The restoration of the lost alveolar crest is an integral part of modern implantology. The bone block technique using autogenous grafts is an established method for hard tissue augmentation and has been evaluated in numerous clinical studies1-5 and meta-analyses.6-8

With the classical procedure, the bone block is adapted to the residual ridge and attached by means of microscrews without any interspace between them. Khoury et al presented a new method, which is commonly referred to as the split bone technique. The block, which is usually harvested from the mandibular ramus, is severed with a disc, adapted to the local bone, and fixed by means of osteosynthesis screws. The resulting interspace is filled with bone particles.9,10 One of the many modifications of this technique uses thinning of the bone block in a bone mill instead of splitting the bone with a disc. The extracted bone particles serve to fill the interspace.11

**Purpose:** The aim of this retrospective case-control study was the evaluation of the split bone technique with regard to the occurrence of early complications, implant survival rate, and peri-implant bone resorption. The effect of patient-related factors (sex, age, tobacco consumption), implant location, and the implant system used on bone resorption was analyzed. **Materials and Methods:** Patients treated by means of the split bone technique with autologous bone blocks from the external oblique line in a two-stage grafting procedure were observed for up to 5 years after implant placement. The control group was a randomly selected group of patients with implants inserted without any augmentation procedures. Vertical bone resorption was measured radiographically, implant survival was calculated by means of the Kaplan-Meier procedure, and complications were recorded numerically. **Results:** A total of 194 augmentations in 164 patients were performed in the 10-year period. One graft was lost due to exposure and infection of the recipient site, and in four cases, severe resorption of the graft prior to implant placement made a second augmentation necessary. Eighty-seven patients with 100 grafts and 173 implants in the study group and 91 patients with 173 implants in the control group participated in the follow-up. Implant survival was 100% in the study group and 98.5% in the control group (P = .262; log-rank test). The median vertical peri-implant bone resorption after 5 years was 0.7 mm in the study group and 0.6 mm in the control group (P = .371; Mann-Whitney U test). In the study group, the difference between male (0.4 mm) and female (0.9 mm) patients was significant at the end of the follow-up period (P = .022). Significant differences were also found between smokers (2.8 mm) and nonsmokers (0.6 mm) after 5 years (P = .002). **Conclusion:** The split bone technique using autogenous bone represents a reliable therapy method with a very low complication rate and an implant survival rate of 100% after 5 years. The technique did not result in any increase in peri-implant bone resorption during the follow-up period. Smoking and gender may negatively influence peri-implant bone resorption when using this technique. Int J Oral Maxillofac Implants 2019;34:1152–1160. doi: 10.11607/jomi.7470

**Keywords:** alveolar ridge augmentation, bone block graft, implant survival, peri-implant bone resorption, split bone technique
Although this technique is now a well-known method recognized by many practitioners, only a few studies have investigated this technique scientifically. Khoury demonstrated a high predictability of this procedure with regard to bone volume stability in the healing phase until implant placement. Unfortunately, no information was provided concerning implant survival or peri-implant bone changes. Bartels et al compared the split bone technique using alternatively autogenous bone blocks or a Poly-D-L-Lactide foil fixed at a distance. The study demonstrated a significantly lower complication rate (graft loss and wound dehiscences) and higher implant survival when using autogenous bone blocks. No differences in peri-implant bone loss, however, were found 1 year after implant placement.

No further studies that take the implant survival or success into account subsequent to the reconstruction of the alveolar ridge using this technique are available to the authors’ knowledge.

The aim of this retrospective case-control study was to evaluate the split bone technique with regard to the occurrence of early complications, implant survival rate, and peri-implant bone resorption up to 5 years after implant placement. Both patient-dependent and independent factors with a potential influence on bone loss were considered.

**MATERIALS AND METHODS**

**Patients**

The collective was provided by a private referral practice for oral surgery. Patients who had undergone horizontal bone augmentation using the split bone technique and subsequent implant placement in a two-stage grafting procedure in the period from January 1, 2007 to December 31, 2016 were included. The indication for using the procedure was defined by the transverse bone deficit, which should have a horizontal residual bone width below 4 mm. Patients were excluded if any other augmentation procedure (eg, sinus floor elevation or vertical block grafting) was performed simultaneously in the same crest area. Participation in the recall service of the practice was a prerequisite for patient inclusion. Patients without radiographic examination at follow-up or those whose radiographic images were not evaluable were excluded. A randomized control group was generated from the implant database of the practice with patients who were neither treated with the aforementioned technique nor with any other augmentation technique prior to implant placement. Random selection using a spreadsheet (Microsoft Excel 2003) was continued until the same number of evaluable implants was available as in the study group.

The conduct of the investigation was approved in advance by the Ethics Committee of the State Medical Association Rhineland-Palatinate.

