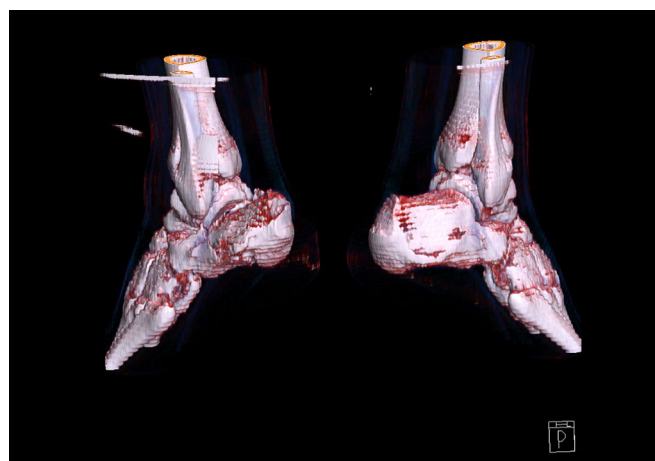
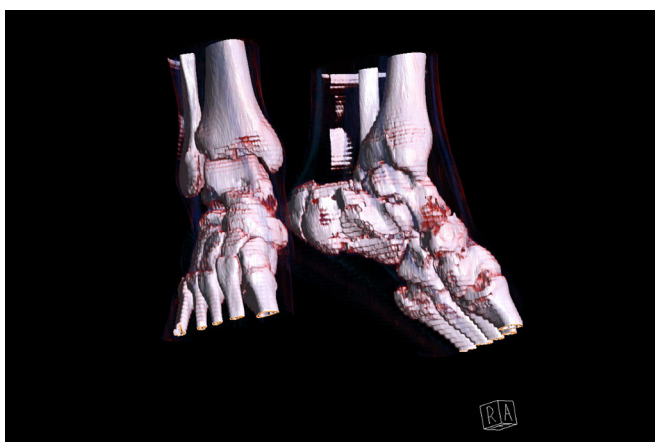
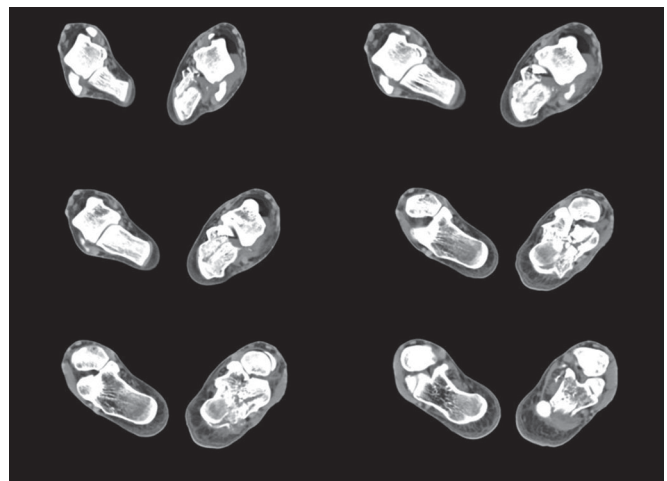


Fig. 3. Calcaneus CT series scan.



According to the Sanders classification, the patient has sustained type [3BC type]. According to the AO classification, fracture was classified as [2C] according to AO classification. Furthermore, a bone loss was noted, which required graft use. After a discussion with the treating physician, the patient decided not to undergo additional surgery to acquire the autograft and decided to use the synthetic graft option. Informed consent was provided by the patient according to the rules and regulations of Medical University–Pleven.

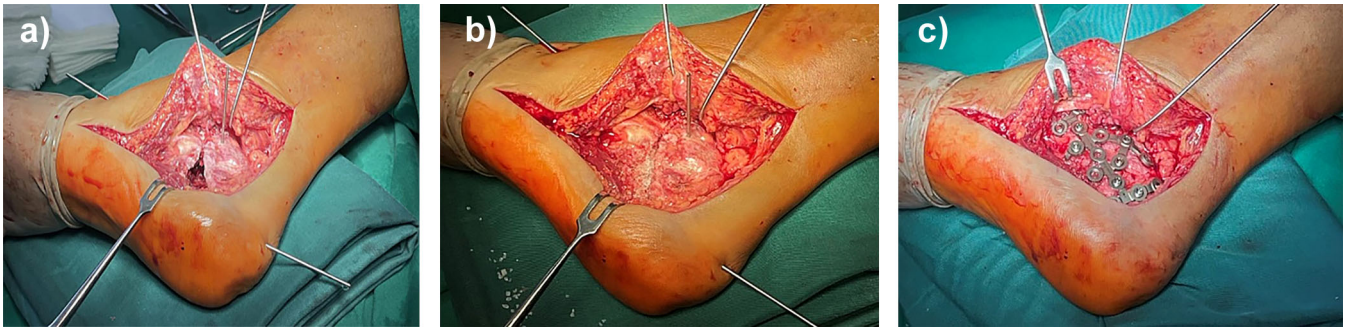
TREATMENT

After admission, he underwent standard pre-operative preparation, which included thromboprophylaxis with low-molecular-weight heparin 6000E, a short leg cast, and ice therapy of the injured part.

