Comparison of Conventional Transcrestal Sinus Lift and Ultrasound-Enhanced Transcrestal Hydrodynamic Cavitational Sinus Lift for the Filling of Subantral Space: A Human Cadaver Study

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The implant-supported prosthetic rehabilitation of the posterior maxilla may require sinus-grafting procedures due to poor quality and low volume of bone. This can be accomplished using a "lateral window" sinus augmentation or with an osteotome sinus floor elevation (OSFE). The hydrodynamic ultrasonic cavitational sinus lift (HUCSL) (Intralift) is derived from the osteotome technique and allows the reduction of some of the traumatic effects of the osteotome technique. The aim of this study was to compare OSFE and the HUCSL procedures on fresh human cadaver heads. Primary outcomes were the height and width of the grafting area in the sinus floor area. Eighty-four maxillary sinuses were selected. On each fresh cadaver head, 2 sinus lifts were done using OSFE and HUCSL in the maxillary sinuses. Computerized tomography scans were performed on each head before and after the surgeries. Measurements were done on radiologic pictures using dedicated software, and the integrity of the sinus membrane was observed after dissecting the maxillae. The use of HUCSL resulted in a significantly higher sinus floor augmentation in the mesio-distal and bucco-palatal direction compared with the osteotome technique ($P < .001$). There was no correlation between mesio-distal and bucco-palatal diameters of sinus floor augmentation when only the osteotome protocol was considered ($r = 0.27$ and $P = .08$). In contrast, the mesio-distal and bucco-palatal diameters of floor augmentation were correlated when the HUCSL protocol was considered ($r = 0.79$, $P < .001$). HUCSL represents a good alternative method for sinus floor elevation.

Key Words: sinus floor augmentation, Summers technique, transcrestal sinus floor elevation, hydrodynamic ultrasonic cavitational sinus lift, Intralift, piezosurgery

INTRODUCTION

The implant-supported prosthetic rehabilitation of the posterior maxilla can be hindered by scarce and poor quality bone. Several advanced surgical techniques have been developed to overcome these limitations and they have shown predictable results.[1] The osseous ridge may need augmentation bucco-lingualy and/or apico-coronally prior to implant placement. The former requires a guided bone regeneration (GBR) procedure or a block graft[2] to augment bone width, and the latter is usually achieved with a sinus floor elevation to augment bone height. The principle of sinus floor augmentation is to intrude the floor of the maxillary sinus by lifting up the Schneiderian membrane after a lateral access to the sinus membrane.[3] In 1994, Summers presented the osteotome sinus floor elevation (OSFE), which is a modified surgical protocol using a crestal access.[4] In this technique, an osteotome is used to fracture the sinus floor and to lift the sinus membrane; then, grafting materials and implants can be inserted in the subantral space through the osteotomy site. The implants placed with OSFE have comparable success rates than those inserted in nonaugmented sites.[5] Comparing OSFE to the lateral window sinus lift, less morbidity[6] and faster treatment are reported with OSFE.[7] Some limitations of this method have been reported, caused by the absence of direct visual control of the sinus membrane integrity. Also, numerous authors underlined the aggressive character of the transcrestal method using OSFE: benign paroxysmal positional vertigo

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(BPPV) has been described as a consequence of the impaction of the osteotome. The trauma induced by the percussion with the surgical hammer, along with the hyperextension of the neck during the operation, can displace otoliths and induce BPPV.[8] To reduce the morbidity of OSFE, several modifications have been made to the initial protocol. The balloon sinus lift is another technique with crestal access, in which a balloon is inserted under the sinus membrane to push the membrane up, thanks to the inflation of the balloon. This technique is derived from classic "Summers" technique, and it has shown predictable results.[9,10] However, this method is technically demanding, and the balloon device may substantially augment the costs of the surgery. Similarly, a syringe can be used to inject a saline solution into the osteotomy site, thus creating a tenting effect under the Schneiderian membrane.[11]

In 2001, Vercellotti[12] described a new procedure for sinus elevation using an ultrasonic surgical technique that simplifies maxillary sinus surgery using the piezoelectric bony window osteotomy. The elevation of the membrane from the sinus floor was performed using both piezoelectric elevators and the pressure of a physiologic solution subjected to piezoelectric cavitation. A significant reduction of membrane perforation frequency has been reported with this method, because the sinus membrane was not subjected to tearing forces.

