Radiographic outcomes of transcrestal sinus floor elevation performed with a minimally invasive technique in smoker and non-smoker patients

The loss of maxillary posterior teeth may be associated with a reduction in the vertical dimension of the residual ridge partly resulting from the pneumatization of the maxillary sinus (Farina et al. 2011). In some instance, the insertion of implants of desired length in the edentulous posterior maxilla may therefore be not compatible with residual ridge height (Eufinger et al. 1997, 1999; Pramstraler et al. 2011). Transcrestal sinus floor elevation (tSFE) is a surgical procedure to vertically enhance the available bone in the edentulous posterior maxilla through an access to the sinus floor created into the bone crest. According to a recent systematic review, tSFE is highly cost-effective when performed at sites with a height of the residual ridge above 5 mm (Listl & Faggion 2010). Smoking may negatively affect the healing capacity of injured tissues in several organ systems (Mosely et al. 1978). With regard to bone reconstructive procedures, smokers have been shown to respond less favorably to surgical procedures for ridge augmentation (Jones & Triplett 1992; Lindfors et al. 2010). Lower reconstructive outcomes and higher risk of infective complications following sinus lift (SL) with a lateral approach were reported for smokers compared with non-smokers (Barone et al. 2006; Anduze-Acher et al. 2012). Also, implants placed at sites undergone augmentation procedures including sinus elevation are at higher risk of failure in smokers than in non-smokers (Geurs et al. 2001; Strietzel et al. 2007; Huynh-Ba et al. 2008; Lin et al. 2012). To date, no specifically designed studies have addressed the effect of smoking on the outcomes of tSFE procedures.

Recently, we proposed a minimally invasive procedure for tSFE, namely the Smart Lift technique, which is characterized by a transcrestal access to the sinus cavity by means of specially designed drills and osteotomes (Trombelli et al. 2008, 2010a,b). Previous studies showed that the Smart Lift technique results in a predictable, apical displacement of the sinus floor (Trombelli et al. 2010a, 2012) along with a limited postoperative morbidity (Trombelli et al. 2010a). The
present study was performed to evaluate the association between smoking status and the radiographic outcomes of tSFE performed according to the Smart Lift technique.

Material and methods

Experimental design
The study was designed as a prospective cohort study. All the clinical procedures were performed in full accordance with the Declaration of Helsinki and the Good Clinical Practice Guidelines (GCPs). Each patient provided a written informed consent before participation. The present manuscript was prepared in full accordance with STROBE guidelines for reporting cohort studies [http://www.strobe-statement.org] [supporting information Data S1].

Patient selection
Patients were consecutively recruited and treated at one university center and three private dental offices from 2008 to 2010. Inclusion criteria for patient eligibility were as follows: [i] age ≥ 18 years; [ii] systemic and local conditions compatible with implant placement and sinus floor elevation procedures; [iii] placement of an implant ≥ 8 mm long concomitant with tSFE; [iv] non-smokers [i.e., patient who had never smoked]; [v] current cigarette smokers [i.e., patients who smoked at least five cigarettes per day [cig/day] at the screening visit]; [vi] patient willing and fully capable to comply with the study protocol. For S patients, the daily cigarette consumption as well as the number of years of smoking habit was recorded.

Site-specific inclusion criteria were as follows: [i] at least 6 months elapsed from tooth loss; [ii] residual bone height (RBH) [as radiographically assessed pre-surgery and clinically confirmed with the Probe Osteotome during tSFE procedure] ≥ 4 and ≤ 8 mm; and [iii] absence of endodontic lesions at teeth adjacent to the implant site.

Surgical procedure
Before SL procedure, all oral diseases, including periodontal disease, were thoroughly treated. Surgical procedures were performed by five expert clinical operators with previous experience in tSFE procedures. More specifically, all operators had been previously involved in research protocols on the Smart Lift technique [Franceschetti et al. 2012].

The RBH at the site where the implant had to be inserted was first measured on periapical radiograph or CT scan. Two grams of amoxicillin (Zimox 1 g, Pfizer Italia S.r.l., Borgo San Michele, Italy) was administered to each patient 1 h prior to the initiation of the surgical procedure.

