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Modified Le Fort I interpositional grafting of the severe atrophied maxilla—a retrospective study of 106 patients over 10 years

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Abstract

Objectives: The objective of this study was to evaluate a modified Le Fort I interpositional grafting followed by dental implants for the rehabilitation of edentulous atrophied maxillae (Cawood classes IV and V). The surgical modification was a bilateral sinus floor augmentation prior to the osteotomy. This generated a closed recipient bed which allowed the use of particulated bone grafts (xenogenic bone mineral) and a reduced amount of autologous iliac bone grafts.

Materials and Methods: A total of 106 patients with maxillary interpositional bone grafts were included in this retrospective analysis between 2006 and 2020. The panoramic radiographs and lateral cephalograms were analyzed to assess the gain and stability of the maxillary bone and the peri-implant bone loss. In addition, the observational period of up to 14 years implant survival and success was evaluated.

Results: A stable vertical bone height with mean 0.63 ± 1.41 mm resorption over 5 years after implant loading was observed. A mean of 0.20 ± 0.37 mm marginal bone loss was noted after 5 years. The implant survival was 96.4% after 5 years and implant success can be rated 91.7% in a mean follow-up period of 93 months and 168 months maximal observation time. Perioperative complications included sinus membrane perforation (59.43%), wound healing disturbances (25.47%), and transient primary complications (13.78%). All receded apart from two subtotal graft losses (1.8%).

Conclusions: The modified Le Fort I osteotomy with interpositional bone grafts is a predictable procedure in terms of bone and implant stability. Patients with atrophic maxillae who are fit for surgery should be informed about risks and benefits of this treatment alternative.

KEYWORDS
atrophied maxilla, Le Fort I interpositional grafting

1 | INTRODUCTION

Resorption of the alveolar bone is inevitable after tooth loss (Araújo and Lindhe, 2005). This alveolar atrophy has severe consequences, not only for the retention of dentures, but also for the chewing ability and facial esthetics. Despite a difficult baseline situation, the interest in fixed dental restorations has risen in the last decades.

As the long-term stability and success of a treatment with dental implants depends on sufficient bone availability and quality, it is often required to augment bone in the above-mentioned cases. There are numerous augmentation free approaches to provide fixed osseointegrated implant-supported dentures, even for the atrophied maxilla. These include short, narrow, and tilted implants, pterygoid implants, zygomatic implants as well as printed subperiostal implants (Araujo et al., 2019; Jehn et al., 2020; Lin and Eckert, 2018).

However, all these concepts have specific drawbacks. Conventional straight implants of regular length are still an accepted option. Localized bone augmentation is often required to enable 4 – 8 implants of regular length and diameter in the maxilla. These localized methods include sinus floor elevation, bone splitting, and lateral bone augmentation by GBR. Using these methods, vertical deficits have to be compensated with the dentures. That means that the teeth emerge from the artificial gingiva and the gingival transitional line has to be masked by the upper lip above the smiling line. Secondly, due to the oblique shape of the anterior crest of the maxilla, an atrophy results in sagittal discrepancy. This requires the dentures to compensate the retroposition by strong and heavy material and the tongue and speech volume is normally reduced due to this structure. If the aim is a natural looking restoration with crown and bridgework, the artificial teeth should emerge from natural and healthy gingiva. For that purpose, a vertical bone augmentation has to create a natural basis. The methods for vertical bone augmentation include onlay grafting, distraction osteogenesis, and interpositional grafting techniques. The established method to correct intermaxillary vertical and horizontal discrepancies at the same time is Le Fort I interpositional grafting (Chiapasco et al., 2007).

Classical Le Fort I osteotomy has long been a standard surgical procedure to reposition the maxilla and was first used by Wassmund in 1921 (Buchanan and Hyman, 2013). With the down-fracture technique further developed by Bell and Epker, the maxilla was fully mobilized not only horizontally, but also vertically (Bell et al., 1977). The classical Le Fort I interpositional grafting did not involve the dissection of the Schneiderian membrane. As a consequence, bone grafts lay open to the sinus cavity, and this often-demanded cancellous autologous bone grafts from the iliac crest for healing. Secondly, in the time before dental implants, these grafted maxillae tended to resorb. This problem was addressed by Keller and coworkers, who combined Le Fort I interpositional bone grafting with dental implant placement and occlusal loading (Keller et al., 1987; Sailer, 1989). This medical procedure is a well-documented method with over 1000 documented cases in the literature (Chiapasco et al., 2007; Nyström et al., 2009; Pieri et al., 2012) and a recent meta-analysis demonstrating a success-rate over 90% (Poli et al., 2019).

The modification presented here, involves the dissection of the Schneiderian membrane, similar to a bilateral sinus lift elevation at the beginning of the surgery. The nasal mucosa is dissected as well. This alteration results in a graft recipient bed which is secluded to the nasal and sinus cavities and now can be treated with particulated bone substitute materials. These materials reduce the need for iliac bone block grafts and therefore minimize patient morbidity.

The objective of this retrospective study is to analyze the long-term stability of the augmented bone and dental implants after a modified Le Fort I interpositional grafting with bone substitute materials. In addition, prosthetic success was evaluated.

2 | MATERIAL AND METHODS

The study protocol was conducted with the ethical approval of the University Medical Center Schleswig-Holstein (File no.: D 419/19) and registered in the German Clinical Trials Register (DRKS-ID: DRKS00026086).

