Intraoperative Measurement of the Distance from the Bottom of Osteotomy to the Mandibular Canal Using a Novel Ultrasonic Device

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ABSTRACT

Background: In our previous study, we found that a novel ultrasound (US) device may serve as a useful intraoperative tool to measure the distance from osteotomy to the inferior alveolar canal (IAC).

Purpose: To validate our previous results in a larger group of osteotomies in the posterior mandible.

Methods: During dental implant placement surgery, osteotomies were created using a standardized 2-mm-diameter pilot drill. The distance from the bottom of the osteotome to the IAC was assessed using an ultrasonic device and compared with a standard panoramic radiograph used to measure the same residual distance. The total distance from the crestal bone to the IAC was measured on a preoperative computed tomography (CT) and compared with total US measurements by summing the drill depth with residual depth measurements.

Results: Mean radiographic and US residual distances were 5.19 ± 1.95 mm, 5.01 ± 1.82 mm, $p = 0.79$ respectively. These measurements presented strong positive correlations ($r = 0.61$, $p = .01$). Mean total CT distance was 13.48 ± 2.66 mm; mean total US calculation was 13.69 ± 2.51 mm. No significant difference was found ($p > .05$).

Conclusions: The results support our previous pilot study and confirm that the tested US device identifies the IAC and measures the distance from the osteotomy to the roof of the mandibular canal.

KEY WORDS: cone-beam computed tomography, implant, mandibular nerve, mandibular osteotomy

INTRODUCTION

Dental implants are becoming the preferred treatment for replacing missing teeth. In the USA, the number of implants placed by general practitioners, periodontal surgeons, and maxillofacial surgeons is growing by 500,000 a year and the estimated USA market for dental implants is $1 billion.[1] Although high survival rates are reported,[2] several intraoperative complications may occur.[3–5]

One of the most serious complications following dental implant placement in the posterior mandible is injury to the inferior dental nerve. Prevalence of traumatic nerve injury stands on 5 to 15%,[6] and may cause permanent or transient paresthesia. In addition, a life-threatening complication is perforation of the mandibular lingual cortical plate and damage to the sublingual and submental arteries.[7,8] This event may cause airway obstruction in rare cases.[9] In order to avoid such injuries during implant placement, preoperative and intraoperative radiographs are often taken. Periapical and panoramic views are the most commonly used radiographs due to their availability in dental clinics, low cost and low radiation.[10] However, other three-dimensional imaging methods, such as computed tomography (CT) and magnetic resonance imaging (MRI), are also frequently used to demonstrate the location of anatomical structures within the bone.[11]

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Dental CT is the most accurate technique used to evaluate bone dimensions in edentulous sites, and is thus considered the gold standard. However, several drawbacks of CT still exist: relatively high ionizing radiation, high cost, and 0.5 to 3 mm inaccuracy of the measurements in the vertical axis.[12–14] These inaccuracies require a 2-mm safety zone between the apex of the drill and the top of the mandibular canal to avoid neural damage.[15] However, in cases of severe alveolar atrophy, with ≤10 mm residual vertical bone height, operators are often faced with a dilemma of using short or even very short implants,[16] or taking a risk of installing implants in close proximity to the mandibular canal.

Ultrasound (US) is a noninvasive, inexpensive, and painless imaging method. Unlike X-rays, it does not cause harmful ionizing radiation and can be used for both hard and soft tissue detection.[17] Medical ultrasound (US) devices are used mostly for diagnostic imaging of tendons, muscles, joints, vessels, and internal organs. US devices are also being used as an intraoperative guide in anesthesiology while injecting local anesthetic solutions near nerves, in amniocentesis, and in fine needle aspiration biopsies.[18] In addition, US guidance can prevent injuring the facial nerve during biopsy of the parotid gland.[17] The use of ultrasonography for diagnostic imaging and intraoperative guidance has several further advantages: it provides images in real time, it is portable and can be brought to a sick patient's bedside. Drawbacks of ultrasonography include its relative dependence on a skilled operator.[18]

In our previous pilot clinical study, we investigated the potential of a novel US device (JetGuide, Haifa, Israel) to measure intraoperatively the distance from osteotomy to the floor of the maxillary sinus or to the top of the mandibular canal. We compared US measurements to radiographic measurements obtained by intraoperative panorex with a surgical gauge. Our results indicated a strong positive correlation between US and radiographic measurements in the mandible; nevertheless, a nonsignificant and weak correlation was found in the maxilla. Based on these results, we have concluded that the tested US device may serve as a useful intraoperative tool to measure the distance from osteotomy to the mandibular canal.[19] Therefore, the aim of the current, prospective clinical trial was to validate our previous results in a larger group of osteotomies in the posterior mandible.

