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Frontal sinus augmentation: Preliminary results of a new approach in prosthetic orbital reconstruction

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ABSTRACT

Purpose: Reliable application of endosseous implants for prosthetic facial reconstruction depends on the bone volume available at the defect site. Regarding the orbit, sufficient bone presentation in the medial superior orbital rim is limited due to the frontal sinus. The aim of this article is to report for the first time on the augmentation of the frontal sinus for gaining bone volume for supraorbital implant placement.
Materials and methods: Between 2007 and 2014, five patients with orbital exenteration were treated by frontal sinus augmentation using autogenous cancellous bone graft from the ilium. Extraoral implants for prosthetic orbit reconstruction were placed 4–7 months later. In advance, cadaver surgery was performed to prove the feasibility of the method. Surgical technique is described, and intraoperative images are provided.
Results: The frontal sinus was successfully augmented in all five patients. No major complications related to the procedure were observed. A total of nine orbital implants were inserted in the augmented bone, thereof one sleeping implant. Six implants were restored prosthetically, two implants were lost at exposure. The observation period ranged from 6 to 97 months (mean: 52.8 months). Mean time for patient rehabilitation was 13 months. High patient satisfaction was achieved with the implant-retained orbital prosthesis.
Conclusion: The augmentation of the frontal sinus allows implant placement by providing sufficient bone volume in the medial supraorbital rim. Considering the surgical success of this method and patient satisfaction, this new approach is concluded to be a viable option in a unique subset of patients.
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1. Introduction

Facial deformities due to inborn or acquired facial defects often lead to functional impairment and psychological strain in affected patients (Bronheim et al., 1991). Especially defects after orbital exenteration are among the most emotionally distressing deformations (Bonanno et al., 2010). Covering these defects with craniofacial prostheses fixed by osseointegrated implants represents an approved technique applied for many years (Branemark et al., 1982; Parel et al., 1991). However, reconstruction of the orbit with osteointegrated implants must overcome a number of anatomic challenges. Ideally, three to four implants are placed radially in the orbital rim to ensure axial loading and to provide adequate prosthetic stability (Sinn et al., 2011). Concomitantly, implants should be primarily inserted into the supraorbital rim, due to high implant failures in the infraorbital rim (Toso et al., 2017). For an optimal position of the implants, sufficient bone volume is required, and the lateral rim is often recommended as preferred implantation site (Sinn et al., 2011). However, depending on the extent of resection or trauma, the remaining span of the lateral orbital rim is often limited (Goh and Teoh, 2015). Regarding the supraorbital rim, the medial part is problematic in most cases. Due to pneumatization of the frontal sinus, correct positioning with axial loading of the implants is restricted. This is biomechanically unfavourable (Sinn et al., 2011). Bone heights of 1 mm–13 mm are determined for the medial superior orbital rim, with the low values at the points closest to the frontal sinus. However, a minimal bone

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height of 3–4 mm is necessary for implantation, as available implants are 3–5 mm long (Klein et al., 1997). This difficulty can be overcome by the addition of bone in the frontal sinus floor to increase the dimension of available bone for implant placement. This approach for retaining orbital prostheses is based on the sinus augmentation of the maxilla, first described by Tatum in 1976 (Tatum et al., 1993). Since then, this method has become a common surgical technique in dentistry and presents a safe and predictable procedure to create available bone for implants (Jensen et al., 1998; Del Fabbro et al., 2004).

Owing to this technical possibility, the vertical bone height deficiency in the frontal sinus can be solved. The aim of this study was to introduce the augmentation of the frontal sinus for providing sufficient bone for supraorbital implant placement for the first time and to report our experience with this new procedure in the management of prosthetic orbital rehabilitation.

