Brazilian Dental Science

unesp
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CASE REPORT DOI: https://doi.org/10.4322/bds.2022.e3572

Posterior rehabilitation using 3D-printed dental implants and synthetic regenerative biomaterials

Reabilitação posterior com implantes impressos e biomateriais sintéticos

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ABSTRACT

Aim: To describe through a clinical case report the surgical sequence of rehabilitation with 3D-printed implants associated with maxillary sinus floor lift with synthetic regenerative materials, including biphasic bioceramic. **Case Report:** Patient had an agenesis of the upper left premolars (#12 and #13), a vertical bone deficiency caused by maxillary sinus' pneumatization, and a horizontal alveolar resorption around the missing teeth area. During the surgical procedures, incisions, detachment, and osteotomy were performed in the lateral region of the maxillary sinus. The sinus membrane was detached and lifted 10 mm. Then, a thick poly(dioxanone)-based synthetic resorbable membrane (Plenum) was inserted and adapted inside the sinus to protect the sinus membrane. After the osteotomies with sub-instrumentation, 3D-printed implants (Plenum) were installed in the #12 area (3.5mm x 11.5 mm; 30N) and #13 area (4.0mm x 10mm; 20N). The maxillary sinus was entirely filled with a biphasic bioceramic, HA/β-TCP (70:30) 500-1000 μm (Plenum) and covered by the same synthetic resorbable membrane. Connective tissue graft from the palatal area was positioned internally to the flap and stabilized with sutures to improve the vestibular tissue architecture. The entire surgical wound was sutured, and the tissues stabilized. No complications occurred in the postoperative period. **Conclusion:** The use of synthetic regenerative memberane and 3D-printed implants seems to be a promising option in areas of deficient bone remnants.

KEYWORDS

Dental Implants; 3D Printing; Maxillary Sinus; Sinus Floor Augmentations; Tissue Grafting.

RESUMO

Objetivo: Descrever por meio de um relato de caso clínico a sequência cirúrgica de reabilitação com implantes obtidos por impressão 3D associados à elevação do assoalho do seio maxilar com materiais regenerativos sintéticos, incluindo uma biocerâmica bifásica. **Relato de Caso:** Paciente apresentava agenesia dos pré-molares superiores esquerdos (24 e 25), deficiência óssea vertical causada pela pneumatização do seio maxilar e reabsorção alveolar horizontal ao redor da área dos dentes ausentes. Durante os procedimentos cirúrgicos foram realizados incisões, descolamento e osteotomia na região lateral do seio maxilar. A membrana sinusal foi descolada e elevada 10 mm. Em seguida, uma membrana reabsorvível sintética à base de poli(dioxanona) espessa (Plenum) foi inserida e adaptada dentro do seio para proteger a membrana do seio. Após as osteotomias com subinstrumentação, implantes impressos em 3D (Plenum) foram instalados na área do 24 (3,5mm x 11,5mm; 30N) e na área do 25 (4,0mm x 10mm; 20N). O seio maxilar foi inteiramente preenchido com biocerâmica bifásica, HA/β-TCP (70:30)

500-1000 μm (Plenum) e recoberto pela mesma membrana sintética reabsorvível. O tecido conjuntivo da região palatina foi posicionado internamente ao retalho e estabilizado com suturas para melhorar a arquitetura do tecido vestibular. Toda a ferida cirúrgica foi suturada e os tecidos estabilizados. Não ocorreram complicações no pós-operatório. **Conclusão:** A utilização de biomateriais regenerativos sintéticos e implantes impressos parece ser uma opção promissora em áreas de remanescentes ósseos deficientes.

PALAVRAS-CHAVE

Implantes Dentários; Impressao 3D; Seio Maxilar; Elevação do Seio Maxilar; Enxerto de Tecidos.

INTRODUCTION

Osseointegrated implants have proved to be a great alternative to replace missing teeth in the anterior or posterior regions of the maxilla. However, achieving success through these rehabilitations is still a challenge as it is necessary to meet esthetic requirements while maintaining masticatory function [1]. Teeth loss in the posterior region may leads an alveolar bone resorption associated with maxillary sinus' pneumatization. These conditions may present vertical bone defects that make rehabilitation with osseointegrated implants impossible or difficult [2]. To overcome these conditions, new implant geometries allow their stability in minimal bone remnants and the development of new surfaces favor osseointegration, minimizing the stability drop between primary and secondary stability [3,4].