On the basis of these results and by combining several methods, the minimally invasive transcrestal hydrodynamic ultrasonic cavitational sinus lift (HUCSL = Intralift) for piezotome I/II has been developed.[13] The surgical steps of this technique are (1) to perform an initial osteotomy reaching the sinus floor level; (2) to push the sinus membrane up with the hydrodynamic pressure of the ultrasonic surgery device; and (3) to insert the grafting material in the subantral free space. Preclinical studies[14,15] and clinical applications[13,16] of this method have shown promising results, but there are still limited data that compare this new technique with conventional methods for sinus floor elevation.

We hypothesize that the Intralift method is equivalent to the Summers method for sinus floor elevation. We also hypothesize that less sinus membrane perforations occur when the Intralift method is used.

The aim of this in vitro study was to compare the osteotome technique (Summers) and the Intralift procedure on human cadavers. The main outcomes evaluated were the diameter and height of the biomaterial grafted in the subantral space. The secondary objective was to evaluate the incidence of sinus membrane perforations.

Materials and Methods

Forty-two fresh human heads (resulting in 84 maxillary sinuses) were selected in the laboratory of anatomy of Bordeaux Segalen University. Entire heads were used for the study, without dissection of the maxillae. The mean age of the subjects was 75 years. All fresh human heads were imaged before the surgical procedure using the computerized tomography (CT) scanner Sensation 16 (Siemens, Herlangen Germany). The inclusion criteria of the specimens were bilateral edentulous maxillae; substantial bone resorption on the alveolar ridges; a residual ridge height between 3 and 6 mm, and a minimal width of 6 mm. Pathologic sinuses (fractures, polyps, oro-antral fistula) and sinuses with septa were excluded from the study after analyzing the results of the first scanner.

Specific equipment was used to perform the 2 different surgical procedures. For the Intralift technique, we used ImplantCenter-2 devices (Satelec Acteon, Mérignac, France), contra-angles and piezotome handpieces (Satelec Acteon), round burs (Nobel Biocare, Bagnolet, France), 2-mm-diameter pilot drills (Nobel Biocare), and sets of inserts TKW1 to TKW5 (Satelec Acteon). For the osteotome technique, osteotome kits (Stoma, Emmingen-Liptingen, Germany), drilling kits (Nobel Biocare), and surgical mallets (Henry Schein ASA Dental, Paris, France) were used. For the filling of the subantral space, collagen sponges (ETIK Collagène, Pierre Roland, Satelec, France) and 0.5- to 1-mm-diameter granules of Fake BioOss (Geistlich Pharma, Roissy-en-France, France) were used. A mean quantity of 2 g of Fake BioOss was used for each sinus. Sutures were done using MERSILK 3-0 sutures (Ethicon, Issy-les-moulineaux, France) for both techniques.

On each fresh cadaver head, an Intralift technique (Satelec Acteon) was performed in one sinus and the osteotome technique in the other. The 2 methods were distributed randomly in each sample. Two experienced operators performed both techniques. The surgical methods and protocols used in this study are similar to clinical protocols established previously.[15,17] First, a mucoperiosteal flap was performed for both techniques to expose the entire maxillary ridge, using midcrestal incisions and mesial and distal releasing incisions. The surgical protocol for the Intralift technique followed the Intralift protocol: a pilot trepanation was performed with the diamond-coated TKW1 ultrasonic tip for piezotome I/II/SOLO (Satelec Acteon). The sinus floor was opened with the diamond-coated atraumatic TKW2 ultrasonic tip. Then, a receptacle was prepared for the elevation applicator TKW5 with the flat diamond-coated TKW4 ultrasonic tip. The flow rate of saline solution was 80 mL/min for the TKW1 to TKW4 tips. Finally, the sinus membrane was separated from the antral bone with the hydrodynamic ultrasonic cavitational applicator TKW5 using saline solution at a flow rate of 30 mL/min for 5 seconds, thus creating a subantral space under the elevated sinus membrane. Once the sinus membrane was elevated, a collagen sponge of approximately 20 mm^3 was inserted subantrally before filling the subantral space with the radiopaque bone graft material (Fake BioOss, 0.5–1 mm, Geistlich Pharma). A mean quantity of 2 g of Fake BioOss was inserted to stabilize the elevated sinus membrane and maintain the elevation volume achieved with the tHUCSL-Intralift procedure. The flap was sutured around the elevated area.