2. Materials and methods

Between 2007 and 2014, a total of 5 patients with a history of orbital exenteration were consecutively enrolled in this study. All 5 patients underwent augmentation of the frontal sinus and implant placement at the Department of Oral and Maxillofacial Surgery, Charité University Hospital, and at the Department of Oral and Maxillofacial Surgery, Trauma Hospital Berlin. Anaplastology team was the same in both departments, and treatment planning and surgery were performed in accordance with the team. The criteria for frontal sinus augmentation were as follows. First, at least one more additional implant was required for anchorage of prosthesis. Second, the medial supraorbital rim provided adequate prosthetic stability and no alternative or more appropriate implant placement location existed. Third, the residual bone height of the medial supraorbital rim was less than 3 mm due to sinus pneumatization. Prior to surgical treatment, a clinical examination of the patients and cone-beam computed tomography (CBCT) was performed. The frontal sinus was evaluated for disorders and patients with active sinus infection, recurrent fungal or chronic sinusitis, mucosal abnormalities, or neoplasms were excluded from the operation. The nasofrontal duct was confirmed to be intact. Informed consent was provided by all patients. The treatment protocol was the same for nonirradiated and irradiated patients.

Criteria for successful surgery were determined by the absence of major complications peri- and postoperatively, augmented bone volume being visible in postoperative CBCT scans, and subsequent implant placement into the planned positions. Implant failure was defined as implant removal or the implant being present with mobility or pain. Implants that did not fail and completed prosthetic treatment were counted as successful implants. Adequate prosthetic rehabilitation was defined by a stable and consistent prosthetic attachment with axial loading of implants.

In advance, for proving the feasibility of the method, laboratory cadaveric investigation was conducted at the Anatomical Institute, Charité-Universitätsmedizin Berlin. On a cadaveric glutaraldehyde-fixed human head, elevation of the frontal sinus floor was performed. Graft material was introduced into the space created inferior to the sinus membrane. No perforation of the membrane occurred. The sinus outflow tract was not affected by the procedure (Fig. 1).

The study was approved by the Ethics Committee of the Charité University of Medicine (Berlin, Germany) (EA2/023/14).

2.1. Treatment protocol

The augmentation of the frontal sinus was conducted under general anesthesia. All patients received prophylactic systemic antibiosis and steroids preoperatively. The patients were positioned supine with the neck slightly extended and elevated. After sterile preparation and draping, an incision line about 2 cm in length was designed in the medial supraorbital area, just above the supraorbital rim (Fig. 2). The same surgical approach could be used for the later implant placement and had the advantage of being covered by the orbital prosthesis subsequently. Local anesthesia with epinephrine was infiltrated subcutaneously to allow better control of hemostasis. Skin incision was performed and the superior orbital rim and anterior table of the frontal sinus were exposed, followed by incision and elevation of the periosteum. Care was taken to avoid damage to the supraorbital neurovascular bundle. According to the maxillary sinus lift, an oval window in the anterior table of the frontal sinus was determined with the inferior border 2–5 mm superior to the sinus floor (Mohan et al., 2015). Using a diamond bur, the bone window was prepared (Fig. 3). The sinus membrane was gently detached and reflected from the sinus floor with conventional sinus lift instruments. The bone window was elevated superiorly along with the sinus membrane to provide sufficient space for the bone graft (Fig. 4). When a perforation of the sinus membrane was observed, a collagen tape (Bio-Gide, Geistlich Pharma AG, Switzerland) was placed. Simultaneously, autogenous cancellous bone was harvested from the iliac crest and mixed with the patient's blood. The graft material was then filled into the space created by the previous procedure and gently firmed (Fig. 5). Periosteum was repositioned and sutured, serving as a barrier membrane, followed by tension-free closure of the skin flap. Osseous consolidation was allowed for at least 4 months. Monitoring of the augmented bone volume was performed with CBCT, and the length and position of the implants were planned.