2.1 | Patient selection

A total of 104 patients enrolled by the Department of Oral and Maxillofacial Surgery, Helios Hospital Kassel were included in this article. Two Patients were contributed by the Department of Oral and Maxillofacial Surgery, University Medical Center Schleswig-Holstein. These patients had all been referred for surgical treatment to the hospitals.

Inclusion criteria for the study was a completed modified Le Fort I osteotomy with interpositional bone grafts followed by dental implants from years 2006 to 2020. Consecutively, all available patients were included and operated by the same surgeon (H.T.). The common baseline status was an advanced, severe atrophic edentulous or nearly edentulous maxilla, described in the literature as Cawood class IV and V (Cawood and Howell, 1988). Clinical records as well as combined sets of panoramic radiographs and lateral cephalograms, at least pre- and post-augmentation surgery and post-implant placement, if conducted, had to be available.

Exclusion criteria were pregnancy, poor general health conditions (patients undergoing chemotherapy or radiotherapy for head and neck malignancies, severely immunocompromized patients, and diabetic patients with poor glycemic control) and patients with antiresorptive medications. In case of reported sinus pathologies, three-dimensional pictures were obtained and the pateints were treated beforehand.

Consecutively, all available 106 patients were included in the given time interval. No patient was excluded from the analysis.

2.2 | Surgical procedure

The modified Le Fort I osteotomy with interpositional bone grafts starts off with an incision in the middle of the edentulous maxillary alveolar ridge, reaching from the region of the second molar to second molar in the upper jaw with bilateral releasing incisions lateral from the tuberosity. A full-thickness mucoperiosteal flap was elevated up to the infraorbital nerves, which were protected during the further course of the surgery. The nasal aperture was dissected, and the mucosal lining of the nasal floors was elevated. After osteotomy with a diamond bur, the Schneiderian membrane at both sinus floors was carefully elevated. For down-fracture, the maxilla was detached at the pterygomaxillary junction by means of a chisel, as well as the nasal septum and the lateral nasal walls. The arterial supply of the maxilla remained intact by preserving the palatal and pharyngeal vessels. The upper jaw is now mobilized and moved caudally and forward. The Le Fort I interposition gap including the sinus floors and the nasal floor is filled with a mixture of xenogenic bone graft material of bovine origin (75%; Geistlich Bio-Oss®, Baden-Baden, Germany), ground autologous bone chips from the iliac crest (25%) and venous blood. In average, 10 grams of bone substitute material was used. The jaw is fixed by L-shaped mini plates (2.0 mm system, KLS Martin, Tuttlingen, Germany) at the zygomatic and nasal buttresses. Usually, a thin frame of autologous iliac cancellous bone strips was used to additionally laterally augment the alveolar ridges and to bridge the Le Fort I gap. Micro-screws are used to secure the iliac bone grafts (1.5 mm system, KLS Martin, Tuttlingen, Germany). All voids between the iliac bone strips were filled with the mixed particulated graft. Collagen membranes are used for coverage of all grafts (Geistlich Bio-Gide®, Baden-Baden, Germany) underneath the suture lines. The vestibular flap was mobilized by periosteal incision and submucous dissection and then sutured (Supramid 4–0, Resorba®, Nürnberg, Germany).

All patients received a preoperative single shot i.v. antibiosis of 500mg Sulbactam/1g Ampicillin i.v. (Unacid®, Pfizer Deutschland GmbH, Berlin, Germany) or, in case of allergy, 600mg Clindamycin i.v. followed by a postoperative i.v. antibiotic prophylaxis for 5 days with these substances. All patients were treated as inpatients and stayed at the hospital for 3 – 5 days. Suture removal was scheduled on an outpatient basis after 10 days in most cases.

In this two-stage approach, the delayed dental implant placement was conducted after a bone healing period of 4 months with simultaneous removal of the osteosynthesis material. Subsequently, after another 3 months, the dental implants were uncovered followed by prosthetic treatment, usually at the referring home dentist's office (Figure 1). Soft tissue grafting procedures were performed in 2 cases.

2.3 | Follow-up visits

The follow-up visits were scheduled at the offices of the referring home dentists. At the time of this study, the clinical data were obtained from the referring dentists by a telephone interview and by submission of panoramic X-rays, if available. In case a referring dentist could not be identified, the patients were directly contacted and asked to come in for an appointment in the hospital.

As this was no prospective study with fixed intervals, the follow-up X-ray data for bone height measurements were grouped in the following time intervals 6–12 months, 13–42 months, and 43–72 months. For the implant survival analysis, the exact time of loss was recorded in months.

2.4 | Radiographic data evaluation

Lateral cephalograms and panoramic radiographs were taken preoperatively, post-augmentation surgery and post-dental implant surgery (Orthophos SL 2D, Dentsply Sirona, Bensheim, Germany). Additional sets of cephalograms were taken at later time points in 25 patients. Additive panoramic x-rays were obtained in 82 patients.

In lateral cephalograms, maxillary bone height was measured, using the Nasion–Sella line as a major reference. Individual landmarks were documented for each patient on this line, from where a perpendicular line was drawn up to the deepest point of the bone in the anterior region of the maxilla, near the A point. The augmented height was set as the baseline. The magnification factor of the cephalogram was calibrated by the reference gauge in the image. In addition, the SNA angle was measured.