The Summers technique was performed according to the Summers protocol.[18] After full-thickness mucoperiosteal flap reflection, a round bur was first used to mark the target positions. Then, the pilot drilling (2.2 mm) was done with a depth evaluated from preoperative CT scan images: approximately 1 mm of bone was kept intact under the sinus floor. The elevation of the maxillary sinus was achieved using a 2.8-mm-diameter osteotome with moderate percussions to fracture the initial sinus floor. Then, the lifting of the sinus floor was continued with osteotomes of increasing diameters (3.5 and 4.2 mm diameter) until tissue compression stopped the progres-

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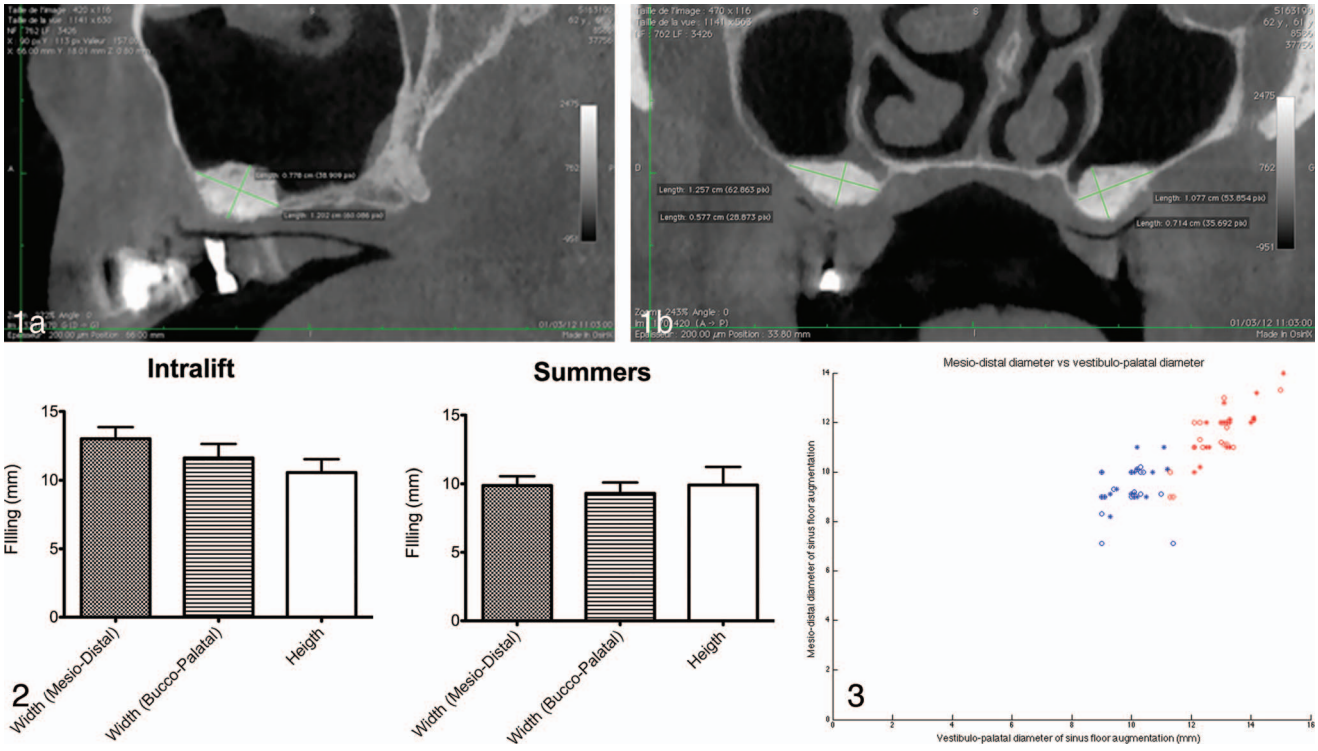