As same as in previous studies, implants (EO System, Straumann, Switzerland) were placed according to a two-stage

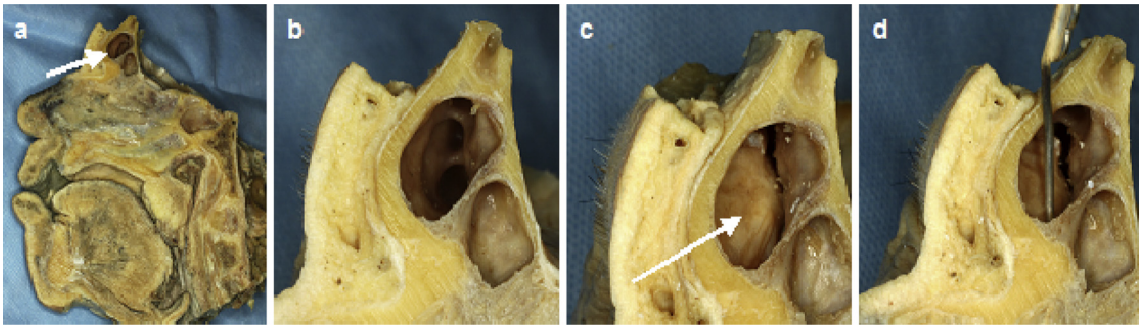

Fig. 1. (a) Sagittal overview of a cadaveric head, → identifying the frontal sinus. (b) Frontal sinus with septa preoperatively. (c) → Elevated sinus membrane filled with graft material. (d) Patent sinus outflow tract proved by a dental probe.

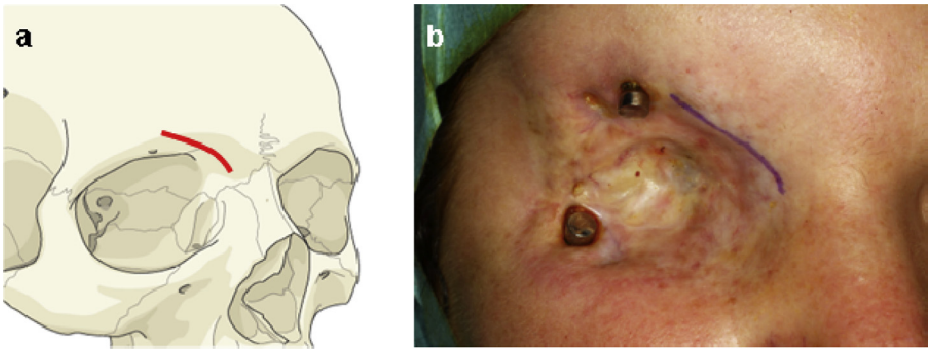

Fig. 2. (a, b) Incision line designed above the medial supraorbital rim.

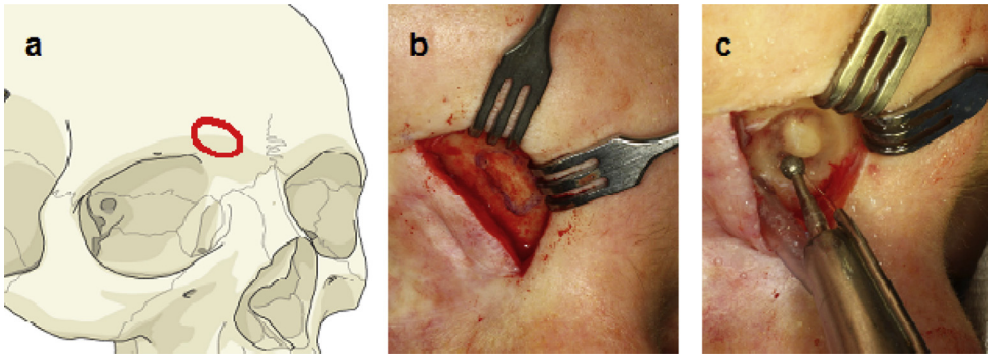

Fig. 3. (a, b) The anterior table of the frontal sinus was exposed, an oval window was determined and (c) prepared with a diamond bur.