MATERIALS AND METHODS

This study was approved by the Helsinki committee of Rambam Health Care Campus (RHCC). Patients who completed initial therapy in the Department of Periodontology RHCC, and were scheduled for implant placement in the posterior mandible, were recruited for this study. Patients were excluded if presenting one (or more) of the following criteria: under the age of 18, scheduled for immediate implant placement or for flapless procedure, pregnant woman, and failing to identify the mandibular canal on panoramic view. In order to avoid injury to the inferior dental nerve, and according to our department's surgical protocols, before surgery, surgical sites were scanned by cone beam CT and the distance from the crestal bone to the top of the mandibular canal was measured (at the planned osteotomy locations) and recorded (termed: total CT).

Surgical procedures were performed by two periodontal surgeons (EEM and HZ-G) who were trained to use the novel ultrasonic device. Following local anesthesia, full thickness mucoperiosteal flaps were reflected. Pilot drills were performed using 2-mm diameter ceramic burrs. The depth of each osteotomy was measured using a standardized surgical probe (termed: probing drill depth, PDD).

Ultrasonic Measurements

Drill depth and the distance from the bottom of the osteotomy to the top of the mandibular canal were measured three times by the ultrasonic device. The minimum range of the measured parameters was 2 mm; maximum range was 35 mm at a 0.2 mm resolution of the device. An average of the three measurements was used as the final measurement. These measurements required insertion of the tip of the ultrasonic hand piece into the osteotomy opening (Figure 1, A and B). The ultrasonic waves propagate via a laminar stream of physiological solution (saline) that flows from the hand piece to the osteotomy opening. The first reflection of the US waves comes from the entrance of the osteotomy and the second reflection comes from the bottom of the osteotomy. Thereafter, the US waves propagate through the trabecular bone until they reach the coronal surface of the mandibular canal and are then reflected back to the US transducer. The US transducer transforms the US pressure waves into electronic signals which are amplified, processed, and the distances finally displayed on the device panel screen for the surgeon. The amount of