Ceftriaxone of 2g was administered 30 minutes before surgery. The patient was positioned in the lateral position on the operating table, with extensive padding over bony prominences, and a tourniquet was used after applying a rubber bandage.

The lateral Kocher approach to calcaneus was made per standard protocols, with care to preserve neurovascular structures intact. As standard, the aim of surgery was to restore the height, length, and axis of the calcaneus, restore the joint surface, Böhler and Gissane angle, and provide stable osteosynthesis. Following temporary reduction with K-wires and prior definite fixation with AO “Sanders Plate”, the artificial bone graft (Glassbone, Noraker, Ref GB1.3/16, 1 – 3 mm, 45S5 type) was used to fill the large void area (Figure 4). All reduction procedures were done under fluoroscopy control.

Fig. 4a) b) c). Peri-operative recording of large void area in calcaneus after reduction, filled void area, and definitive fixation.



Individual physiotherapy was commenced the day after surgery and continued after discharge from the clinic. The patient was not allowed to bear any weight on the affected limb for the first three months after surgery. Throughout this period, mobility was facilitated through the use of two crutches. Subsequently, after these three months, a gradual increase in load on the affected extremity was permitted. This progressive loading continued over three weeks, which resulted in full weight-bearing capacity on the affected limb.

On follow-up 6 months, the patient presented without substantial subjective complaints, was pain-free, reported normal daily living activities, and walked in a walking boot without crutches. On clinical examination, the patient was found to have a full, pain-free, active range of motion. The incorporation of the bioactive glass granules was evaluated visually by analyzing morphological changes of the granules, especially the definition of their outlines on plain films and CT slices [Fig. 7].

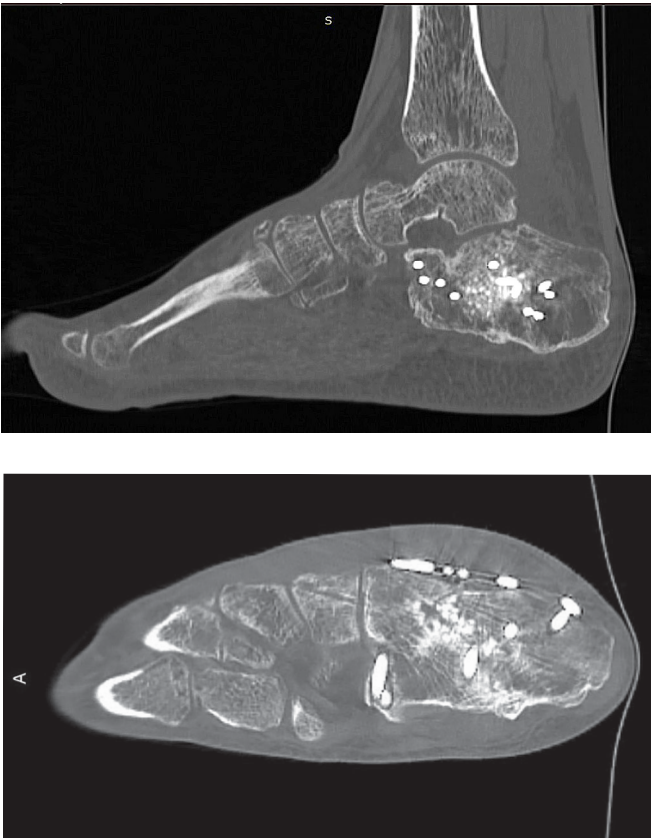
Fig. 5. Two months post-surgery.



Fig. 6a) b). Two months post-surgery with full range of motion and good skin closure.



Fig. 7a b). Eight months post-surgery CT slides



DISCUSSION

Several organic and inorganic materials could be used as substitutes in the fracture treatment [10]. They are autogenous bone grafts, calcium sulfate, hydroxyapatite, tricalcium phosphate, polymethyl-methacrylate, bone morphogenetic proteins, and bioactive glass granules [2, 10, 11, 12]. Additionally, inert inorganic materials such as alumina, zirconia, and titanium alloy could be used. However, lack of resorbability and osteointegration ability at the bone-metal interface makes them less desirable choices [13].