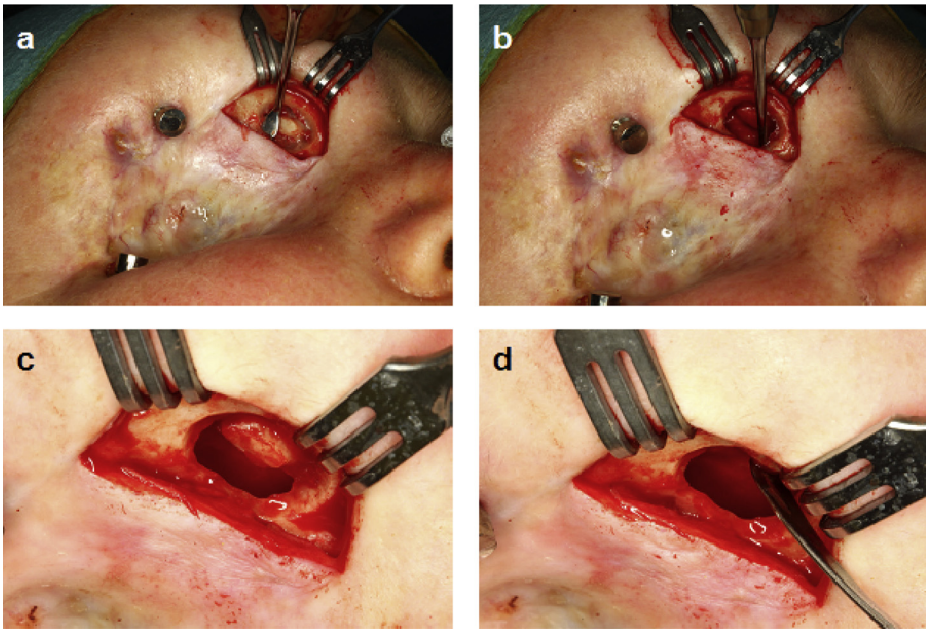

Fig. 4. (a, b) The sinus membrane was gently detached and reflected from the sinus floor. (c, d) The bone window was elevated superiorly along with the sinus membrane.

procedure under general anaesthesia (Albrektsson et al., 1987; Toso et al., 2017) (Fig. 6). Implant healing time was at least 6 months. Before loading of an orbital prosthesis, implants were exposed in local anaesthesia. The procedure of implant exposure and handling of peri-implant tissue was performed using a standard protocol as previously described (Klein and Menneking, 1999). The implants were provided with magnetic abutments (Steco-System-Technik, Hamburg, Germany). After a healing time of 2–4 weeks, the orbital prostheses were fabricated by the Anaplastology team using conventional laboratory procedures.

2.2. Postoperative management

After frontal sinus augmentation and implant placement, all patients were advised to place a cold compress on the surgical site for the first 24 h and to avoid physical stress as well as positive or

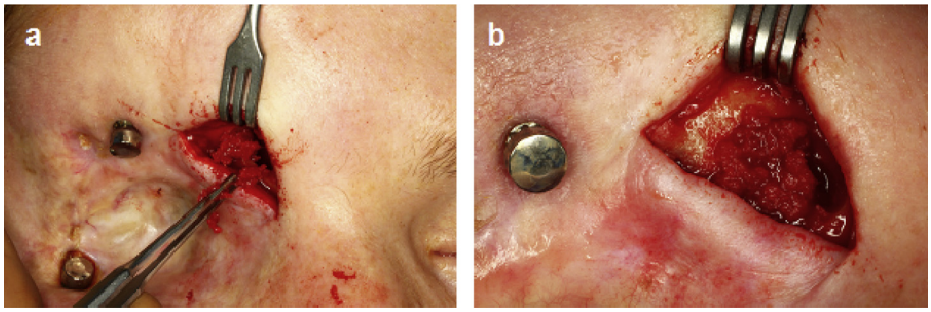

Fig. 5. (a) Graft material was used to fill in the space inferior to the elevated bone window and gently firmed. (b) Graft material in place.

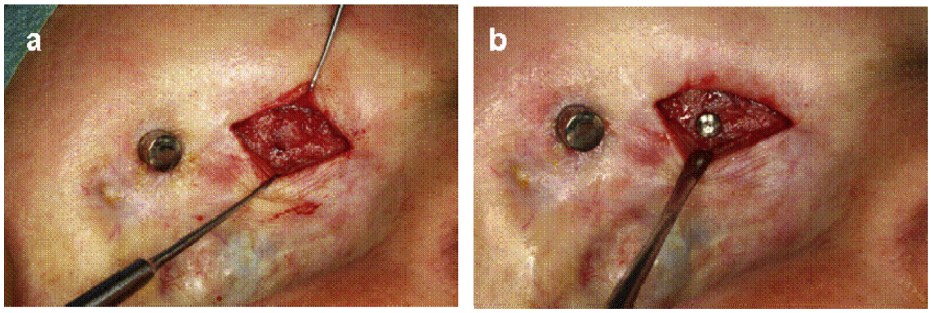

Fig. 6. Implant placement after sinus augmentation. (a) Osseous consolidation was confirmed and (b) implant was installed into the augmented bone.