The marginal bone loss (MBL) was estimated by using the Tuebinger measurement method (Gomez-Roman et al., 1995). Accordingly, the bone loss around the implant was measured in panoramic X-rays. The baseline for calculating the marginal bone loss was the visible implant shoulder at time point implant loading. In this study, the mean value of two representative implants for each patient was followed over the years. These were either the two implants placed bilaterally in the canine region or the two middle anterior implants. The known implant length was used for calibration of the individual magnification factor. The radiographic analysis was performed on SIDEXIS 2.63 software (Dentsply Sirona, Bensheim, Germany) by a single examiner at the end of the study (S.M.A.). Overall, 210 orthopantomograms and 437 lateral cephalograms were evaluated.

2.5 | Statistical analysis

The Kaplan–Meier estimator was used to calculate the dental implant survival. The log-rank test was applied to compare subgroups. The level of significance was set at $p \leq .05$. The histogram and table charts were created in Microsoft Word and Excel. The survival analysis curves were generated with the statistical software SPSS®.

The implant success rates were measured according to the criteria established by Buser et al. (1990):

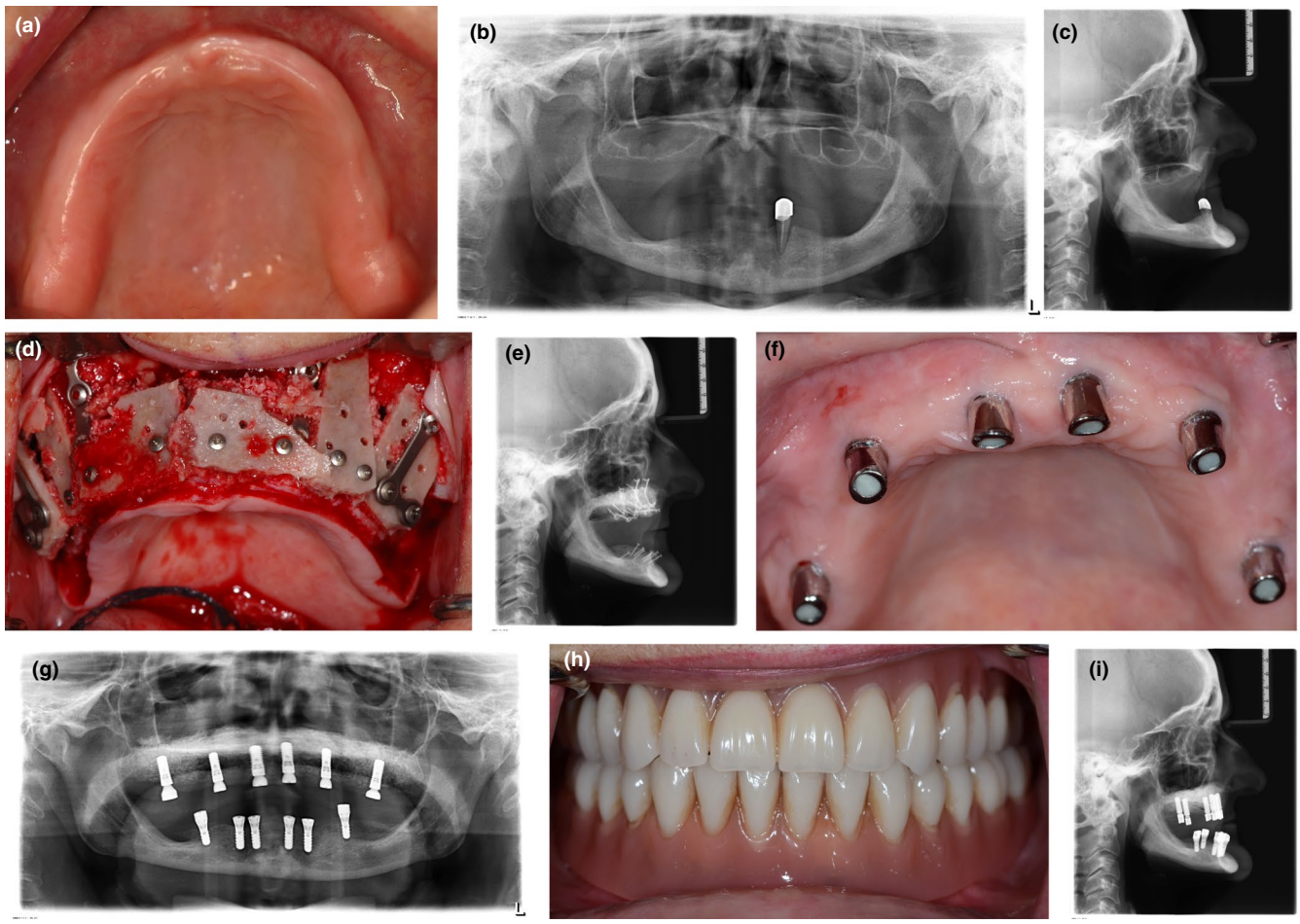

FIGURE 1 (a) baseline intraoral view of the maxilla. (b) preoperative panoramic radiograph of an atrophied Maxilla Cawood Class V. (c) preoperative lateral cephalogram with an atrophied Maxilla Cawood Class V. (d) intraoperative view with strips of iliac bone bridging the osteotomy line. The interposition gap is filled with a mixture of xenogenic bone graft material of bovine origin and ground autologous bone chips from the iliac crest. (e) postoperative lateral cephalogram after augmentation. (f) clinical view after dental implant placement and treatment with telescopic abutments. (g) post-augmentation panoramic radiograph after implant placement. (h) clinical view of the final prosthetic restauration. (i) post-augmentation lateral cephalogram after implant placement, showing parallel placing of the implants

1. The absence of persistent subjective complaints such as pain, foreign body sensation and/or dysesthesia.
2. The absence of a peri-implant infection with suppuration.
3. The absence of mobility.
4. The absence of a continuous radiolucency around the implant.