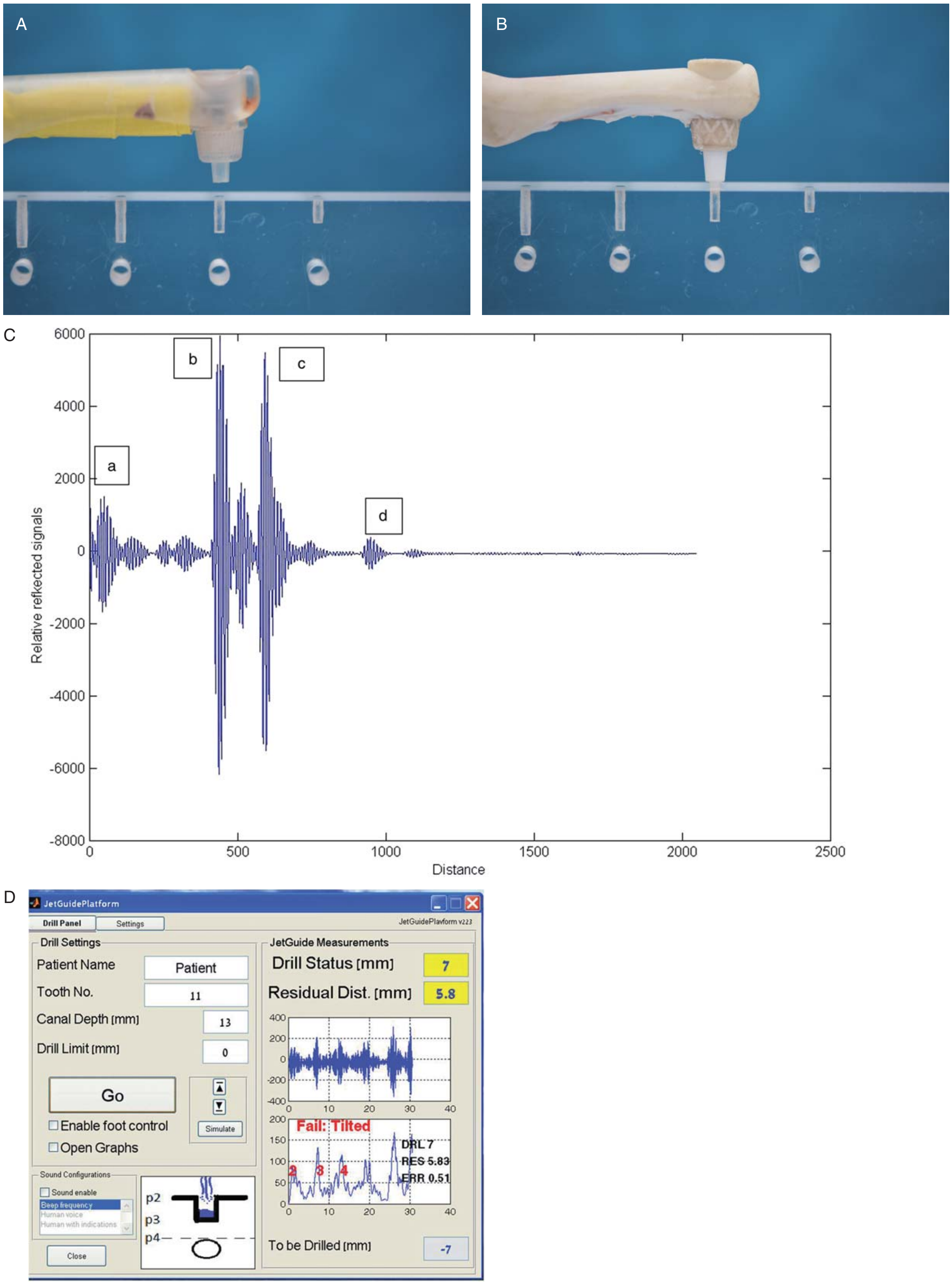

Figure 1 Method of use of US device. *A*, US device was designed for intraoral use. In the previous model of the device, the headpiece's head had to be held 1 mm above the osteotomy opening to allow US measurements. *B*, In the current improved model of the device, the plastic tip is inserted into the osteotomy opening. *C*, US waves that hit the tissue are reflected and captured by a transducer that transforms the US waves into electric signals: signal (a) at the open of the osteotomy, signal (b) at the bottom of the osteotomy, signal (c) at the top of the mandibular canal, and signal (d) at the bottom of the mandibular canal. *D*, US measurements (in mm) are displayed on a screen: drill depth and residual distance.

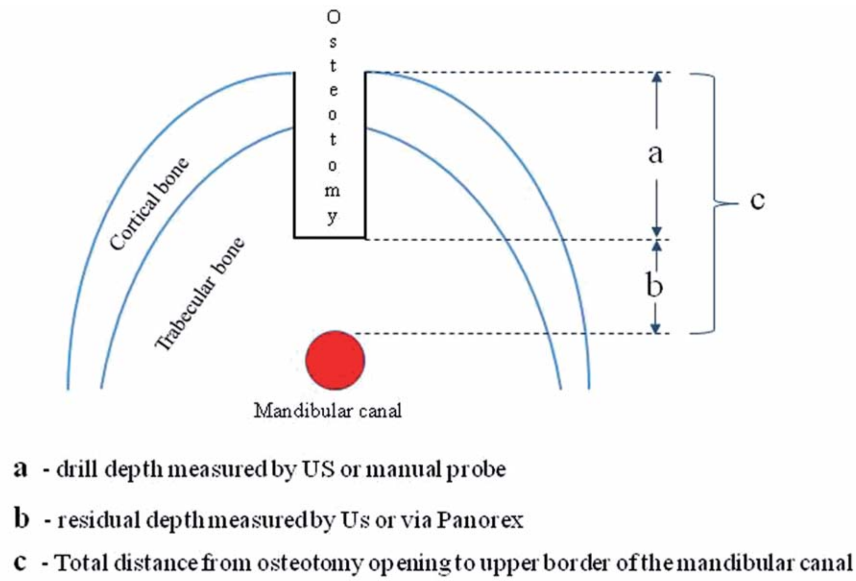

Figure 2 An illustration demonstrating the clinical, ultrasonic, and radiographic measurements.

physiological solution within the tissue influences the waves' reflection; therefore, the device is able to recognize and differentiate between cancellous bone, cortical bone, and soft tissue (Figure 1C). Osteotomy drill depth (US drill) and the residual distance (US residual) are displayed on the device panel screen (Figure 1d).