negative pressure for 4 weeks. Postoperative oral antibiotic therapy and nasal steroid spray were prescribed, both for a 7-day course. Postoperative CBCT scans were performed to assess the augmented bone volume and implant position. Patients were discharged 3–4 days after frontal sinus augmentation and 1–2 days after implant placement.

Routine clinical follow-up was scheduled for both surgical procedures at 1, 2 and 4 weeks postoperatively and then every 2 months until implant placement or implant exposure. After prosthetic restoration, the patients were routinely seen for clinical examination at 4 weeks and every 3 months thereafter within the first year. Beginning with the second year, the evaluation was performed annually. A standard follow-up protocol was used and prosthetic (implant stability, retention lose), technical (fractures) and biological (periimplant situation) complications were monitored.

3. Results

Five patients (two women and three men) ranging in age from 46 to 60 years (mean 55.5 years) participated in the study. Four patients had a history of extended orbital exenteration with postresection radiotherapy up to a dose of 68 Gy due to tumor. In one patient, extended orbital exenteration had been performed due to trauma. All patients required augmentation of the frontal sinus because of insufficient residual orbital bone before implant placement. In four patients, the lateral orbit and inferior orbital rim were partly resected. In one patient, implants in the lateral and inferior orbital rim had failed due to continuous infection.

Surgery for frontal sinus augmentation was performed successfully in all five patients. There were no major complications intraoperatively. Tearing of the sinus membrane occurred in two patients but could be covered with a collagen tape. Postoperatively, minor complications such as swelling and hematoma occurred, but no infection, sinusitis or paresthesia was noted. Wound healing was uneventful in the harvesting and recipient site. Postoperative CBCT scans indicated that sufficient bone volume for implant placement was gained in every patient. A total of nine implants were inserted in the planned positions, comprising one implant in one patient and two implants in four patients (Fig. 7). One implant served as sleeping implant for future use in case of implant loss and was not involved in the statistical analysis. Thus, 8 implants were considered for the study. The observation period of the implants ranged from 6 to 97 months (mean: 52.8 months), four implants had a follow-up period over 4 years, and two implants were followed up over 7 years. A total of 5 implants were successful (62.5%). Three implants (37.5%) were lost, one implant after 8 years of prosthetic loading. Two implants were loosened at exposure, so that 66% of the implant failures were early failures without functional loading. Two implants were placed in nonirradiated sites, and six implants in irradiated sites. All three implants lost were placed in irradiated patients (failure rate of 50%). Three implants in irradiated sites were successful (50%). In nonirradiated sites, all implants were successful. According to the augmented bone volume, implants of different lengths were used: three implants were of 3.5 mm length, of which two failed (one implant was loosened at exposure, and the second failed after 8 years of prosthetic function). Five implants were 5 mm in length, of which four implants were successful and one implant failed.

All patients were adequately rehabilitated with orbital prostheses fixed on endosseous implants, of which at least one implant in each patient was installed in the augmented frontal sinus (Figs. 8 and 9). Time for patient rehabilitation ranged from 10.6 to 15.3 months (mean: 13 months), beginning with the surgery for frontal sinus augmentation, and finishing with insertion of the orbital prostheses (Table 1). All patients reported being pleased with the aesthetic result and considered the treatment to be appropriate for obtaining an optimal stability of the prosthesis. Thus a high degree of patient satisfaction was achieved with the implant-retained orbital prostheses.