The Smart Lift procedure represents a modification of the technique proposed by Fugazzotto [Fugazzotto & De Paoli 2002]. The major novelty of the Smart Lift resides in the fact that all manual and rotating instruments are used with adjustable stop devices that restrict the working action of burs and osteotomes to the vertical amount of residual bone, thereby preventing the accidental penetration of instruments into the sinus cavity. Moreover, with the Smart Lift technique, the vertical augmentation of the implant site is provided by the condensed trephined bone core that is displaced into the sinus, thus elevating the Schneiderian membrane and creating a space for blood clot formation.

The preparation of the implant site is performed according to a standardized sequence of instruments that was extensively described in previous studies [Trombelli et al. 2010a,b, 2012, Fig. 1]. In all cases, an additional graft, chosen among different hydroxyapatite-based (Bio-Oss®, spongiosa granules 0.25–1.0 mm, Geistlich Pharma, AG, Wolhusen, Switzerland; Biostite®, GABA Vebas, S. Giuliano Milanese, Milan, Italy; Gen-Os®, Osteobiol Tecnos Dental, Pianezza, Torino, Italy) or β-tricalcium phosphate-based [Cerost®, granules 0.5–0.7 mm, Thommen Medical, Waldenburg, Switzerland] biomaterials, was pushed into the sinus by gradual increments using the Smart Lift Elevator. The choice of the type and amount of the graft biomaterial were left at the operator’s discretion. The implant was inserted with either submerged or transmucosal healing protocol.

Patients were prescribed a non-steroidal anti-inflammatory agent as needed and 0.12% chlorhexidine mouthrinse, 10 ml t.i.d. for 3 weeks. The choice of a post-surgery antibiotic treatment was left to the discretion of the operator. Sutures were removed 7 days after surgery.

Experimental parameters

Surgical and post-surgical complications
The incidence of membrane perforation was evaluated by the Valsalva maneuver immediately after the fracture of the sinus floor by means of the Smart Lift Elevator and at the completion of the grafting procedure. Other surgical or post-surgical complications associated with the SL procedure, including benign paroxysmal positional vertigo [BPPV], postoperative infection, postoperative hemorrhage, nasal bleeding, blocked nose, hematomas, either assessed by the operator or reported by the patient, were also recorded.

Radiographic measurements
Radiographs were obtained immediately after surgery and at 6 months with a paralleling
technique using a Rinn film holder with a rigid film-object X-ray source and then scanned and digitized. Using an image-processing software, Adobe Photoshop CS5 (Adobe Systems, Inc., San José, CA, USA) digitized images were stored at a resolution of 600 dpi. On radiographs taken immediately after surgery, the following radiographic measurements were performed using a digital caliper:

1. Radiographic implant length (rIL): distance [in mm] between the implant shoulder and the implant apex as assessed at the midportion of the implant;
2. Residual bone height at the mesial (mRBH) and distal (dRBH) aspects of the implant: distance [in mm] between the mesial and distal aspect of the implant shoulder, respectively, and the sinus floor;
3. Height of the graft apically (aGH): distance [in mm] occupied by a radiopaque area between the implant apex and the sinus floor as assessed at the midportion of the implant.

To account for radiographic distortion, radiographic measurements (i.e., mRBH, dRBH and aGH) on each radiograph were adjusted for a coefficient derived from the ratio: true length of the implant/rIL. aGH was re-assessed at 6 months after adjustment for 6-month rIL.

For each patient, the following derived radiographic parameters were obtained:

1. Residual bone height: calculated as the mean value of mRBH and dRBH;
2. Implant penetration [IP]: calculated as the difference between rIL and RBH;
3. Extent of the SL: calculated as the sum of IP and aGH.

All measurements were performed by a single trained examiner (G.F.) who had previously undergone a calibration session for aGH assessment on a sample of 15 patients not included in the study [k-score for intra-examiner agreement: 0.981] and had participated as clinical examiner in a previous clinical trial using the same radiographic measurements (Trombelli et al. 2012).