Radiographic Measurements

Digital panoramic radiographs (Plamenca Proline XC, Helsinki, Finland) were taken with a standardized gauge inserted into the osteotomy. The radiographic distances from the bottom of the osteotomy to the upper border of the mandibular canal (termed XR residual) were measured by an examiner (MS) who was blinded to the US measurements. Radiographic measurements were obtained using a computer software (Dimaxis Pro version 4.1.6, Plamenca, Helsinki, Finland). The results were reduced by 20% in order to correct magnification at the posterior mandible.[10]

Calculation of the Distance from the Bone Crest to the Top of the Mandibular Canal

Total distance was measured on preoperative CT and recorded. Furthermore, this distance was calculated by the summation of:

1) US measurements: US drill plus US residual.
2) Probing drill depth plus radiographic residual distance (Figure 2).

Statistical Analysis

A StatPlus® statistical package (AnalystSoft, Vancouver, BC, Canada) was used. Means, ranges, and standard deviation (SD) values were initially calculated for: probe drill depth, ultrasonic drill depth, residual ultrasonic measurement, and residual radiographic measurements.

Wilcoxon test was used to compare measurements obtained by different techniques and for validation of the results due to the small sample size.

Pearson's correlation coefficient test was used to assess association between different measuring techniques. $p \leq .05$ was determined as significant.

RESULTS

Ten patients (five women and five men) aged 43 to 68 were enrolled in the study. Eighteen implant osteotomies were performed, measured, and recorded. In one case, the mandibular canal could not be identified on the panoramic view and was therefore excluded.

Osteotomy depth was measured by standardized surgical probe and using the ultrasonic device. Mean probing drill depth was 9.32 ± 1.52 mm, while US drill depth was 8.58 ± 2.1 mm. Significant differences were not observed between these measuring techniques ($p = .32$); however, the correlation between them was relatively week ($r = 0.25$, $p = .2$).

The residual distance was measured from the bottom of the osteotomy to the top of mandibular canal

TABLE 1 Correlation and Variance between Clinical, Radiographic, and US Measurements (Pearson's Correlation Coefficient Test and Wilcoxon Test)

	Probing drill (Mm)	US drill (Mm)	Residual US (Mm)	Residual radiograph (mm)
Mean ± SD	9.32 ± 1.52	8.58 ± 2.1	5.01 ± 1.82	5.19 ± 1.95
Correlation	Probing drill versus US drill		Residual US versus residual radiograph	
	$r = 0.25$, p = .2		$r = 0.61$, p = .01	
Variance	$p = .32$		$p = .79$	

using panoramic radiographs and via ultrasonic device (Table 1): mean radiographic residual distance was 5.19 ± 1.95 mm. Almost similar results were recorded with the ultrasonic device (mean 5.01 ± 1.82 mm, $p = .79$). These radiographic and ultrasonic residual-distance measurements presented strong positive correlations ($r = 0.61$, $p = .01$; Figure 3).

The total distance from the crestal bone to the mandibular canal was measured on the preoperative CT and calculated by summing US measurements (total US measurements) and by summing the probing drill depth with the residual radiographic measurements (total clinical measurements). Mean total CT distance was 13.48 ± 2.66 mm; mean total US calculation was 13.69 ± 2.51 mm; and mean total clinical measurement was 14.48 ± 2.97 mm. Differences were not observed between these three measuring methods ($p > .05$); moreover, a very strong positive correlation was found between total CT and total US ($r = 0.95$, $p = .00$). A positive correlation, but to a lesser extent, was found between total clinical measurements and total CT ($r = 0.7$, $p = .00$) and between total clinical measurements and total US ($r = 0.73$, $p = .00$).