Bioactive glass could be defined as “one that elicits a specific biological response at the interface which results in the formation of a bond between the tissues and the material” [14]. Thus, its formulation is designed to provoke a reaction from the nearby cells at the tissue-glass interface.

In this case study, we have implanted the 45S5 bioglass composition. This composition was particularly interesting due to its ability to form a strong bond to the bone tissue [14, 15]. Further research by Hupa, 2018, found this bonding results from the formation of a hydroxyapatite layer on the glass surface due to a chain of reactions that occurs when bioglass is exposed to body fluids [15, 16, 17]. This hydroxyapatite layer imitates natural apatite and provides an environment for the absorption of proteins, growth factors, and attachment, pro-

liferation, and differentiation of osteoprogenitor cells [17, 18, 19]. Of course, the golden graft standard is still autograft, which possesses all the necessary characteristics required, such as osteoconductivity, osteogenicity, and osteoinductivity [20]. However, harvesting autograft requires additional surgery to acquire the graft, which might not be appropriate in certain populations or trauma in weight-bearing areas.

For example, Ilharreborde et al. (2008) investigated using BAG versus iliac crest bone graft in the adolescent population for posterior spine fusion surgery [21]. They found both graft types to be similarly successful but noted that 2% of patients experienced complications (pain) from the graft harvesting surgery. This pain was still reported in the fourth year of follow-up.

Studies by Swan and Goodacre (2006), Hernigou et al. (2014), Jessop et al. (2015), and Brudnicki et al. (2019) reported additional complications such as difficulty in walking, hematomas, and infections in patients who underwent graft harvesting from the iliac crest [22, 23, 24, 25, 26].

Courvoisier et al. (2023) also studied BAG use in the adolescent population for posterior spine fusion surgery and reported no complications [27]. Unlike Ilharreborde et al. (2008), Courvoisier did not use grafts from the iliac crest, thereby avoiding the side effects associated with additional surgery [21, 27]. They argued for the use of synthetic fillers because autologous grafts may be harvested in insufficient quantities for patients who require larger fusions or need to fill larger void areas. We agree with Reissmann et al. (2013), who found that patients who underwent bone grafting from the iliac crest reported decreased quality of life from our clinical experience.

In our case, the patient opted for a synthetic graft because he had refused autograft surgery [28].

An essential feature of biomaterials intended for traumatology is the ability to provide mechanical support to the bone, including the capacity to bear weight and withstand the mechanical load applied to them [29, 30]. This biomaterial (graft), thus, must be able to carry weight without bending, deformation, or failure. Whereas it is not the aim of the article to describe the mechanical properties of BAG, we have to mention that analysis by Fu et al. 2011, shows that porous bioactive glass could be fabricated to withstand compressive force comparable to trabecular and cortical bone [30]. Thus, bioactive glass could be used in body areas subject to physical loading. For instance, an RCT study by Heikkila et al. in tibial plateau fracture, after a 1-year follow-up, has not found redepression of the tibial articular surface in both bioactive glass (S53P4 type) and autologous graft group [7].

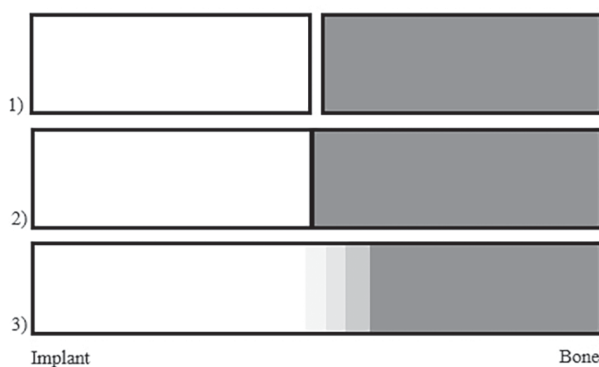
On the contrary, Jonsson and Mjoberg 2015, who investigated autograft vs porous titanium granules as an

allograft, found recurrent depression of the tibial articular surface within a year of initial surgery in 8 patients who were treated with autologous graft [31]. Further on, Jonsson and Mjoberg, 2015, did not report problems during the drilling or screwing through the titanium granules, whereas Heikkila et al. did not provide comment on this part of the surgery. We, in our case study, preferred not to drill or place screws through the bioactive glass. Unlike Heikkila et al. 2011 and Jonsson and Mjoberg 2015, we have moisturized the granules with the blood from the patient, not saline, to make granules adhere together, to improve handling, and to fill in the defect. Also, unlike saline, blood contains natural growth factors and cells that can accelerate bone regeneration [32].