Statistical analysis
Data were entered in a unique database file (STATISTICA® software version 7.1; StatSoft, Italy s.r.l., Vigonza, Italy) and expressed as median (interquartile range). The statistical analysis was conducted on the intention-to-treat (ITT) study population. The patient was regarded as the statistical unit. Six-month aGH and SL were regarded as the primary and secondary outcome variable, respectively.

Smoking exposure [pack*years] was calculated as [number of cigarettes/day/20]*number of years of smoking). Smoker patients were categorized according to either the daily cigarette consumption [low: <15 cigarettes/day; moderate: ≥15 and <20 cigarettes/day; high: ≥20 cigarettes/day] or their smoking exposure [low: ≤15 pack*years; moderate: 16 ÷ 29 pack*years; high: ≥30 pack*years].

Non-smoker and smoker groups, S patients with different daily cigarette consumption and S patients with different smoking exposure were compared for outcome variables as well as for demographic characteristics [age, gender] and aspects related to the surgical procedure [RBH, implant length and width, IP]. Within-group comparisons [pre-surgery vs. 6 months] were performed with Wilcoxon test. Intergroup comparisons were performed with Fisher’s exact test, chi-squared test, Mann-Whitney U-test and Kruskal-Wallis ANOVA (Tables 1 and 3).

The level of statistical significance was fixed at 0.05. When testing for multiple comparisons, the Bonferroni correction was applied.

A web-based software (http://www.dssresearch.com/KnowledgeCenter/toolkitcalculators.aspx) was used for the calculation of the statistical power of the study. The calculation was performed with a parametric test, assuming a patient sample 15% lower than that obtained in our per-protocol study population (i.e., n = 17 patients per group), as proposed by previous authors (Lehmann 2007). Assuming a standard deviation in aGH of 1.0 mm and an expected intergroup difference in aGH of 1.0 mm on the basis of data of previous trials evaluating aGH following tSFE procedures (Pjetursson et al. 2009, Trombelli et al. 2012), the study had a power of 83% in detecting a significant intergroup difference at P = 0.05 with a two-sided parametric test.

Results
Study population
The ITT population consisted of 45 patients [age: 53.0 years, IR: 47–58, range: 27–70, 28 women] undergone 45 tSFE. The five clinical operators contributed with 20, 7, 7, 6 and 5 patients, with an unbalanced distribution of patients according to smoking status within some patient subgroups [data not shown]. At one center, all [n = 6] treated patients received a postoperative, prophylactic administration of amoxicillin [Zimox 1 g, Pfizer Italia S.r.l., Borgo San Michele, Italy; 1 g b.i.d. for 6 days]. At the same center, one implant in an S patient failed to osseointegrate before the 6-month visit. For this patient, radiographic measurements were not performed at 6 months.

Non-smoker and smoker patients were 25 and 20, respectively. None of the patients in the S group referred a variation in the smoking habit between baseline and the 6-month visit. The description of demographic characteristics and aspects related to the surgical procedure in NS and S groups is reported in Table 1. tSFE was performed with additional use of Bio-Oss® spongiosa granules in 14 NS and eight S patients, Bioistite® in seven NS and eight S patients, Gen-Os® in four NS and