3 | RESULTS

3.1 | Study population

The population consisted of 81 (75.47%) women and 25 (24.53%) men. The differentiation in age and gender distribution shows highest treatment numbers in the age group from 50 to 69 years for women (48.42%) and between 50 and 59 (16.84%) for men. The average age was 58.4 years. Of the 106 patients, 68 suffered from systemic diseases. In this patient population, cardiovascular diseases (48 patients) were most frequent, followed by thyroid disorders (4 patients). Six patients suffered from osteoporosis. Five patients are in treatment for diabetes and three patients are meanwhile undergoing antiresorptive therapy. Twelve patients were active smokers. Twenty-nine patients showed medical records within normal limits. Three patients who presented odontogenic sinusitis were treated with surgical removal of the odontogenic origin and sinus drainage before surgery.

3.2 | Graft integration and dental implant placement

In 106 patients, the atrophied maxilla was reconstructed by modified Le Fort I interpositional bone grafting. A total of 84 patients (79,25%) received 587 dental implants. Seven patients were still in the course of prosthetic treatment at the evaluation time point. In a single case, the patient received a conventional denture without dental implants. The follow-up was lost in 10 patients after Le Fort

I interpositional grafting. Additionally, there were 4 dropouts, with two patients being excluded from the present analysis due to poor general health conditions and another two cases due to almost total graft loss. In the latter cases, this resulted in discontinuation of the treatment for these patients and placement of zygomatic implants.

3.3 | Perioperative complications

Perioperative complications of Le Fort I interpositional grafting included sinus membrane perforation, transient hypo- and paresthesia, wound healing disturbances and transient oro-antral fistulae (Table 1).

In 59.43% of the cases, the sinus membrane perforated intraoperatively. This complication was treated immediately during surgery with use of collagen membranes.

Transient hypo- and paresthesia was reported in 5 graft procedures post-surgically (5.3%). Symptoms were restricted to areas of the upper lip and nose tip region. In one case, the complete area of the Nervus infraorbitalis was affected. Puncture and two-point test showed residual sensibility in all affected patients. There was no case of permanent sensory disturbance.

Wound-healing disturbance was observed in 27 procedures, presenting an incidence of 25.47%. Twenty-three of these cases were non-purulent wound dehiscences and healed with wound irrigation or secondary suturing. Four sites were infected and sequesters had to be removed, resulting in partial graft loss, still these patients received the planned dental implants. In no case, any secondary re-grafting was required. In two patients, graft losses after wound dehiscence and infection were considered as failures and these patients were successfully treated with zygomatic implants.

In 8 cases (8.48%), there was a transient oro-antral connection after the augmentation, which healed spontaneously or could be closed by a small flap.

3.4 | Vertical bone gain measured in lateral cephalograms

Anterior height changes of the maxilla immediately after the augmentation surgery was in average 8.67 ± 3.48mm. The minimal achieved vertical bone gain was 2.4 mm and maximum height change was 16.56 mm after the augmentation (Median: 8.54 mm).

TABLE 1 Perioperative complications

Perioperative complications	*n*
Sinus membrane perforation	63
Transient hypo- and paresthesia	5
Wound dehiscences	27
Transient Oro-antral fistula	8

3.5 | Anterior positioning of the maxilla

The upper jaw was positioned anteriorly to compensate for the pseudo class III in the course of maxillary bone atrophy. In the sagittal plane, the Sella-Nasion-A-point-angle showed a mean advancement of 4.94° ±3.88° (minimum: 0° maximum: 16.7° median: 4.2°).

3.6 | Vertical bone loss measured in lateral cephalograms

The bone level post-augmentation surgery was set as the baseline. An initial bone resorption of 1.16 ± 0.46 mm was measured until the time point of implant placement. A further resorption up to 2.03 ± 0.77 mm occurred until the time point implant loading. After prosthetic function, the average vertical bone loss amounted to 2.58 ± 1 mm in the time interval 13–42 months and 2.66 ± 1.81 mm at 43–72 months, respectively, measured from baseline augmentation. This meant a final mean graft height loss from prosthetic loading onwards after 5 years of 0.63 ± 1.41 mm (Figure 2).

3.7 | Marginal bone loss measured in panoramic radiographs

The average marginal bone loss was 0.13 ± 0.26 mm, 0.22 ± 0.49 mm, and 0.26 ± 0.38 mm in the selected intervals 6–12, 13–42, and 43–72 months after implant loading, respectively. The average value was 0.20 ± 0.37 mm over 5 years (Figure 3).