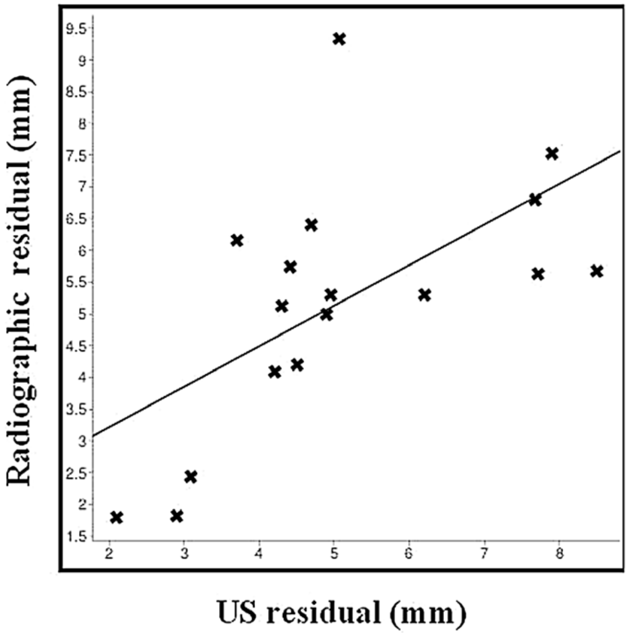

Figure 3 Residual distance measurements: Pearson's correlation between US and radiographic.

DISCUSSION

In the present study, we found that US device identified intraoperatively the roof of the mandibular canal and provided real-time measurements of: drill depth, residual distance from osteotomy to the mandibular canal, and the total vertical dimension from bone crest to the mandibular canal. US measurements were found to be in strong positive correlation with measurements obtained by other clinically available technologies: preoperative vertical dimension of bone using CT, intraoperative probing of osteotomy depth, and intraoperative radiograph with gauge to measure residual distance.

In a previous pilot study, we used a similar US device to measure the residual distance from osteotomy to maxillary sinus floor and to the mandibular canal in real time. Eleven mandibular and 10 maxillary osteotomies were tested. In accordance with our current results, we found a positive correlation between radiographic (panoramic) and ultrasonic measurements ($r = 0.57$, $p = .007$). However, when we dichotomized the results into maxilla and mandible, we found a strong positive correlation between radiographic and US measurements in the mandible, but a weak and nonsignificant correlation in the maxilla. We assumed that these results could be related to difficulties in identifying the floor of the maxillary sinus on panoramic views.[19] Therefore, in the present study we measured only mandibular osteotomies. Furthermore, in order to gain more accurate ultrasonic measurements, slight changes in the US device were made: generally, a stem of water (that transfers the US waves) streams from a plastic tip at the headpiece's head (Figure 1A). In the previous model of the device, the plastic tip had to be held in a parallel position 1 mm above the osteotomy opening. Even a minor deviation from this position could cause inaccurate measurements. In the current study, in order to avoid misalignment of the device, the water jet streamed from a small plastic tip (2 mm wide, 2 mm long) that was inserted into the osteotomy. The improved design of the device reduced the number of US error measurements (when compared with our previous pilot study) and shortened the time required for individual measurements. Moreover, a steeper learning curve is now expected. This made the device ultimately more user-friendly and accurate. An additional benefit to the novel US device may be the detection of buccal or lingual perforations during osteotome preparation. At present, periapical and panoramic radiographs are used intraoperatively to evaluate the residual distance from the osteotomy to vital anatomic structures. However, both have several shortcomings: exposing the patient to radiation, elongating operation duration, patient discomfort, and increasing the risk for contamination. Nevertheless, the biggest concern using these methods is failing to identify the mandibular canal that occurs in 28% of patients using periapical radiographs[20] and in 36% of the patients using panoramic radiographs.[21] Additionally, distortion of periapical and panoramic radiographs frequently occurs due to angulation of the periapical film[22] and due to the position of the mandibular canal in a horizontal plane that influence the apparent amount of bone above the canal in panoramic views. For example, if the canal lies close to the lingual cortex, it will be projected higher on the panoramic radiograph.[23]

Computer-aided surgery is gaining popularity in recent years. It allows a greater accuracy in implant positioning, taking advantage of the amount of available bone and the later prosthetic restoration.[24] This method is useful in situations where an exact implantation is demanded, such as: anatomical limitations, atrophic maxillae, sinus lifts, or zygomatic implants. Stereolithographic guides have been developed as a solution for transferring the implant plan from the dental CT scan to the surgical settings. In that sense, stereolithographic guides have been the first step in implementing image-guided surgery to facilitate more judicious placement of dental implants. Nevertheless, despite careful planning of implant location using CT and specific software, numerous studies that investigated the accuracy of this methodology presented conflicting results.[25–28] An alternative, less common approach, is real-time navigation that relies on a preoperative CT and a tracking system for the surgical instrumentation that allows following the instrumentation position during the surgery and their visualization on the computer screen.[29] In this method, precision varies according to the navigation system used.[30] An infrared camera is the common tracking system, with a precision of approximately 0.3 mm.[31] Stereolithographic guides and real-time navigation require preoperative CT and both have added costs to the implant procedure.