Table 1. Characterization of patients with different smoking status

<table>
<thead>
<tr>
<th></th>
<th>Non-smokers (NS)</th>
<th>Smokers (S)</th>
<th>P (Mann-Whitney)</th>
</tr>
</thead>
<tbody>
<tr>
<td>n° of patients</td>
<td>25</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Daily cigarette consumption (cigarettes/day)</td>
<td>0</td>
<td>15 (IR: 14.5–20.0, range: 6–40)</td>
<td>0.148</td>
</tr>
<tr>
<td>Smoking exposure (pack*years)</td>
<td>0</td>
<td>18.4 (IR: 13.3–26.3, range: 3–40)</td>
<td>0.227</td>
</tr>
<tr>
<td>Age (years)</td>
<td>54.0 (IR: 49.0–60.0, range: 37–70)</td>
<td>52.5 (IR: 43.8–57.0, range: 27–64)</td>
<td>0.148</td>
</tr>
<tr>
<td>Gender (male/female)</td>
<td>9/16</td>
<td>8/12</td>
<td></td>
</tr>
<tr>
<td>Residual bone height (mm)</td>
<td>5.0 (IR: 4.2–6.1, range: 3.3–7.6)</td>
<td>5.3 (IR: 4.7–5.8, range: 3.7–7.3)</td>
<td>0.676</td>
</tr>
<tr>
<td>Implant length (mm)</td>
<td>9.5 (IR: 8.5–10.0, range: 8.0–11.5)</td>
<td>9.5 (IR: 9.5–10.3, range: 8.0–11.0)</td>
<td>0.408</td>
</tr>
<tr>
<td>Implant diameter (mm)</td>
<td>4.0 (IR: 4.0–4.1, range: 3.3–5.0)</td>
<td>4.0 (IR: 4.0–4.5, range: 3.5–5.0)</td>
<td>0.359</td>
</tr>
<tr>
<td>Implant penetration (mm)</td>
<td>4.1 (IR: 3.7–5.3, range: 2.2–6.3)</td>
<td>4.1 (IR: 3.7–4.9, range: 3.1–6.0)</td>
<td>0.865</td>
</tr>
</tbody>
</table>

Data are expressed as median, IR and range.
three S patients and Ceros® in one S patient. No significant difference in patient distribution according to the type of graft biomaterial was observed between NS and S groups. Patient distribution according to implant system in NS and S groups is shown in Table 2.

In S group, daily cigarette consumption was 15.0 cig/day [IR: 14.5–20.0, range: 6–40]. Daily cigarette consumption was low [10 cig/day, IR: 10–12, range: 6–13] in five patients, moderate [15 cig/day, IR: 15–15, range: 15–18] in eight patients and high [20 cig/day, IR: 20–35, range: 20–40] in seven patients [P < 0.001].

Smoking exposure was 18.4 pack-years [IR: 13.3–26.3, range: 3–40]. Smoking exposure was low [10.2 pack-years, IR: 7.5–13.9, range: 3.0–15.0] in eight patients, moderate [22.5 pack-years, IR: 18.4–23.8, range: 17.5–25.0] in seven patients and high [30 pack-years, IR: 30.0–40.0, range: 30.0–40.0] in five patients [P < 0.001].

No differences in demographic characteristics and aspects related to the surgical procedure were found between S patients with either different daily cigarette consumption or different smoking exposure.

Table 2. Distribution of non-smoker (NS) and smoker (S) patients according to the implant system

<table>
<thead>
<tr>
<th>Implant system</th>
<th>NS (n = 25)</th>
<th>S (n ~ 20)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPI Element®</td>
<td>16</td>
<td>14</td>
</tr>
<tr>
<td>Certain® or Prevail®</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Standard Plus-Tissue</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Level®</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Osseospeed®</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Implus TTS®</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Pro-Series®</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 3. Radiographic outcomes of transcrestal sinus floor elevation in non-smoker (NS) and smoker (S) patients

<table>
<thead>
<tr>
<th></th>
<th>NS (n = 25)</th>
<th>S (n ~ 20)</th>
<th>P (Mann–Whitney)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post-surgery aGH (mm)</td>
<td>2.3 (IR: 1.3–2.8, range: 0–6.3)</td>
<td>2.5 (IR: 1.7–3.4, range: 0–4.4)</td>
<td>0.675</td>
</tr>
<tr>
<td>6-month aGH (mm)</td>
<td>2.0 (IR: 1.2–3.0, range: 0–5.0)</td>
<td>2.4 (IR: 1.6–2.9, range: 0–3.9)</td>
<td>0.707</td>
</tr>
<tr>
<td>P (Wilcoxon)</td>
<td>0.211</td>
<td>0.293</td>
<td></td>
</tr>
<tr>
<td>Post-surgery SL (mm)</td>
<td>6.5 (IR: 5.7–7.7, range: 4.0–9.5)</td>
<td>6.9 (IR: 6.0–7.7, range: 3.6–8.9)</td>
<td>0.883</td>
</tr>
<tr>
<td>6-month SL (mm)</td>
<td>6.7 (IR: 5.7–7.2, range: 3.5–9.4)</td>
<td>6.1 (IR: 5.9–7.4, range: 3.6–9.3)</td>
<td>1</td>
</tr>
<tr>
<td>P (Wilcoxon)</td>
<td>0.244</td>
<td>0.244</td>
<td></td>
</tr>
</tbody>
</table>