Figures 1–3. Figure 1. Postoperative computerized tomography images of the filling of subantal space: (a) sagittal view; (b) frontal view. **Figure 2.** Width (mesio-distal and bucco-palatal) and height of the sinus grafting using the osteotome sinus floor elevation or hydrodynamic ultrasonic cavitational sinus lift method. **Figure 3.** Correlation of the diameters of the sinus floor elevation on both axes. The combination of hydrodynamic ultrasonic cavitational sinus lift and osteotome sinus floor elevation results in mesio-distal and vestibulo-palatal diameters is highly correlated ($r = 0.87$, $P < .001$). There was no correlation between mesio-distal and bucco-palatal diameters of sinus floor augmentation when only the osteotome protocol was considered ($r = 0.27$ and $P = .08$). In contrary, the mesio-distal and bucco-palatal diameters of floor augmentation were correlated when the Intralift protocol was considered ($r = 0.79$, $P < .001$).

sion of the instruments. At this stage, the integrity of the membrane was controlled with an undersized depth gauge of 2.1 mm; however, microperforation of the Schneiderian membrane could not be excluded at this stage of the procedure. After the elevation of the sinus membrane, 2 g of Fake BioOss was inserted into the subantral space with osteotomes. The flap was sutured around the elevated area.

After the surgeries, postsurgical CT scans were performed on each head, using the same protocol as in the preoperative CT scans. The amount of sinus floor elevation was evaluated in both protocols by comparing the presurgical and postsurgical CT scans. Measurements were done using Osirix V.3.5.1 32-bit software.[19,20] The width (millimeters) and the height (millimeters) of the sinus floor augmentation were measured, including the radio-opaque material grafted and the alveolar crest. The height was measured on transversal and parasagittal sections. The bucco-palatal diameter was measured on transversal and horizontal sections; the mesio-distal diameter was measured on horizontal and parasagittal sections.[15,21] Due to the variability of ridge height from one sinus to another, the height of the sinus floor augmentation was acquired by subtracting the height of the residual alveolar bone ridge from the height of the new ridge after augmentation. The measurements were done 3 times on each sinus, by 3 different operators, and mean values were used for the results.

Finally, all the maxillae were dissected to allow direct visualization of the sinus floor area to evaluate the integrity of the sinus membrane in the elevated zone. The presence of membrane perforation was recorded.

Statistical analyses were done using Matlab software (R2012b, Matlab, Natick, Mass). An analysis of variance blending the axis of measure (mesio-distal diameter, bucco-palatal diameter, and height of subantral filling) and technique (osteotomes or Intralift) was accomplished to compare the amount of floor augmentation between both techniques. To compare mesio-distal and bucco-palatal diameters of floor augmentations for both techniques and between both practitioners, the Huynh-Feldt and Flingner-Killeen tests allowed, on one hand, to evaluate that independent tested variables (technique and expertise) have a similar effect on each sinus, and on the other hand, to assess whether analysis and comparisons were valid. The threshold value for statistical significance was set at $P < .05$.

Results

Preoperative measurements made on CT scans showed that the mean residual bone height on the 84 sinuses was 4.35 ± 0.7 mm.

Postoperative CT scan observations revealed the filling of the subantral area in mesio-distal sections (Figure 1a) and bucco-palatal sections (Figure 1b). Measurements showed that

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the mean sinus floor filling using the Intralift method was 13 ± 0.85 mm in height, 11.6 ± 1.02 mm in the bucco-palatal direction, and 10.57 ± 0.94 mm in the mesio-distal direction. Using the Summers method, the mean sinus floor filling was 9.87 ± 0.67 mm in height, 9.3 ± 0.79 mm in the bucco-palatal direction, and 9.9 ± 1.29 mm in the mesio-distal direction (Figure 2). In this study, the use of the Intralift method resulted in a significantly higher sinus floor augmentation in the mesio-distal and bucco-palatal directions compared with the osteotome technique ($P < .001$).

The direct observations of the sinus floor made after dissecting the maxillae at the end of the experiment revealed that the sinus membrane was perforated in 15 cases (35.7%) in the Summers group and in 1 case (2.3%) in the Intralift group.