Currently, the use of US in implant surgery is limited to the measurement of soft tissue thickness. These measurements help practitioners to select the proper orthodontic miniscrews in clinical practice,[32] aid in implant placement without incision and flap elevation, as well as assist with the detection of implants deeply submerged after thick connective tissue grafts for surgical exposure for subsequent prosthodontic rehabilitation.[33] In the present study, we present a greater benefit to the use of US which may provide simpler, safer, and more accurate implant placement.

According to the results of the present study, real-time ultrasonic measurements of the total distance from bone crest to the mandibular canal were almost identical to the preoperative CT measurements ($r = 0.95$, $p = .00$). Hence, with further research and development of the device, it may reduce the need for preoperative CT.

CONCLUSIONS

The results of the current study support our previous pilot study and confirm that the tested US device is able to identify the mandibular canal and to measure the distance from the osteotomy to the roof of the mandibular canal. Intraoperative measurements during drilling for dental implants may provide the operator with an additional knowledge regarding the location of vital anatomical structures and may significantly reduce neural injury. Further large cohort and multicenter studies are required to confirm these results.

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REFERENCES

1. Press room, Dental implant facts and figures. American Academy of Implant Dentistry, 2015.

2. Pjetursson BE, Asgeirsson AG, Zwahlen M, Sailer I. Improvements in implant dentistry over the last decade: comparison of survival and complication rates in older and newer publications. Int J Oral Maxillofac Implants 2014; 29(Suppl):308–324.
3. Pigadas N, Simoes P, Tuffin JR. Massive sublingual haematoma following osseointegrated implant placement in the anterior mandible. Br Dent J 2009; 206:67–68.
4. Hegedus F, Diecidue RJ. Trigeminal nerve injuries after mandibular implant placement – practical knowledge for clinicians. Int J Oral Maxillofac Implants 2006; 21:111–116.
5. Rokadiya S, Malden NJ. An implant periapical lesion leading to acute osteomyelitis with isolation of Staphylococcus aureus. Br Dent J 2008; 205:489–491.
6. Gregg JM. Neuropathic complications of mandibular implant surgery: review and case presentations. Ann R Australas Coll Dent Surg 2000; 15:176–180.
7. Bavitz JB, Harn SD, Homze EJ. Arterial supply to the floor of the mouth and lingual gingiva. Oral Surg Oral Med Oral Pathol 1994; 77:232–235.
8. Hofschneider U, Tepper G, Gahleitner A, Ulm C. Assessment of the blood supply to the mental region for reduction of bleeding complications during implant surgery in the interforaminal region. Int J Oral Maxillofac Implants 1999; 14:379–383.
9. Woo BM, Al-Bustani S, Ueeck BA. Floor of mouth haemorrhage and life threatening airway obstruction during immediate implant placement in the anterior mandible. Int J Oral Maxillofac Surg 2006; 35:961–964.
10. Kim Y-K, Park J-Y, Kim S-G, Kim J-S, Kim J-D. Magnification rate of digital panoramic radiographs and its effectiveness for pre-operative assessment of dental implants. Dentomaxillofac Radiol 2011; 40:76–83.
11. Gray CF, Redpath TW, Smith FW, Staff RT. Advanced imaging: magnetic resonance imaging in implant dentistry. Clin Oral Implants Res 2003; 14:18–27.
12. Halperin-Sternfeld M, Machtei EE, Horwitz J. Diagnostic accuracy of cone beam computed tomography for dimensional linear measurements in the mandible. Int J Oral Maxillofac Implants 2014; 29:593–599.
13. Di Giacomo GA, Cury PR, de Araujo NS, Sendyk WR, Sendyk CL. Clinical application of stereolithographic surgical guides for implant placement: preliminary results. J Periodontol 2005; 76:503–507.