**Surgical Procedure, Prosthodontics, and Follow-up**

The interventions (bone grafting) were performed either under local or general anesthesia by two practitioners. After a crestal incision, a mucoperiosteal flap was prepared and the region to be augmented was uncovered. After harvesting the bone block from the external oblique line of the mandible, this was adapted to the recipient region (Fig 1). The block was thinned in a bone mill (Bull Bone Mill, Ustomed) (Fig 2), positioned at a distance to the local bone, and fixed with osteosynthesis screws (Cortex Screw PlusDrive, DePuy-Synthes). The interspace was filled with autologous bone particles ground in the bone mill and mixed with venous blood. Thereafter, the osteosynthesis screws were fully tightened (Fig 1). A periosteal incision was performed in all cases. The flap was repositioned, and the wound was sutured using atraumatic material.

Implant placement was scheduled for 4 months after grafting and carried out according to the manufacturers’ protocols. The osteosynthesis screws were removed at that time. Stage two surgery was scheduled for 3 months after implant insertion. The prosthetic treatment was subsequently carried out by the referring dentist.

Patients were informed about the need of an annual follow-up after completing the implant surgery. They received a letter reminding them of the recall on a yearly basis.

**Early Complications**

The occurrence of complications was recorded numerically and separately for the donor and recipient sites. Potential postoperative complications were rebleeding, wound dehiscence, exposure and loss of the graft, wound infection, and sensitivity disorders of the inferior alveolar nerve.

**Implant Survival**

The cumulative survival rate was calculated using Kaplan-Meier analysis, and group differences were evaluated by means of the log-rank test.

**Radiographic Examination of Peri-implant Bone Changes**

Panoramic radiographs obtained with the Orthoralix 9200 system (Gendex Dental Systems) (software: VixWin) as well as with the Sirona Orthophos XGS system (Sirona Dental Systems) (software: Sidexis) were evaluated. The Sidexis program was used for the measurements. At least two panoramic radiographs (taken
at stage two surgery and one at follow-up) were necessary for inclusion.

The anchor point for all measurements was a line drawn along the shoulder of the implant. The magnification factor was calculated from the known implant length and the length of the implant measured on the image. Subsequently, the distance between the reference line and the alveolar limb was measured on the mesial and distal aspects of the implant (Fig 3). Measurements were repeated three times, and the calculated means were used for statistical analysis. The detected magnification factor was used to calculate the actual value. For this purpose, the mean values were divided by the magnification factor. The baseline

![Image](image-url)

**Fig 1** Representative patient case taken from the study group: The alveolar crest defect subsequent to traumatic injury was reconstructed by means of the split bone technique. The thinned block defined the dimension of the volume to be reconstructed. The interspace was filled with bone particles. The implant was inserted after 4 months. Stage two surgery was performed after another 3 months. The 2-year follow-up shows a satisfactory clinical outcome.

**Fig 2** The blocks were harvested from the mandibular ramus and thinned in a bone mill. The bone particles and venous blood were used to fill the interspace between the block and the residual bone.
radiographic examination for the prospective follow-up was performed immediately after stage two surgery.

Bone loss in the study and the control groups was measured on the radiographs at the mesial and distal aspects of each implant at 1-year intervals over a period of up to 5 years. For further calculations, the values obtained from the mesial and distal measurements were averaged.

In order to determine possible bone loss, the follow-up value on the radiographs was subtracted from the initial value at the time of stage two surgery.

Statistical Methods
All data were imported into the statistics program (SPSS 24, SPSS). Descriptive statistics were performed and boxplots created for the graphical presentation of the values.

Peri-implant bone loss in the study group was compared with the control group. The influence of patient age, sex, implant location (maxilla vs mandible), the implant system applied, and tobacco consumption within the study group on bone loss was then analyzed.

Group differences were investigated by means of the Mann-Whitney U test for two groups and with the Kruskal-Wallis test for more than two groups. Differences were considered as statistically significant if \( P < .05 \).

RESULTS

Patient Population
In the period from January 1, 2007 to December 31, 2016, 164 patients who met the inclusion criteria were treated using the split bone technique in a three-stage procedure. A total of 194 augmentations were performed under local (84.4%) and general (15.6%) anesthesia, and 295 implants were placed under local anesthesia in the augmented alveolar ridge after 4 months (mean: 4 months and 15 days \( \pm 1 \) month and 8 days). The implant systems used in the study group were Camlog Screw Line (n = 90), Straumann BL (n = 46), Straumann TL (n = 17), and Ankylos CX (n = 20). Stage two surgery was performed after 3 months (mean: 3 months and 17 days \( \pm 1 \) month and 9 days).