3.8 | Implant survival

All 587 placed dental implants were included in this Kaplan–Meier estimator (Figure 4). The average observation time was 93 months. The dental implant survival in this study was 97.1% after one year (542 under observation). The 5-year survival probability amounted to 96.4% (313 under observation). The 10-year survival rate was calculated with 95.85% (29 under observation). A total of 21 implants were lost. A total of 566 implants were censored as the observational period ended.

Additionally, Table 2 lists implant survival in the observation time from 13 month after implant placement until 5-year follow-up. A total of 526 implants were included in this analysis. A total of 7 implants failed during the observation time in this functional time span. A total of 207 implants were lost to follow-up at the end of this analysis.

The individual implant losses are listed in Table 3. These losses can be divided into the following sections: no osseointegration ($n = 6$), implant removal due to pain, infection, fistula, or formation of cysts ($n = 6$) and removal of dental implants as a result of poor osseointegration ($n = 9$). These casualties occurred in 13 patients, with 10 patients losing one implant and 3 patients having multiple losses (4; 4; 3). Seven implants were early losses in the first 15 month

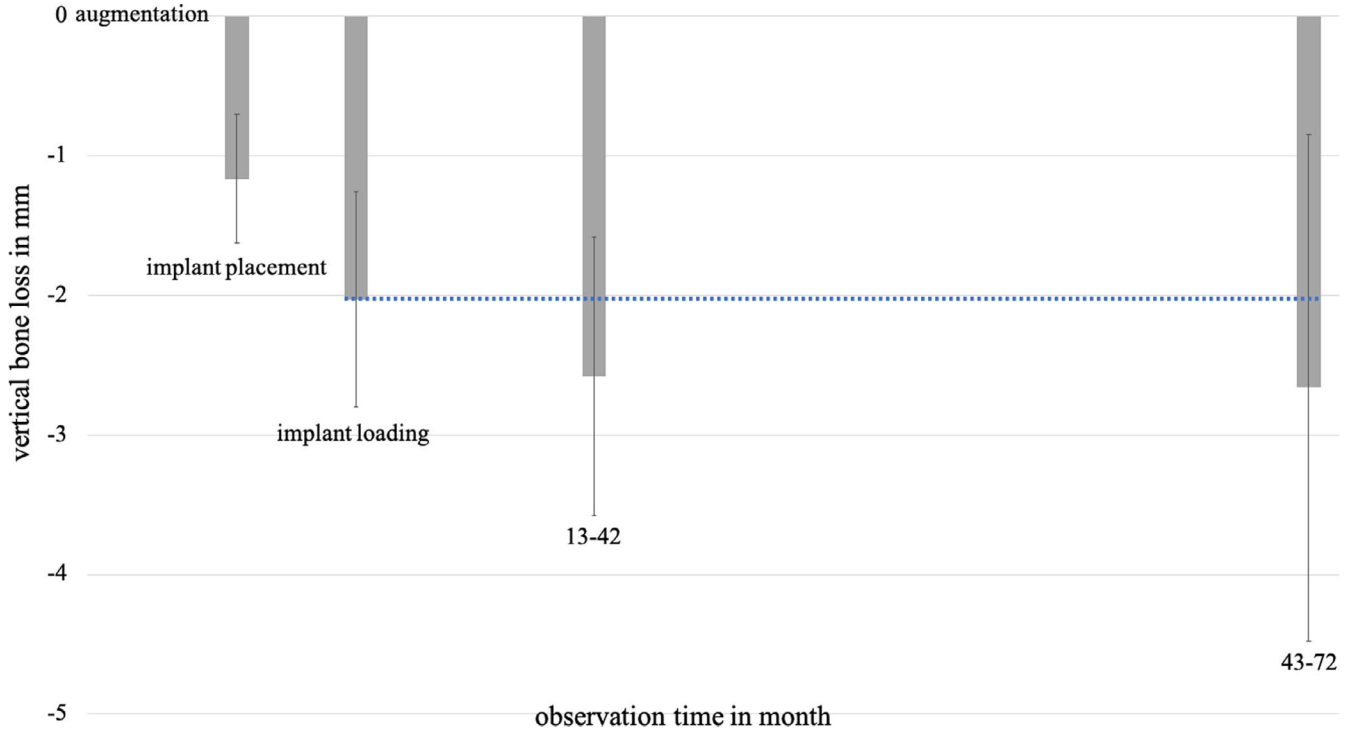

FIGURE 2 Vertical bone loss measured in lateral cephalograms in set time intervals after augmentation surgery—*post-augmentation* [baseline], initial bone resorption until *implant placement* [1.16 ± 0.46 mm; mean value, standard deviation], further resorption until *implant loading* [2.03 ± 0.77 mm], after prosthetic function at *13–42 months* [2.58 ± 1 mm] and *at 43–72 months* [2.66 ± 1.81 mm]. Final mean graft height loss from *prosthetic loading* onwards after 5 years [0.63 ± 1.41 mm]—time point *prosthetic loading* marked by blue dotted line