Regarding the follow-up, two of the five patients died in 2017 and 2018, and all other implants are still in place. A mean

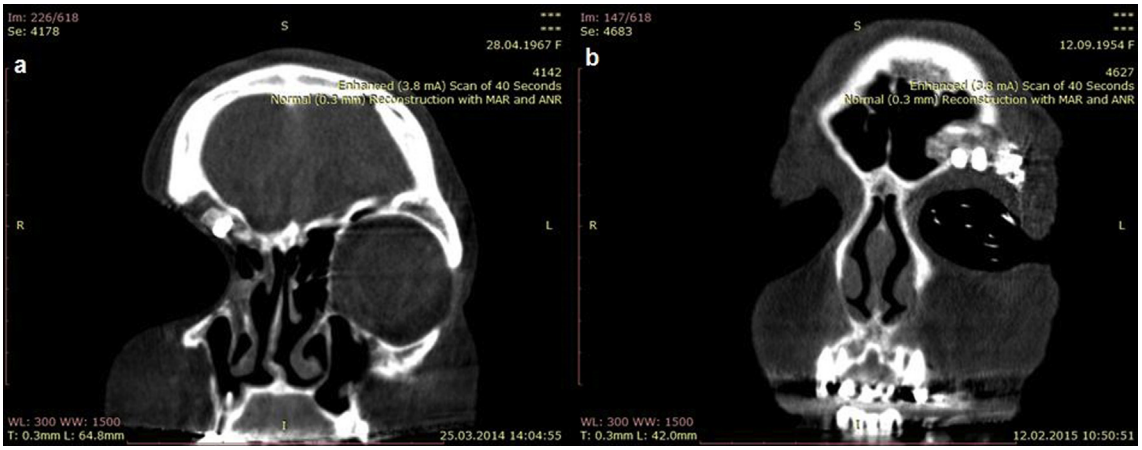

Fig. 7. Coronal cone beam computed tomography scans of the augmented frontal sinus in two cases. (a) One implant was placed into the right frontal sinus, and (b) two implants were placed into the left frontal sinus (note the titanium mesh reconstructing the lateral orbit).

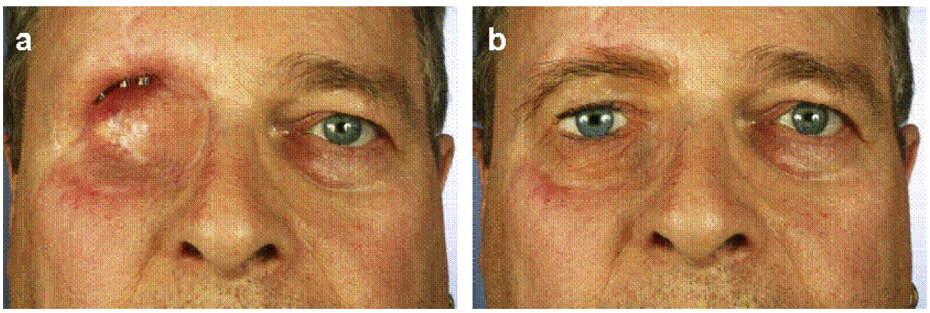

Fig. 8. (a) Patient with three endosseous implants, of which the medial supraorbital implant is installed in the augmented frontal sinus. (b) Orbital prosthesis in situ.

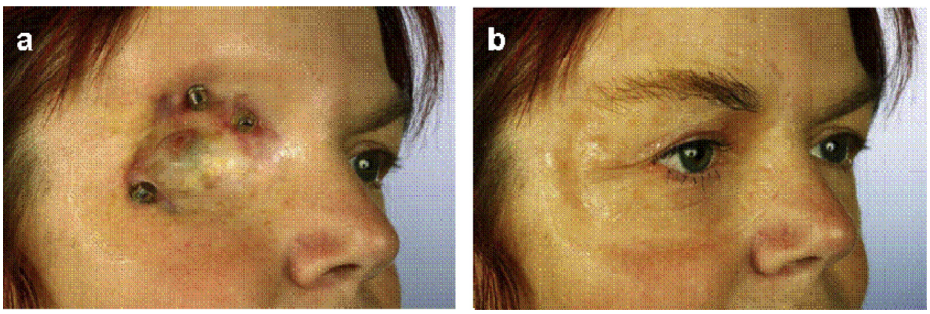

Fig. 9. (a) Patient with three endosseous implants, of which the medial supraorbital implant is installed in the augmented frontal sinus. (b) Orbital prosthesis in situ.