There was a strong correlation ($r = 0.87$, $P < .001$) between mesio-distal and bucco-palatal diameters of floor augmentation when the data from OSFE and HUCSL are combined (Figure 3). There was no correlation between mesio-distal and bucco-palatal diameters of sinus floor augmentation when only the osteotome protocol was considered ($r = 0.27$ and $P = .08$). In contrast, the mesio-distal and bucco-palatal diameters of floor augmentation were correlated when the intralift protocol was considered ($r = 0.79$, $P < .001$; Figure 3).

Discussion

This study showed that sinus floor augmentation on human cadaver heads can be achieved to a larger extent in height and width with HUCSL than using the method with osteotomes. The diameter of the grafted area evolved in a similar way on both mesio-distal and bucco-palatal axes with the ultrasonic Intralift. This was not observed with the osteotome technique. Also, the height of the sinus floor augmentation followed the increase of the mesio-distal and bucco-palatal diameters.

There have been several human cadaver studies performed before to evaluate various sinus lift techniques and potential complications.[22–24] This model presented a good reproduction of the clinical situation allowing an easy transfer of new surgical methods to patients. Moreover, potential complications of sinus floor elevation procedures can be observed directly after dissection of the maxillae. Also, conventional follow-up methods based on X rays can be easily performed.

In this study, the sinus floor augmentation in height and width obtained with the HUCSL (Intralift) method was better than using the osteotomes method. These results may be due to several factors: the hydrodynamic pressure applied by ultrasound over the membrane is homogeneously distributed because of its centrifugal orientation. The cavitation effect of ultrasounds leads to a progressive detachment of the Schneiderian membrane and also may help to insert the material under the sinus membrane in a centrifugal manner. Moreover, a uniform pressure is applied to the sinus membrane, especially at the delicate margins where the sinus membrane is still attached to the bony floor.

Another hypothesis pertains to the ultrasonic oscillations of the injected water column caused by the modulated piezotome hand piece. These oscillations might add a safety component to the elevation process, because of the cavitation effect of the liquid.[15] This may give the sinus membrane a relaxation time between the pressure peaks and could lead to a sinus membrane elevated using ultrasonic-activated hydrodynamic pressure "hopping" over bony crests and septa inside the sinus.[25]

In contrast, using the osteotome lift procedure, the pressure on the membrane is located only at the top of the instrument. When pushing up, the entire surrounding sinus membrane receives tearing forces and thus cannot be elevated sufficiently with the same force as Intralift.[14,16] Moreover, the impaction of the osteotome in the osteotomes method leads to a force oriented mainly in the axis of the osteotome, thus increasing the risk of membrane perforation. Previous in vitro experiments of Jank et al[14] showed that the Intralift method would reduce the incidence of sinus membrane rupture after a single puncture of the membrane with a 1.2-mm-diameter pilot drill compared with the conventional osteotome technique. This was confirmed in our study by direct observations of dissected maxillae showing that sinus membranes have been perforated more frequently with the osteotomes than with the transcrestal HUCSL.

It is noteworthy that the 2 methods used in this study to perform a sinus lift, as well as the balloon-assisted sinus topspin, are generally recommended to prepare the cavity for a single implant placement. The results observed in this study reveal that it might be possible to perform a sinus lift of large dimensions in the antero-posterior axis, using several transcrestal sinus lift approaches juxtaposed. This would reduce the invasiveness of the conventional sinus lift procedure and could also be used when large bone septa are located in the sinus floor.[26] This crestal approach for a large sinus lift has already been described using press-fit bone cylinders[27] or the osteotomes technique,[28] and they allow a reduction in morbidity for the procedures.

Conclusion

This in vitro study demonstrated that according to 3 quantitative variable of sinus floor filling (vestibulo-palatal and mesio-distal diameters and height), and taking into account the protocol of this study, the Intralift method represents a good alternative for transcretal sinus floor elevation compared with Summers technique. If future clinical applications of this method confirm the results of the present study, this technique will provide an advantage over the lateral window access because of reduced invasiveness.

Abbreviations

BPPV: benign paroxysmal positional vertigo
GBR: guided bone regeneration
HUCSL: hydrodynamic ultrasonic cavitational sinus lift (Intralift)
OSFE: osteotome sinus floor elevation

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