14. Van Assche N, van Steenberghe D, Quirynen M, Jacobs R. Accuracy assessment of computer-assisted flapless implant placement in partial edentulism. J Clin Periodontol 2010; 37:398–403.
15. Lindhe J, Lang NP, Karring T. Clinical Periodontology and Implant Dentistry. 5th ed. 2 Volumes. Oxford: Blackwell Munksgaard, 2008:611.
16. Lee SA, Lee CT, Fu MM, Elmisalati W, Chuang SK. Systematic review and meta-analysis of randomized controlled trials for the management of limited vertical height in the posterior region: short implants (5 to 8 mm) vs longer implants (> 8 mm) in vertically augmented sites. Int J Oral Maxillofac Implants 2014; 29:1085–1097.
17. Shah N, Bansal N, Logani A. Recent advances in imaging technologies in dentistry. World J Radiol. 2014; 6:794–807.
18. WHO study group. Training in diagnostic ultrasound: essentials, principles and standards; Report of WHO study group 1998. p. 875.
19. Machtei EE, Zigdon H, Levin L, Peled M. Novel ultrasonic device to measure the distance from the bottom of the osteotome to various anatomic landmarks. J Periodontol 2010; 81:1051–1055.
20. Misch CE. Diagnostic imaging techniques. Contemporary implant dentistry. 3rd ed. St. Louis: CV Mosby Company, 2008:38–67.
21. Klinge B, Petersson A, Maly P. Location of the mandibular canal: comparison of macroscopic findings, conventional radiography, and computed tomography. Int J Oral Maxillofac Implants 1989; 4:327–332.
22. Greenstein G, Tarnow D. The mental foramen and nerve: clinical and anatomical factors related to dental implant placement: a literature review. J Periodontol 2006; 77:1933–1943.
23. Worthington P. Injury to the inferior alveolar nerve during implant placement: a formula for protection of the patient and clinician. Int J Oral Maxillofac Implants 2004; 19:731–734.
24. Jacobs R. Preoperative radiologic planning of implant surgery in compromised patients. Periodontol 2000 2003; 33:12–25.
25. Wanschitz F, Birkfellner W, Watzinger F, et al. Evaluation of accuracy of computer-aided intraoperative positioning of endosseous oral implants in the edentulous mandible. Clin Oral Implants Res 2002; 13:59–64.
26. Van Assche N, Van Steenberghe D, Guerrero ME, et al. Accuracy of implant placement based on pre-surgical planning of three-dimensional cone-beam images: a pilot study. J Clin Periodontol 2007; 34:816–821.
27. Wittwer G, Adeyemo WL, Schicho K, Figl M, Enislidis G. Navigated flapless transmucosal implant placement in the mandible: a pilot study in 20 patients. Int J Oral Maxillofac Implants 2007; 22:801–807.
28. Ozan O, Turkyilmaz I, Ersoy AE, McGlumphy EA, Rosenstiel SF. Clinical accuracy of 3 different types of computed tomography-derived stereolithographic surgical guides in implant placement. J Oral Maxillofac Surg 2009; 67:394–401.
29. Wanschitz F, Birkfellner W, Figl M, Patruta S, Wagner A, Watzinger F, Yerit K, Schicho K, Hanel R, Kainberger F, Imhof H, Bergmann H, Ewers R. Computer-enhanced stereoscopic vision in a headmounted display for oral implant surgery. Clin Oral Implants Res 2002; 13:610–616.

30. Hoffmann J, Westendorff C, Schneider M, Reinert S. Accuracy assessment of image-guided implant surgery: an experimental study. Int J Oral Maxillofac Implants 2005; 20:382–386.
31. Brief J, Edinger D, Hassfeld S, Eggers G. Accuracy of image-guided implantology. Clin Oral Implants Res 2005; 16:495–501.
32. Cha BK, Lee YH, Lee NK, Choi DS, Baek SH. Soft tissue thickness for placement of an orthodontic miniscrew using an ultrasonic device. Angle Orthod 2008; 78:403–408.
33. Culjat MO, Choi M, Singh RS, Grundfest WS, Brown ER, White SN. Ultrasound detection of submerged dental implants through soft tissue in a porcine model. J Prosthet Dent 2008; 99:218–224.