Table 1
Summary of patient and implant data.

Patient	1	2	3	4	5
Gender	Male	Male	Male	Female	Female
Age (yr)	58	55	57	46	60
Diagnosis	Trauma	Tumor	Tumor	Tumor	Tumor
Radiation status	nonirradiated	irradiated	irradiated	irradiated	irradiated
Implant number	2	2	2	1	2
Thereof sleeping implant	0	0	1	0	0
Implant length (mm)	5 (x2)	3,5 (x2)	3,5 (x2)	5	5 (x2)
Failed implants	0	2	0	0	1
Time to implant failure after placement (mo)		7 and 97			6
Follow-up of implants after placement (mo)	66	7 and 97	90	54	6 and 36
Time to patient rehabilitation with orbital prosthesis (mo)	13	13	15	13	11

observation period of 70.3 months (range 46–102 months) was documented.

4. Discussion

The aim of this study was to present the augmentation of the frontal sinus for use in prosthetic orbital rehabilitation. To the best of the authors' knowledge, this method was conducted for the first time in the frontal sinus. After a preceding laboratory cadaveric investigation, it was demonstrated to be successful in living patients. Frontal sinus augmentation enables implant placement for an appropriate orbital rehabilitation. It provides an alternative implant placement location to the inferior and lateral orbital rim. With the location in the medial orbital rim, optimal stabilization of the orbital prosthesis can be achieved (Sinn et al., 2011). Furthermore, in the long term, supraorbital implants seem to be more successful then infraorbital implants, maybe due to less skin mobility and decreased soft tissue reaction (Toso et al., 2017).

The technique of sinus augmentation, based on the maxillary sinus lift introduced by Tatum in 1976, is well established (Tatum et al., 1993; Jensen et al., 1996; Del Fabbro et al., 2004). However, surgical intervention of the intact frontal sinus is a delicate issue. Potential major complications include intracranial and orbital injuries, obliteration of the frontal sinus outflow tract, and frontal sinus infection (Folbe et al., 2016). Sinus infection can result in severe local sequelae, such as orbital abscesses, mucopyocele, and osteomyelitis, which can secondarily progress into potentially life-threatening conditions (Kelly et al., 2005; Gagliardi et al., 2017). In the present study, only minor complications appeared: intraoperatively, tearing of the sinus membrane took place but could be solved easily by placing a collagen tape. Postoperatively, swelling and hematoma did not compromise wound healing. Certainly, any direct frontal sinus intervention has to be conducted extremely cautiously and with the utmost precision. The augmentation of the frontal sinus should be subject to very restricted indications. We have defined three criteria to be complied with in patients needing orbital implants for prosthetic rehabilitation: First, at least one more additional implant is required for anchorage of prosthesis. Second, the medial supraorbital rim provides adequate prosthetic stability, and no alternative or more appropriate implant placement location exists. Third, the residual bone height of the medial supraorbital rim is less than 3 mm. Considering these restrictions, a small and unique subset of patients remains. In this study, only five patients qualified for frontal sinus augmentation from 2007 to 2014. In all five patients, augmentation of the frontal sinus was successful and eight implants for prosthetic retention were inserted. Three of eight implants failed (37.5%). This failure rate seems to be quite high, but has also been observed in other studies investigating orbital implants (Nishimura et al., 1998; Roumanas et al., 2002; Toljanic et al., 2005; Karakoca et al., 2010). Furthermore, it should be considered that one implant failed after 8 years of prosthetic loading. Two implants were loosened at exposure. A high rate of early failures for orbital implants was reported before and might primarily be associated with nonosseointegration (Toso et al., 2017). All three implants lost were placed in irradiated patients. This is in line with other studies, describing increased failure rates for orbital implants in irradiated bone (Wolfaardt et al., 1993; Sinn et al., 2011; Karakoca et al., 2010; Guedes et al., 2015). Two implants 3.5 mm in length failed, and one implant 5 mm in length failed. This tendency towards a more successful implant survival for 5-mm implants is also in accordance with previous studies of orbital implants (Toso et al., 2017). Even though the present study is limited by a small case number, results show that implants installed into the augmented sinus act as conventional orbital implants. This indicates that frontal sinus augmentation for implant placement represents a viable technique.