Machining lathes are still the main way to obtain titanium implants. This method allows the construction of a solid structure, with different geometries and surface treatments, according to each company's proposal [5]. However, the noticible difference between the elastic modulus of the titanium alloy in solid implants (Ti–6Al–4V) (110 GPa) and the bone (1.3-13.5 GPa) increases the micromovement of the implant in the bone, which can compromise the osseintegration [6].

Recently, additive manufacturing or 3D-printing of titanium implants has stood out from the machining methods (subtractive), allowing greater control in some properties, such as, macrogeometry, wettability, and superficial microstructure [7]. 3D-printed implant microstructure has a structural porosity capable of mimicking the bone trabeculae, favoring cell adhesion and proliferation, that is, accelerate the process of bone neoformation on the implant surface [8]. The elastic modulus is proportional to the rigidity of the material, but the presence of porosities reduces this rigidity. Thus, these combined characteristics of 3D-printed implants allows them to have similar biomechanical behavior compared to the bone, while maintaining adequate mechanical strength [9].

In vertical bone defects in the posterior region of the maxilla, the elevation of the maxillary sinus floor is one way to allow vertical expansion with grafts [10]. The autogenous bone allows the ideal graft properties: osteoconduction, osteoinduction and osteogenesis properties. However, considering the high risk of morbidity in autogenous bone-grafting technique, a safe alternative to maxillary sinus elevation is the use of synthetic materials. Overall, synthethic materials do not present immunogenicity potential when compared to xenogenous or homogenous biomaterials [11]. Among them, the effectiveness of biphasic bioceramic stands out as they are composed of a high resorptitive material, the beta-tricalcium phosphate (β-TCP), and a material of low resorption, the hydroxyapatite (HA). While β-TCP is degraded, new bone is formed between the HA particles [12].

The use of resorbable membranes is extramaly important in order to guide bone regeneration. It allows the mechanical stability of the bone-graft and the osteoconduction and osteogenesis [13]. The poly(dioxanone) polymer is also as a promising material in tissue engineering since it can present a morphology that mimics the extracellular matrix. In addition to presenting other favorable properties in the bone guided regeneration such as adequate mechanical performance, biocompatibility, low inflammatory response and long-term resorption by hydrolysis [14,15]. The advantages of biomaterials that allow favorable and more accelerated biological responses are of extreme relevance to enable the rehabilitation of boundary areas of the jaws.

Therefore, the present case report describes the surgical sequence of an oral rehabilitation using 3D-printed implants associated with maxillary sinus floor elevation using synthetic regenerative materials, including biphasic bioceramic, HA/β-TCP (70:30) and semi-crystalline poly(dioxanone) polymer.

CASE REPORT

Patient W.J.L.V., male, 32 years old, presents agenesis of the upper left premolars, #12 and #13. The patient's history showed no significant medical history and a moderate oral hygiene practice. The radiographic exam showed maxillary sinus' pneumatization causing a vertical bone deficiency in the area (Figure 1). Upon clinical examination, horizontal alveolar resorption was also noticed (Figures 2 and 3). Therefore, it was planned to maxillary sinus elevation associated with 3D-printed implants instalation and synthetic regenerative membrane grafting.

First, a local anesthetic based on 4% articaine hydrochloride with 1:100,000 epinephrine (DFL, Cotia, SP, Brazil) was used to anesthetize the middle and posterior superior alveolar nerves. In addition, infiltrative anesthesia was also used for hemostasis. Then, a relaxing incision was made with a 15C scalpel blade in the mesial region of #12, preserving the distal papilla of #11, followed by an incision in the crest of the buccal ridge of the missing premolars. After the incision, the flap was detached in full thickness, allowing visual access to the bone remnant.

Then, a lateral window was made 3 mm apical to the crest of the ridge using a #8 spherical diamond bur in a micromotor handpiece under constant irrigation to access the maxillary sinus. The osteotomy was performed gently until the entire limit of the access window. After visualization of the sinus membrane, specific curettes were used to detach the membrane. The detachment started with angled curettes in the mesial, distal, apical and coronal directions until completely detached into the sinus. The floor of the maxillary sinus was elevated 10 mm in the vertical direction without being under pressure. Osteotomies with sub-instrumentation were performed to make the surgical alveoli in the #12 and #13 area. Bone quality was assessed in the osteotomies and were qualified as a D3, that is, a thick layer of cortical bone sorrounds a cancellous bone [16].

Figure 1 - Radiographic exam before treatment.