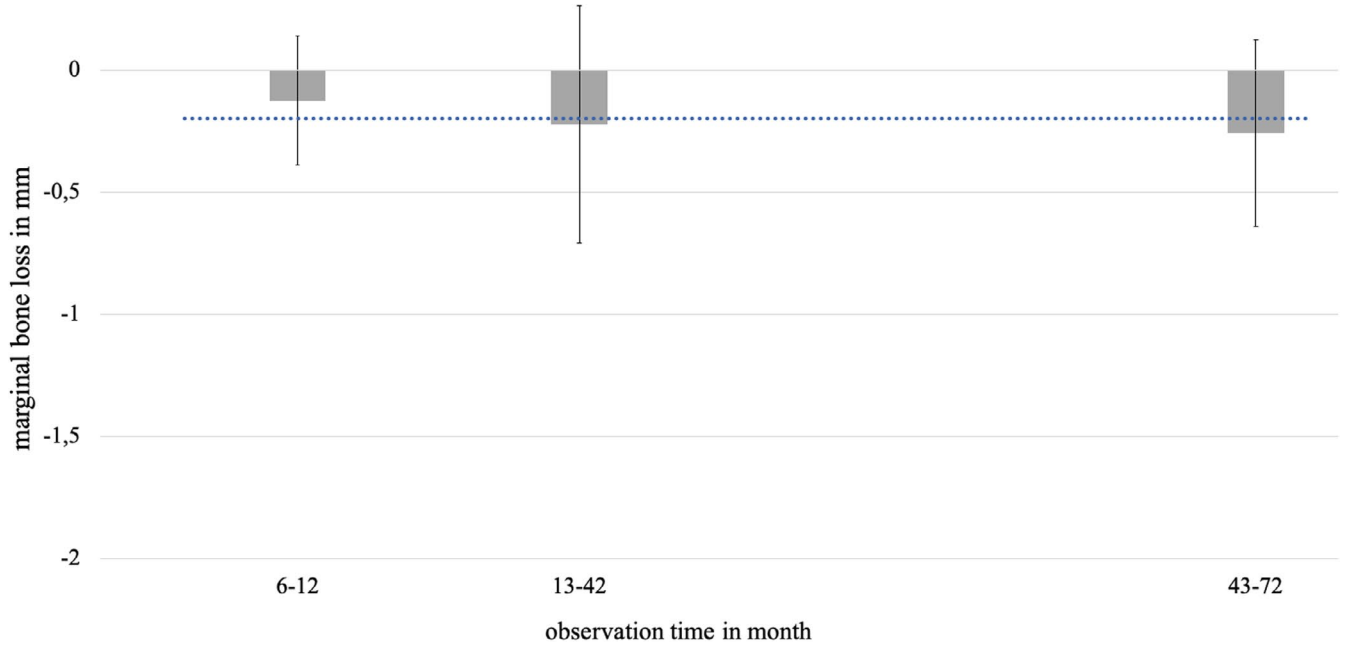

FIGURE 3 Marginal bone loss measured from the implant shoulder in panoramic x-rays in the time intervals *6–12 months* [0.13 ± 0.26 mm; mean value, standard deviation], *13–42 months* [0.22 ± 0.49 mm], *43–72 months* [0.26 ± 0.38 mm] after implant loading. Average value *over 5 years* amounts to 0.20 ± 0.37 mm (blue dotted line)

after implant placement. The average time point of implant losses was after 19.36 ± 11 month (quickest loss after 3 month/ latest loss after 69 month).

When comparing the survival in subgroups of patients without systemic diseases (=healthy) versus patients with systemic diseases (=compromized) with the log-rank test, the results showed 98.1%