Data are expressed as median, IR and range. *One implant failed to osseointegrate before the 6-month visit. For this patient, radiographic measurements were not performed at 6 months.
The *Smart Lift* procedure resulted in a considerable vertical bone enhancement at 6 months in both NS and S groups. The magnitude of these results paralleled previous data on the same technique [Trombelli et al. 2010b, 2012], however, a wide variability in tSFE outcomes is reported among studies. The comparison between treatment outcomes obtained following different tSFE procedures is hindered by differences in the method for assessing the extent of SL. While some studies did not report explicitly the reference points [Horowitz 1997; Zitzmann & Schärer 1998; Nkenke et al. 2002; Artzi et al. 2003; Töfller 2004; Sotirakis & Gonchor 2005; Calvo-Guirado et al. 2006; Kang 2008; Schmidlin et al. 2008], other studies identified the “extent of SL” or “bone gain” with the length of the implant portion protruding into the sinus [Winter et al. 2002; Li 2005; Fermergård & Astrand 2008]. In contrast, in the present as well as in previous studies [Barone et al. 2008; Pjetursson et al. 2009; Trombelli et al. 2010b, 2012], the extent of SL derived from the linear measurement of the protruding implant and the amount of graft biomaterial apical to the implant apex.

The use of aGH as the primary outcome variable is based on long-term radiographic observations, which suggest that the presence of graft biomaterial over the implant apex may lead to new bone formation and subsequent apical displacement of the sinus floor [Bragger et al. 2004; Pjetursson et al. 2009].

In our study, 6-month aGH and SL were not associated with smoking status, thus suggesting that smoking has a limited impact on the radiographic outcomes of tSFE performed with the *Smart Lift* technique. Limited data are presently available to corroborate our findings. A study where tSFE was performed by osteotomes reported similar bone gain in smoker and NS patients at 6 months following surgery [Leblebicioglu et al. 2005].

Differently, when the effect of smoking was investigated for sinus floor elevations obtained with a lateral approach, current smoking significantly reduced the chance to achieve the mean SL at 9 months following surgery [Anduze-Acher et al. 2012]. It may be hypothesized that the detrimental effect of smoking on SL procedures may be in function of the extent of vertical bone enhancement that has to be achieved for implant placement. Also, the effect of smoking may be related to the level of invasiveness of the procedure, which is more limited in the tSFE with *Smart Lift* technique [Trombelli et al. 2010a] compared with the lateral approach [Pjetursson et al. 2008]. Also, it must be considered that S patients ranged from light smokers (6 cigarettes/day) to heavy smokers (40 cigarettes/day), thus raising the hypothesis that the inclusion of light smokers may have partly masked the negative effect of smoking on tSFE outcomes.

Within their limits, however, the present data seem to exclude a dose-dependent detrimental effect of smoking on the radiographic outcomes of the tSFE procedure.

In our material, limited, non-statistically significant changes in the outcome parameters were observed from pre-surgery to 6 months in both S and NS patients. To the best of our knowledge, no previous studies investigated the effect of smoking on post-surgery graft remodeling following tSFE procedures. Consistently with our findings, however, a limited extent of graft remodeling was reported at 6–12 months following tSFE by means of osteotomes and adjunctive use of a graft biomaterial in cohorts of patients including smokers and NS (Pjetursson et al. 2009; Kim et al. 2011). Overall, these data seem to confirm that a limited post-surgical loss in graft height occurs during the first months when tSFE is performed with the adjunctive use of graft biomaterials, smoking status being not an influencing factor on the extent of this remodeling.