Figure 2 - Initial frontal clinical picture.

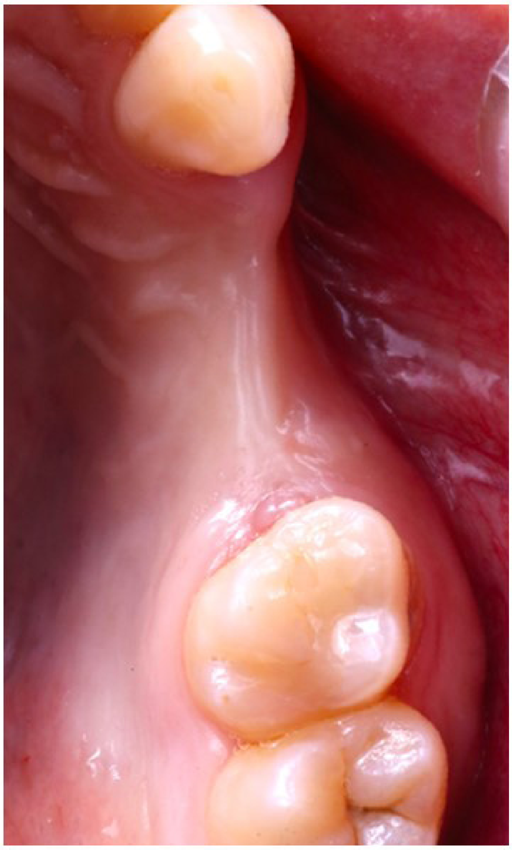

Figure 3 - Initial occlusal clinical picture.

Prior to implant installation, a 0.25 mm thick poly(dioxanone)-based synthetic resorbable membrane (Plenum, Jundiai, SP, Brazil) was inserted and adapted inside the sinus to protect the membrane from contact with the implants and to prevent the membrane from any possible perforation (Figure 4). Then, a 3.5 x 11.5 mm 3D-printed implant (Plenum, Jundiai, SP, Brazil) (Figure 5) was installed in the #12 area with a modification of the sinus lift summers protocol and a 30N torque. A 4.0 x 10 mm 3D-printed implant (Plenum, Jundiai, SP, Brazil) was installed in the #13 area with a 20N torque (Figure 6).

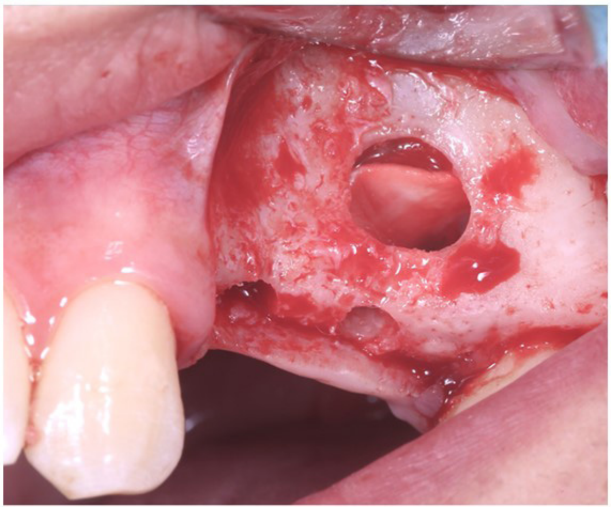

Figure 4 - Poly(dioxanone)-based resorbable membrane positioning inside the sinus.

Then, the left greater palatine nerve was anesthetized prior removing the subepithelial connective tissue. First, the area to be removed was delimited and then, the epithelial tissue was removed by dermabrasion using a #8 diamond spherical bur leaving the connective tissue graft (Figure 7). The tissue removal was not performed in full thickness to ensure the presence of remanescent tissue over the bone, minimizing the risk of bleeding and garanteeing comfort for the patient while healing.

Figure 5 - 3D-printed implant.

The maxillary sinus was filled with a biphasic bioceramic HA/β-TCP (70:30) 500-1000 μm (Plenum, Jundiai, SP, Brazil) (Figure 8). Then, the poly(dioxanone)-based resorbable membrane (Plenum, Jundiai, SP, Brazil) was adapted and positioned in the vestibular access (Figure 9). The connective tissue graft was positioned internally to the flap and stabilized with 5.0 polypropylene monofilament thread sutures (Techsuture®, Bauru, SP, Brazil). Finally, with this same thread, the soft tissues were sutured and stabilized (Figures 10 and 11).