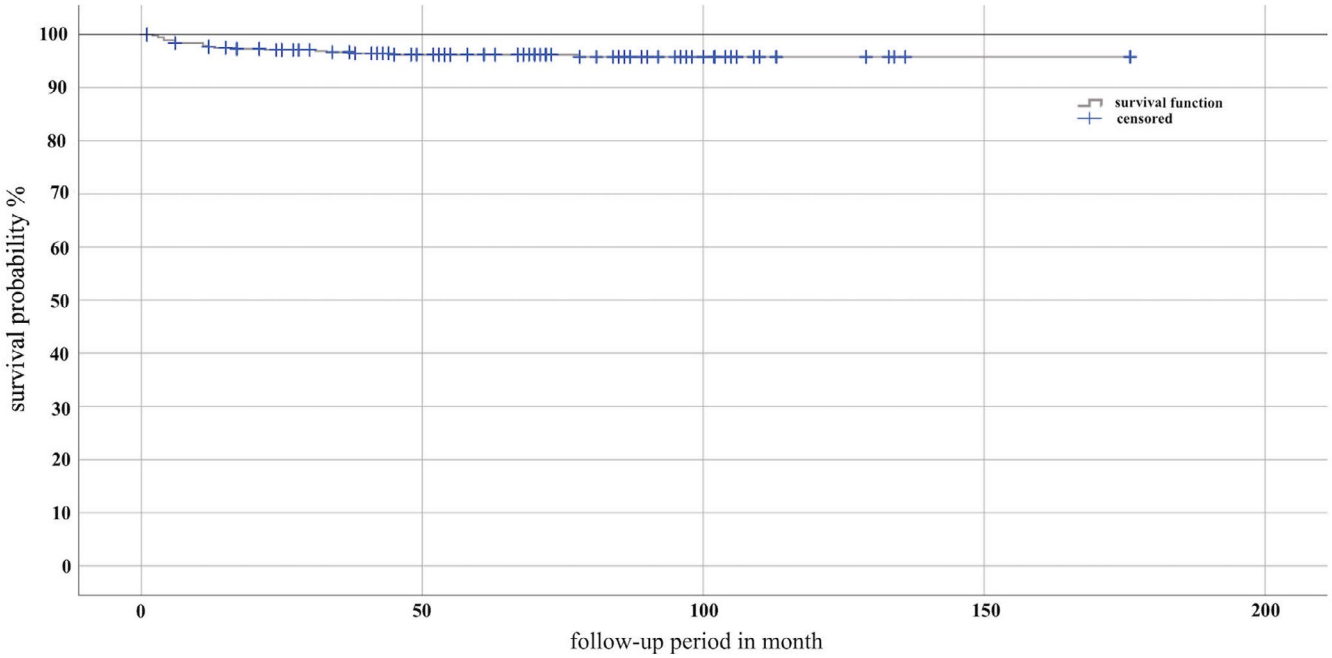

FIGURE 4 Implant survival rates analyzed by Kaplan–Meier estimator. 587 implants were included in this analysis with an average observation time of 93 months. Implant survival after *one year* [97.1% – 542 implants under observation]; *5-year* survival [96.4% – 313 implants under observation]; *10-year* survival [95.85% – 29 implants under observation]. 21 implants lost. 566 implants were censored as the observational period ended

TABLE 2 Life table analysis of implant survival

time in function (months)	implants at start of interval (*n*)	implants lost to follow-up during interval (*n*)	Implant failures (*n*)	Implant failure rate (%)	Cumulative implant survival rate (%)
13–24	526	31	3	0.38	99.62
25–36	493	47	2	0.30	99.70
37–48	444	70	2	0.45	99.55
49–60	372	59	0	0	100

TABLE 3 number of implants lost per patient

n (patient)	Number of implants lost
1	1
2	1
3	1
4	4
5	3
6	1
7	1
8	1
9	1
10	4
11	1
12	1
13	1

survival in the first group (29 patients with 212 dental implants placed) with 1.9% failures. In comparison, the outcome in the second group (55 patients with 375 dental implants placed) was not significantly lower with 95.4% survival and 4.6% losses. *p*-value was $p = .0998$.

3.9 | Implant success

Out of all placed implants, 531 were classified as a success. According to the criteria for implant success from Buser, this accounts for 91.7% at the last follow-up with a mean observation time of 93 months.

3.10 | Prosthetic success

All implants were prosthetically loaded which accounts for 100% prosthetic success during the observation time. No prosthesis was lost.

4 | DISCUSSION

In this study, the clinical outcome of modified Le Fort I interpositional grafting followed by dental implant placement was evaluated retrospectively over an average follow-up period of 7.7 years and a maximum of 14 years in a consecutively recruited study population. A total of 106 surgical procedures were included and 587 dental implants were placed in 84 patients. A high rate (25.47%) of partial wound dehiscences was observed in our study population. However, this can be explained as the incision line is very long (appr. 14cm from position 17 to 27) and the probability of dehiscences rises with length of the wound. Even so, it is rather remarkable that apart from subtotal bone graft loss in two patients (1.8%), primary healing could be achieved in the remaining 72.7% of the cases over such a long distance. A reason for that discrepancy could be, that the xenogenic bone graft material is deeply embedded in the wound and surrounded by autologous bone blocks from the iliac crest and additionally shielded by collagen membranes. These have a barrier function and keep bacteria off which may penetrate through gaps of the suture lines and helps with bolstering sharp edges against the covering mucoperiostal flap (Tawil and Mawla, 2001). Other postoperative complications included transient oro-antral fistula in 8.48%, with all of them being successfully treated as well as transient hypo- and paresthesia. This complication was noticed in 5.3% and is common after Le Fort I osteotomy in general (Chen and Yeow, 1999) but subsided by the time of dental implant placement. Even though our complication rate is higher compared to a prospective study evaluating intra- and perioperative complications of classical Le Fort I osteotomies (Kramer et al., 2004) the within this study mentioned disturbances all receded apart from two graft losses. In contrast, Kramer et al. (2004) observed more severe and long-lasting complications, for example, nasal septum deviations or non-union of the osteotomy gaps. A reason for our initial higher complication rate could be that studies on perioperative complications treated with classical Le Fort I osteotomies include patients with manifold reasons for surgery as compared to whereas all patients in this study suffered from extremely atrophic maxillae and this may have led to a higher occurrence of wound healing disturbances due to extensive flap mobilization (Purcz et al., 2015). The absence of non-unions in our study can be explained because strips of iliac bone always bridged the osteotomy line.

Le Fort I interpositional grafting was effective in increasing the maxillary vertical height up to 8.67 ± 3.48mm enabling two-staged dental implant placement. The bone level gain continued to stay stable after a slight resorption in the first six month after augmentation surgery of 1.16 ± 0.46mm (18,46%). Most studies on bone grafts from the iliac crest in the reconstruction of the atrophied maxilla, only measure the peri-implant bone loss. But in the study from Sjöström et al. (2013) the onlay graft was measured by CT scans. A volume decrease of mean 37% was observed in the first six month, which is definitely higher than the resorption rate in this study. In the follow-up period, vertical bone height loss was low in our study with mean 0.63 mm (5 y), speaking for a stable bone after implant loading.