Based on the visual examination of X-ray films and CT scans, the bioactive glass granules began to integrate with the adjacent bone within the next months, similar to the study of Heikkila et al. 2011 [7]. This integration was marked by the fading of the granules' originally distinct shapes and edges (Fig. 8.) [33].

Comparing to Jonsson and Mjoberg, 2015, inert metals cannot form bone bonding or be reabsorbed. Nevertheless, he did not report any problems with retaining the titanium granules inside bone tissue [31].

Fig. 8. Schematic presentation of bone response toward three types of implant materials. (Adapted from Salinas et al. 2018) [33]



1) Fibrous capsule encapsulates the biotolerant implant material

2) Intimate contact without bone bonding occurs at the interface between bioinert materials and bone (e.g. inert metal).

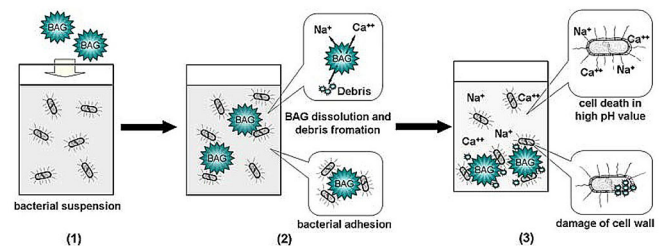
3) Intimate contact with chemical bone bonding between bioactive surface and bone. Note the gradual transformation between bone and implant material.

From another important point, contemporary methods for preventing infections during surgery, such as antibiotic prophylaxis, have significantly decreased the incidence of surgical site infections (SSI). However, no meth-

ods are perfect, and infections at surgical sites still occur.

For instance, Wang et al. 2018 in a retrospective study of 725 patients after ORIF of calcaneus fracture, reported 2.9% of deep SSI out of 66 overall cases of SSI [34]. Due to the ability of bacteria to survive virtually on any natural or synthetic surface, there is a need for implants that possess the intrinsic ability to have an antibacterial effect and produce an effective biofilm barrier. 45S5 BAG has been shown to possess broad-spectrum antimicrobial activity, including against skin pathogenic bacteria. This is achieved by the BAG release of ions (Na, Ca, P, and SiO₄), which increase pH and osmotic pressure, creating a hostile environment for microorganisms. A representation of the study by Hu S, et al. 2009 on the antibacterial properties of BAG 45S5 type can be seen in Fig. 9 [35]. Drago et al. 2013, also reported the use of S53P4 of BAG type in the treatment of osteomyelitis [36]. Heinig et al. 2023 in a case study of open calcaneal fracture, reported using bioactive glass putty due to antibacterial properties [37].

Fig. 9. BAG antimicrobial activity. Cited from Hu S, et al. [35]



1) BAG particles were added to the bacterial suspension. 2) BAG particle dissolution leads to an increase in pH and debris formation. 3) Microorganisms are killed by high pH values and by damage to cell walls caused by BAG debris

This case study presents a case for using bioactive glass (45S5) in reconstructing calcaneal fractures. We believe that the use of synthetic fillers will continue to increase as the population demands less invasive surgeries, as in our case. From practical experience, we may recommend that surgeons mix the BAG with blood to improve the handling of the graft and press-fit granules into the closed void bone area.

Furthermore, in this case study, we intend to propose an RCT trial to investigate the use of BAG in trauma settings in the population who would refuse the autograft option.

To conclude, BAG is potentially a versatile graft material that could be used in trauma cases to reduce the risk of infection, provide mechanical support, reduce overall operative time, and eliminate risks associated with graft site complications.

CONCLUSION

This case study has shown promising outcomes when bioactive glass was used for bone repair, highlighting its effectiveness in stimulating bone growth, biocompatibility, and infection prevention. Furthermore, the use of synthetic allograft simplifies intraoperative work and reduces operative time.

In our opinion, recent developments in the field of biomedical technology, including in the field of bone

graft substitutes require new investigations on BAG use in trauma cases.

Abbreviations

BAG – Bioactive glass

IMNL – Intramedullary locking nail

ORIF – Open reduction and internal fixation

SSI – Surgical site infection

CT – Computer tomography

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Please cite this article as: Simeonov E. Calcaneal reconstruction with a large bony defect with the aid of bioactive glass – case study. *J of IMAB*. 2024 Jul-Sep;30(3):5673-5679. [[Crossref](#) - <https://doi.org/10.5272/jimab.2024303.5673>]

Received: 21/03/2024; Published online: 02/08/2024



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