After 8 months a second stage surgery was done to insert the polyetheretherketone (PEEK) healing abutments (Plenum, Jundiai, SP, Brazil). The radiographic exam showed the implant position and the biomaterial around the implant #13 (Figure 12).

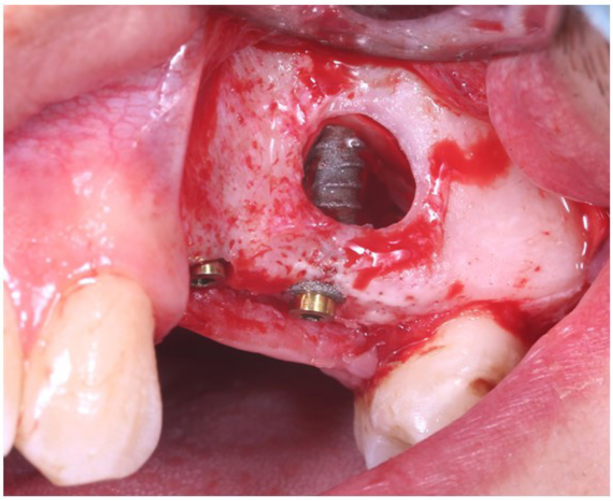

Figure 6 - Implant placement.

DISCUSSION

Among different treatment options to replace a congenitally missing tooth, the dental implant is the main approach of dentists with different specialties [17]. Previous studies have demonstrated mechanical advantages regarding the presence of porosities in the titanium implant

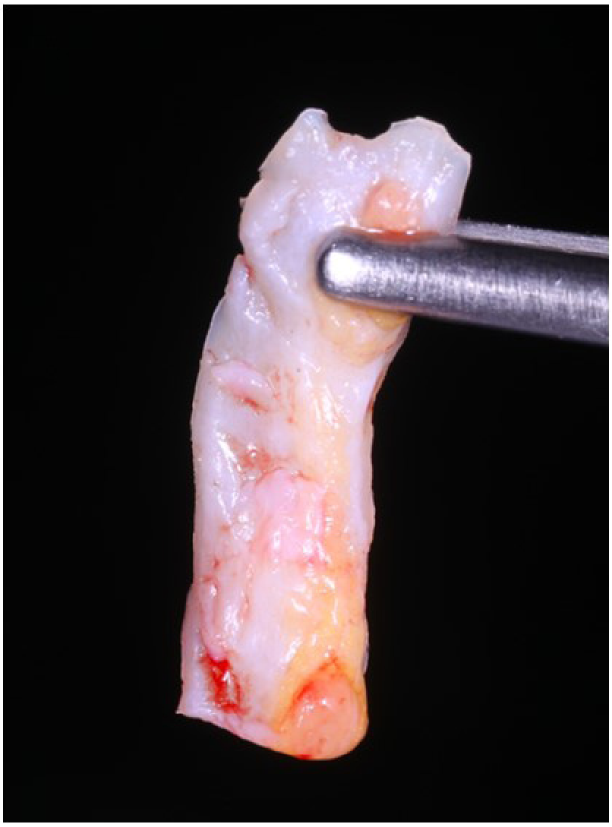

Figure 7 - Connective tissue graft removed from palate.

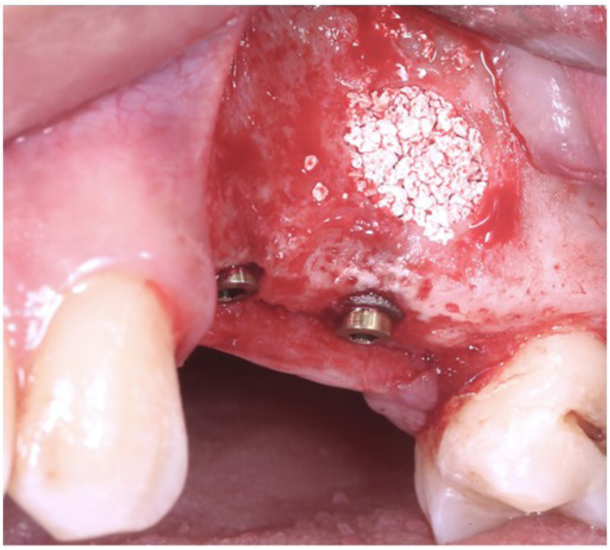

Figure 8 - Maxillary sinus filled with biphasic bioceramic HA/β-TCP (70:30) 500-1000 μm.