When comparing studies on classical Le Fort I interpositional grafting, the marginal bone loss was slightly higher in those studies than here, with 0.6–0.7 mm (Kim et al., 2009) or 2.5 mm bone loss respectively (Nyström et al., 2009), in comparison with average 0.20 mm in this modified technique in the follow-up period. This could be attributed to proper timing of the placement and loading of the dental implants, which applied physiologic strain on the regenerated bone. Furthermore, the bovine bone graft material in the particulated graft areas resorbs slowly (Bechara et al., 2015). This is different to iliac onlay grafting which presents a higher resorption rate (Mertens et al., 2013). In conclusion, the presented modified Le Fort I interposition grafting technique performed better than the traditional surgical protocol.

The implant survival probability analyzed by using the Kaplan–Meier estimator in this study was high with 97.1% after one year. The reduced number of implants under observation after 10 years does not allow for statistically significant statements, even though it can be mentioned that no implant was lost later than 10 years. When looking at implant survival in the functional time span from 13 months to 5-year follow-up, failed implants make up only a small percentage with 1.33% (Table 2). Implant survival in other augmentation procedures varies depending on the method. The vertical onlay osteoplastic showed a survival rate of 79.8% (Iizuka et al., 2004; Nyström et al., 2004). In lateral sinus floor elevations, different survival rates were shown, varying from 60 to 100%, with most depicting survival of over 90% (Hallman and Nordin, 2004; Simion et al., 2004). Studies analyzing the survival rate after a Le Fort I with interpositional bone grafts and a two-stage approach show a wide range between 67 and 95% (Chiapasco et al., 2009; Yerit et al., 2004).

Dental implants in patients with systemic diseases were less likely to survive with 95.4%. In contrast, the probability of implant survival for patients with an unremarkable medical history was at 98.1%. The difference of 2.7% is not significant. This is in line with other studies on failure rates of dental implants when placed in well-medicated risk patients, provided that they have been covered with antibiotics and measures for a complication-free wound healing have been taken (Beikler and Flemmig, 2003; Morris et al., 2000).

The measured implant success was 91.7%, which corresponds with success rates of implants placed in other augmentative procedures, like 83 – 100% for vertical onlay osteoplasty (Iizuka et al., 2004; Van der Meij et al., 2005) and 75 – 100% for lateral sinus elevation (Simion et al., 2004). Studies on implant success after Le Fort I with interpositional bone chips and a two-stage procedure ranged from 82.9 to 91% (Chiapasco et al., 2007, 2009; Yerit et al., 2004).

Concerning the issue “prosthetic success,” our results demonstrate that all dentures were in function and fulfilled the success criteria (Papaspyridakos et al., 2012). Most of the patients in this study received fixed or removable implant-supported dentures after the augmentation and implantation, which are in situ and used without exception. Dental implants have a significant effect on the oral health-related quality of life (OHRQoL) (Pavel et al., 2012) especially

in patients who are highly impaired (Reissmann et al., 2017) as patients in this study with Cawood Class IV and V maxillae can be termed.

The Le Fort I osteotomy has evolved to one of the classical procedures in maxillary surgery and can correct functional and cosmetic irregularities of the skeletal viscerocranium (Buchanan and Hyman, 2013). In contrast to other augmentation methods in the upper jaw, it is therefore possible to compensate growth deficits of the maxilla as well. Consequently, dental implants can be placed in an optimal prosthetic position. This decreases the need for technical compensations of jaw discrepancies and enables a delicate suprastructure following natural esthetic criteria.

This study has limitations due to its retrospective design. However, the analysis is quasi prospective and very clean since all patients were included, treated by the same protocol and surgeon and followed-up in the aftercare. The assessment of the vertical bone stability after augmentation and marginal bone loss after implant loading is based on the evaluation of lateral cephalograms and orthopantomograms in the follow-up period and not on standardized periapical radiographs. In a recent study on measuring accuracy, the measured error of cephalograms and cone beam CT scans was comparable with 0.5 mm (Pittayapat et al., 2015). It should be noted that the prosthetic rehabilitations were performed by normal general dentists in a real-life setting, not in an artificial surrounding of a study center.

Another limitation of this study is, that the analysis on implant survival is implant-based and not patient-based. Therefore, the sample is not statistically independent. However, clustered implant losses were not observed so that the data quality is high (see Table 3), and the above-mentioned statistical problem is less relevant for this study.

In conclusion, modified Le Fort I interpositional grafting is a predictable method for vertical bone augmentation in the atrophied maxilla as well sagittal advancement. Patients with edentulous atrophic maxillae who are fit for surgery should be informed about the benefits and risks of this method in comparison to alternative augmentative and non-augmentative methods.

CONFLICT OF INTEREST

There are no financial conflicts of interests to disclose.

AUTHOR CONTRIBUTION

Sophia Mulugeta Abraha: Conceptualization (equal); Data curation (lead); Formal analysis (lead); Methodology (equal); Project administration (equal); Visualization (lead); Writing – original draft (lead). **Yuan-Ming Geng:** Data curation (equal); Formal analysis (supporting); Investigation (supporting); Methodology (supporting); Writing – review & editing (supporting). **Hendrik Naujokat:** Formal analysis (equal); Investigation (supporting); Methodology (supporting); Writing – review & editing (supporting). **Hendrik Terheyden:** Conceptualization (lead); Data curation (equal); Formal analysis (lead); Investigation (lead); Methodology (lead); Project administration (lead); Resources (lead); Software (equal); Supervision (lead); Validation (equal); Visualization (equal); Writing – original draft (supporting); Writing – review & editing (lead).

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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