In total, the mean observation period of implants was more than 70 months. The following success criteria were formulated based on the criteria of Buser et al. (1990) for intraoral implants: absence of persistent subjective complaints, such as pain, foreign body sensation, and/or dysesthesia; absence of recurrent peri-implant infection with suppuration, of mobility, of continuous radiolucency around the implant; and the possibility for restoration. It would make sense to consider the condition of the peri-implant tissue in extraoral implants to determine success criteria.

Studies have shown that this has a crucial influence on extraoral implants (Klein and Menneking, 1999; Karakoca Nemli et al., 2010).

Due to the missing connection of strong epithelial attachment with anchored collagen bundles such as between the teeth and the gingiva, the risk of inflammation is higher in percutaneous extraoral implants. Studies revealed that the thickness of the tissue and the mobility of the tissue can influence the degree of inflammation, but long-term studies are still missing.

To determine the exact parameters, further studies are needed and would be useful.

Of course, frontal sinus augmentation includes drawbacks that have to be considered and discussed with the patient. Additional surgery in general anesthesia is required, accompanied by its related complications, already described above. Donor site morbidity presents a further limitation, as autogenous bone is considered the gold standard for sinus grafting. The iliac crest allows for harvesting cancellous bone and is well-known in sinus floor elevation of the maxilla (Tatum et al., 1993; Lorenzetti et al., 1998; Thiéry et al., 2013). An additional issue may require a prolonged time period until final patient rehabilitation. In this study, a mean time of 13 months was required from frontal sinus augmentation until insertion of the prostheses. For conventional orbital implants (in the nonirradiated patient), usually a time frame of about 3–5 months until prosthetic rehabilitation is sufficient (Sinn et al., 2011). To bridge this period, patients are in further need of either surgical dressings or glue-fixed prostheses. Currently, a tendency toward a reduced implant healing time even in compromised patients is emerging. Recent studies indicate that for dental implants in irradiated sites, a healing time of 3 months is sufficient (Doll et al., 2015; Ernst et al., 2016). This may in turn lead to considering shortened healing times for extraoral implants, thereby reducing the time period from sinus augmentation to final patient rehabilitation. Furthermore, implants could be placed immediately, i.e., simultaneously with the augmentation of the frontal sinus, provided that primary stability of the implants is achieved. In applying xenogenic graft material for sinus augmentation (although it is predominantly used in nonirradiated patients), the time for osseous consolidation could be reduced, thereby additionally avoiding donor site morbidity (Heberer et al., 2008).

As an alternative to frontal sinus augmentation, autologous onlay grafts and vascularized bone grafts should be considered for gaining bone volume in cases of insufficient residual orbital bone. However, the application of onlay grafts may be limited, as they decrease the vertical height of the orbit, thus interfering with the ideal sculpture of the prosthesis. To the best of the authors' knowledge, onlay grafts were not reported before in prosthetic orbit reconstruction. In large defects, major reconstructive surgery with vascularized bone grafts may represent an appropriate alternative for patient rehabilitation (Costa et al., 2015). However, in limited bone defects requiring only one or two additional implants, augmentation of the frontal sinus might be considered a valuable option for attaining a stable anchorage of the orbital prosthesis.

5. Conclusion

Orbital defects following extended exenteration present a challenging situation for implant installation. The present study shows successful augmentation of the frontal sinus for allowing implant placement in the medial supraorbital rim. By achieving adequate support for the orbital prosthesis and high patient satisfaction, this new approach is concluded to be a viable option in prosthetic orbital reconstruction. Although the number of patients is small, these preliminary results are promising and should be confirmed in further studies with larger cohorts.

Conflicts of interest

All authors disclose any financial interest and personal relationship to organisations and companies that are mentioned in the article.

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