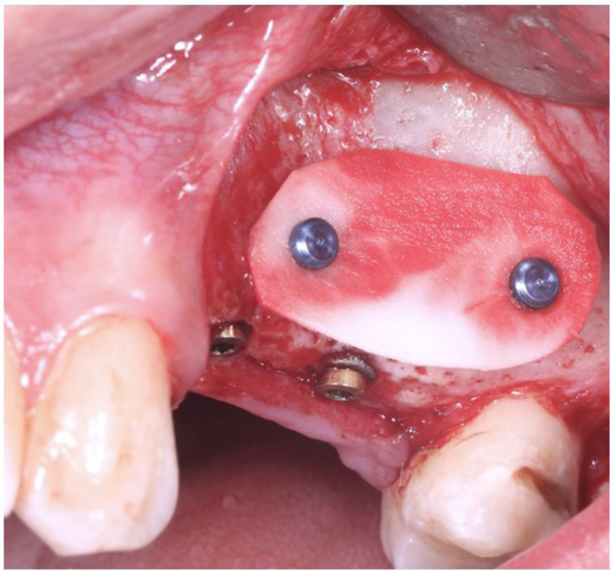

Figure 9 - Poly(dioxanone)-based resorble membrane positioning in the vestibular access.

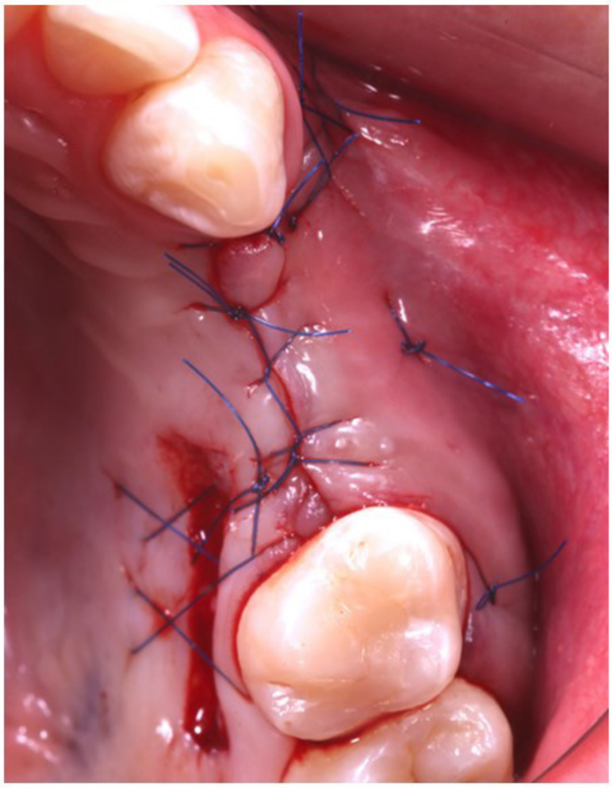

Figure 10 - Final occlusal clinical picture.

body structure, such as reducing the rigidity of the implant closer to bone tissue allowing similar biomechanical behavior, while maintaining adequate mechanical strength [18,19]. Moreover, a long-term clinical study reports numerous advantages for implants with porosities, since this characteristic stimulates and accelerates osseointegration [20].

However, the fabrication of titanium 3D-printed implants proved to be a challenge when compared to the conventional implants [21]. Titanium implants can be obtained by 3D-printing or additive manufacturing by a high-power laser that melts the titanium powder layer by layer. Therefore, allowing great precision in the fabrication of the implants with a macro geometry

Figure 11 - Final frontal clinical picture.

Figure 12 - Radiographic exam after implant and biomaterials placement.

that allows stability in the bone remnants with different densities [22,23]. In this sense, the present work used implants 3D-printed with a specfici macro geometry that allowed a stability in a remnant bone with approximately 3 mm.

This implant has surface characteristics that mimic the microstructure of the bone trabeculae and thus, on micro/nanotopographic scales, have high surface energy, improving wettability, favoring the diffusion and adhesion of fibrin and protein matrix [24]. These surface characteristics can also modulate cell behavior and stimulate their proliferation and differentiation [25]. Other implants also have a nanotextured surface, however, the manufacturing process and surface treatment make this texturing heterogeneous [26]. It seems logical to use implants with homogeneous topographies to accelerate the osseointegration process, especially in areas where bone neoformation is more sensitive, as in guided tissue regeneration.