Eighty-seven patients (28 male, 59 female) who had evaluable radiographic data with 100 augmentations and 173 implants participated in the follow-up (Table 1). Patients were restored with single crowns (n = 96), fixed partial dentures (n = 38), cantilever fixed partial dentures (n = 17), fixed partial dentures linking the implant to a natural tooth (n = 10), and telescoping crowns (n = 12).

Ninety-one patients (40 male, 51 female) with 173 implants were randomly selected from the implant database of the practice and investigated as the control group (Table 1). The following implant systems were used: Camlog Screw Line (n = 111), Straumann BL (n = 33), and Straumann TL (n = 29). The implants were restored by means of single crowns (n = 101), fixed partial dentures (n = 27), cantilever fixed partial dentures (n = 14), fixed partial dentures linking the implant to a natural tooth (n = 5), telescoping crowns (n = 14), Locators (n = 6), and ball retainers (n = 6).

Early Complications
For the calculation of an early complication rate, all treated cases (194 grafts in 164 patients) could be
considered, since a follow-up was not mandatory for this analysis. Table 2 shows the respective complications at the donor and at the recipient sites. A severe resorption of the graft in 2.1% of cases did not allow an implant insertion. A second augmentation procedure was needed in two cases. One graft loss due to a postoperative infection was documented. This patient refused any further surgical treatment.

An infection of the donor site was observed in three patients. It could be controlled by local disinfecting measures.

**Implant Survival**

Implant survival in patients participating in the follow-up was 100% in the study group and 98.5% in the control group. One implant was lost in the control group 4 years after insertion. No significant differences could be calculated for the overall survival rate ($P = .262$, log-rank test) between the two groups.

**Peri-implant Bone Loss**

The Mann-Whitney $U$ test revealed no significant differences between the groups (Fig 4). Peri-implant bone loss as a function of patient age in the study group is shown in Fig 5. The median age (58 years) was used to divide the study population into two groups. No significant differences were observed between both groups throughout the observation period. Figure 6 shows the peri-implant bone loss for male and female patients. A tendency toward a higher peri-implant bone loss in female patients from year 2 to 5 was discernible. The difference was significant ($P = .022$) only in year 5. A significantly higher bone loss was observed 1 year after stage two surgery in the maxilla. The differences,
however, balanced out during the following time period (Fig 7). Tobacco consumption had a negative influence on peri-implant bone stability after 5 years ($P = .002$) in the study group (Fig 8). The Kruskal-Wallis test revealed no significant differences in the central tendency when bone resorption was compared for the four implant systems used (Fig 9).

## DISCUSSION

### Split Bone Technique

Corticocancellous blocks are a reliable treatment option to compensate horizontal and vertical hard tissue defects. With the classical procedure, the graft is adapted to the residual bone as exactly as possible and fixed with osteosynthesis screws. A considerable problem of the classical block technique, especially with purely cortical blocks, is the revascularization of the graft. The high density of cortical tissue makes the ingrowth of blood vessels difficult. Without revascularization, however, a reconstruction of the bone tissue is not possible. The tissue remains nonvital and is worthless with respect to the osseointegration of the implant. This problem led to the development of the split bone technique. With this technique, a cortical slice is loosely attached to the alveolar bone, leaving an interspace between the local bone and the slice. After filling the gap with particulate autogenous material, the screws are tightened to stabilize the entire graft. As published originally, the bone block is split with a diamond disc using this technique, resulting in two thinner blocks (or cortical slices) from one thicker block. Bone particles obtained with a bone scraper or by crushing the remaining bone block are inserted into the gap. If one slice is sufficient for augmentation, the second slice can be repositioned into the donor region and fixed with a screw. The loosely placed particles increase the potential for regeneration and revascularization since they facilitate the ingrowth of blood vessels. A modification of this technique is to thin out the bone block in a bone mill to the required width and to use the obtained chips as an interponate. With this modified technique, the required width of the cortical slice can be accurately determined. In addition,
there is no loss of bone as with the separation of the block with the disc, since all chips are collected in the bone mill and can be used later.

This technique with all its modifications plays an important role in the daily practical routine and has become very popular among many practitioners. It allows an augmentation of large ridge defects without the need to resort to an extraoral donor site. Surprisingly, with the exception of a number of case reports, two prospective clinical studies and one randomized controlled trial (RCT), scientific data evaluating this technique have not been published to the same extent that is known from other techniques, in particular when alloplastic and xenogeneic material is used.

Early Complications
The present study differentiates between complications at the recipient and the donor sites. The complication rate is comparable to other studies. In the study group, a total of 295 implants were inserted and 194 augmentations were performed. At the donor site, infections occurred in 1.5%, wound dehiscence in 1.0%, and temporary sensory disturbances in 0.5% of the cases.