One implant in the S group failed to osseointegrate before functional loading. The overall 1- and 2-year implant failure rate amounted to 2.2% [1 over 45 patients]. These data are consistent with a previous systematic review which reported an incidence of early implant failures of 1.3% [55 over 4388 implants] at sites undergone tSFE [Tan et al. 2008]. Although the available evidence does not identify smoking as an absolute contraindication for implant placement [Levin et al. 2004; Levin & Schwartz-Arad 2005], recent reviews indicated that smoking affects early implant failure [Palma-Carrió et al. 2011] as well as late implant survival [Klokkevold & Han 2007; Heitz-Mayfield & Huynh-Ba 2009]. In particular, the odds ratio for implant failure in the posterior maxilla for smokers vs. NS was 6.4 [Huynh-Ba et al. 2008]. Also, smoking adversely impacted implant survival at sites undergone sinus floor elevation procedures with a lateral approach [Geurs et al. 2001]. Whether and to what extent smoking may affect the long-term survival of implants placed following sinus floor elevation procedures, in general, and tSFE, in particular, needs to be thoroughly investigated.

In our study population, the incidence of membrane perforation was 6.7% [3 over 45 patients], with no significant difference in the incidence of perforations between NS and S patients. Similarly, a study where tSFE was performed with osteotomes in both smoker and NS patients reported an overall incidence of membrane perforation of 3.7%; however, the authors did not specify the incidence of perforations within each patient group [Leblebicioglu et al. 2005]. The observed incidence of membrane perforation may be considered limited with respect to data on complications following tSFE procedures stemming from a recent systematic review [Tan et al. 2008] and in consideration of the amount of SL achieved. Previous studies on tSFE with osteotomes, in fact, have shown that the incidence of membrane perforation is associated with the extent of SL [Reiser et al. 2001]. Interestingly, in our material, a substantial SL was obtained immediately after surgery, exceeding 5 mm in 40 of 45 Smart Lift procedures [data not shown]. Low incidence of membrane perforation observed in our study could be partly due to the use of adjustable stop devices that restrict the working action of burs and osteotomes to the native bone, thereby preventing the accidental penetration into the sinus cavity. Moreover, the combined use of a trephine bur in close proximity to the sinus floor limited the need for repeated malleting, resulting in less traumatic compared with conventional osteotome procedures [Trombelli et al. 2010b, 2012]. Our findings, therefore, seem to indicate that the Smart Lift procedure is associated with a limited incidence of complications in both NS and S patients.

All patients received a pre-medication based on a single dose of 2 g of amoxicillin. In addition, one operator prescribed all [n = 6] treated patients with a postoperative, prophylactic administration of amoxicillin [1 g b.i.d. for 6 days]. To date, no specifically designed studies investigated the potential beneficial effects of prophylactic antibiotic administration in tSFE procedures. Evidence from a limited number of randomized controlled trials, however, indicates that the use of a single dose of 2 g prophylactic amoxicillin prior to dental implant placement may significantly reduce the incidence of implant failure. Differently, it is still not clear whether and to what extent the postoperative assumption of antibiotics may be beneficial and which could be the most effective antibiotic protocol [Esposito et al. 2010; Sharaf et al. 2011].

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Franceschetti et al. Smoking and transcrestal sinus floor elevation
In the present study, different implant systems and graft biomaterials were used in association with the Smart Lift technique. It may be hypothesized that such technical aspects may to some extent have influenced the observed results, and their distribution within study groups may have exerted a confounding effect on the comparison between NS and S patients. Previous studies, however, did not find any significant effect of implant system, length and diameter on radiographic outcomes following tSFE over a 2-year period (Kim et al. 2011). Differently, a significant influence of the type of graft biomaterial on the extent of post-surgical graft remodeling following tSFE was demonstrated in previous studies (Pjetursson et al. 2009; Kim et al. 2011; Trombelli et al. 2012). Thus, although similar increments in height were obtained in NS and S groups as assessed immediately after surgery, it is possible to admit that the physicochemical characteristics of graft biomaterials in terms of resorption rate and osteoconductive properties may have partly affected the 6-month outcomes of the tSFE procedure in NS and S groups.

Within their limitations, the results of the present study indicate that tSFE performed with the Smart Lift technique results in a substantial vertical augmentation at 6 months post-surgery along with a limited incidence of complications in both S and NS.

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Conflict of interest

The authors declare that they have no conflict of interest.

References