Several materials are available for bone reconstruction, including autogenous, xenogenous, homogenous and synthetic grafts. Autogenous bone continues to have the best biological properties, however, disadvantages such as donor site morbidity and limited availability for larger grafts needs to be considered [27]. A study reports large resorptions of grafts used in the maxillary sinus floor elevation technique even when an autogenous bone is used [28]. However, it is of extreme importance to use an adequate particle size for techniques involving the maxillary sinus since any material with smaller particles than 400 μm will undergo greater resorption [29,30].

In this way, synthetic grafts have some advantages over other grafts as they do not present a risk of morbibity, microstructure reproducibility and their composition that allows chemical reaction by osteostimulation [31,32]. Biphasic bioceramic HA/β-TCP (70:30) stands out among the synthetic regeneratives. Considering that synthetic HA is more crystalline than the bone tissue and a resorption is usually observed, its use alone could compromise the regeneration process, leading to bone deformity [33]. On the other hand, β- TCP has a fast resorption and replacement by newly formed bone. Thus, when associated with HA induces osteoinduction and osteoconduction [34]. The present study used HA/β-TCP (70:30) with particles between 500-1000 μm, guaranteeing the maintenance of the bone height by the HA and the accelerate bone neoformation induced by β-TCP between the HA and the implant.

Particulate grafts and synthetic resorbable membranes have similar advantages, such as as reproducibility, however, they do not present a cross-contamination risk. Polydioxanone is a synthetic material capable of fulfilling the requirements of an ideal membrane, being non-immunogenic, mimicking the extracellular matrix, allowing cell adhesion, growth, migration, and differentiation, and for its ability to reabsorb in the long-term (approximately six months) [15,35]. Its resorption occurs trhough a slow hydrolytic degradation, and while is present it stimulates bone regeneration [36]. The malleability, stability, and mechanical strength of poly(dioxanone) membranes had been previously demonstrated [14]. The present study used the poly(dioxanone) synthetic membrane because it has a resorption time compatible with the time period necessary for bone neoformation and implant osseointegration.

PEEK is a high-density polymeric biomaterials that can replace metal in many restoration modalities. This material presents a good chemimcal stability and avoid biofilm colonization [37]. In this sense, at the second stage surgery, peek abutments were used to control the healthy healing of the peri-implant mucosa. At the time of removal of the cover screw and installation of the PEEK abutments, it was possible to observe the stability of the implants, a positive characteristic that achieves osseointegration and treatment success.

3D-printing grafts allow the elaboration of complex structures with greater control over their biomechanical properties, allowing them to mimick the biological structures that need to be replaced. However, more clinical cases need to be carried out in the long-term to confirm the biological and mechanical behavior of 3D-printed implants, their association with synthetic grafts and their correlation with different amounts of the bone remnant.

CONCLUSIONS

The use of synthetic regenerative memberane and 3D-printed implants seems to be a promising option in areas of deficient bone remnants. In the present clinical case, the maxillary sinus floor lift associated with the 3D-printed implants placement did not compromise the stability in a remnant of approximately 3 mm. In addition, the association of these two techniques significantly reduced the treatment time.

Author's Contributions

GRSL, JDMM: Conceptualization, Methodology, Software, Validation, Formal Analysis, Investigation, Resources, Data Curation, Writing – Original Draft Preparation, Writing – Review & Editing, Visualization, Supervision, Project Administration and Funding Acquisition. **DO:** Writing – Original Draft Preparation, Writing – Review & Editing, Visualization, Supervision. **PHCOP:** Conceptualization, Methodology, Software, Validation, Formal Analysis, Investigation, Resources, Data Curation. **MGR, MACS:** Writing – Original Draft Preparation, Writing – Review & Editing, Visualization. **MAB:** Supervision, Project Administration and Funding Acquisition. **NCR:** Conceptualization, Methodology, Software, Validation, Formal Analysis, Investigation, Resources, Data Curation, Writing – Original Draft Preparation, Writing – Review & Editing, Visualization, Supervision, Project Administration.

Conflict of Interest

No conflicts of interest declared concerning the publication of this article.

Funding

This work was supported by the São Paulo Research Foundation (FAPESP – grant numbers 2019/24903-6 and 2021/11499-2). The authors would like to acknowledge the Plenum Bioengineering company for providing the materials used in this case.

Data Availability

Not applicable.

Regulatory Statement

Signed informed consent form has been taken from the patient for the disclosure of the case.

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Date submitted: 2022 Jul 13
Accepted submission: 2022 Sep 26