At the recipient site, 0.5% of cases showed a graft loss, and 2.1% displayed strong resorption. Exposure of the graft occurred in 1.0% of cases. Infections and rebleeding were documented for 0.5% of the cases.

In two cases, a new augmentation was required due to the strong resorption. Implant placement was performed 4 months after the second augmentation. These two cases could not be evaluated any further, since these two patients did not participate in the follow-up. One patient who suffered from a graft loss due to wound dehiscence and infection of the recipient site denied any further treatment. A total of three cases could not be treated according to the treatment protocol.

Sakkas et al investigated the occurrence of complications in 456 augmentations (separately for the donor and recipient sites) with 525 implants. At the donor site, the incidence of wound infection was 2.6%. At the recipient site, it was 5.8%. Wound dehiscence was most prevalent at the recipient site (6.3%). Exposure of the grafts was seen in 5.5% of cases. The incidence of temporary sensory disturbances is described in the literature as being between 0% and 5%. By contrast, the values for harvesting bone from the chin region are between 10% and 50%. Harvesting bone blocks from the mandibular ramus should be preferable to that from the chin.

Marginal Bone Level
Numerous methods have been described to measure peri-implant bone loss. As in the present study, these methods use the distance from a fixed point or line on the implant to the limb of the alveolar crest on the mesial and distal aspects of the implant. The exact positioning of the patient as well as image magnification and distortion are a methodologic hurdle. By means of reference lines or surfaces, it is possible to minimize this problem. These methods only allow the determination of vertical bone loss; it would have also been beneficial to measure horizontal bone loss likewise. However, this would have required three-dimensional imaging that was not possible in this study due to ethical reasons.

There were no significant differences between the study group and the control group regarding the vertical bone loss throughout the 5-year observation period. In both groups, the bone loss increased slowly and continuously and was within the limits widely accepted as success criteria. The investigated bone block technique has no disadvantages in terms of an increase in peri-implant bone resorption. Unfortunately, on account of the considerable dropout rate, the number of available implants was limited for the 5-year evaluation period.

A significant gender difference was found to the detriment of female patients after 5 years in the study group. A hormonal cause may be presumed. Mir-Mari et al also demonstrated a significant difference between men and women in their 9-year retrospective study. This finding was confirmed by Chappuis et al, who also found a significantly higher bone loss in women after 10 years. Resorption is obviously higher in female patients when using the split bone technique.

Patients become more likely to develop primary osteoporosis with age. Bone metabolism is reduced, and bone resorption predominates. Beyond the age of 50, bone density decreases by 10% in women and 5% in men per decade of life. This is not only due to the generally slowed rate of bone metabolism, but also to numerous other diseases, such as diabetes and vitamin D deficiency, as well as the use of medications (steroids, calcineurin inhibitors, thyroxine), which increase the likelihood of developing secondary osteoporosis. Pikner et al investigated bone loss in implants inserted without grafting procedures. Bone loss was higher the older the patients were. Differences were significant at the points in time 1, 3, 5, and 10 years after implant placement. In the study by Gultekin et al, the volume changes after reconstruction of horizontal bone defects in the maxilla were examined. In this study, age was a significant factor with regard to bone resorption. This phenomenon could not be confirmed by the results of the present investigation. There was no correlation between bone resorption and patient age in either the study group or the control group.
With respect to implant location in the study group, the difference in the first year after implant placement was significant ($P = .030$), with higher bone degradation in the maxilla. After 2, 3, and 5 years, the situation reversed, but the differences did not reach any level of significance. This is comparable to the results in previous studies with bone resorption insignificantly higher in the mandible. Mir-Mari et al also found no significant differences between both arches. The maxilla showed a slightly higher bone loss. In contrast, other authors demonstrated a significantly higher bone loss in the mandible after 1, 5, and 10 years with minor differences between the maxilla and mandible.

In the study group, there was also a higher bone resorption in smokers throughout the 5-year period. After 5 years, the difference was statistically significant ($P = .002$). The results of the present investigation show that smoking adversely affects bone resorption. The results are also consistent with those from previous studies. There is a proven causality between tobacco consumption and marginal bone loss. There is hence a higher risk of higher bone loss for smokers. This applies to the same extent if autologous bone transfer is used as part of the implant treatment.

**CONCLUSIONS**

The split bone technique using autologous thinned bone represents a reliable therapeutic method with a very low early complication rate and an implant survival rate of 100% after 5 years. The technique did not result in any increased peri-implant bone loss up to 5 years after implant placement when compared to a control group without any augmentation procedures. After 5 years, a significantly higher resorption was found in females and smokers. Bone resorption was not influenced by patient age, implant location, and the implant system used.

**ACKNOWLEDGMENTS**

The authors declare no potential conflicts of interest regarding the publication of this article.

**REFERENCES**


