Relationship of central incisor implant placement to the ridge configuration anterior to the nasopalatine canal in dentate and partially edentulous individuals: A comparative study

Xueting Jia, Wenjie Hu, Huanxin Meng

Background: The aims of this study were to investigate the ridge contour anterior to the nasopalatine canal and the difference between the incidences of the nasopalatine canal perforation in dentate and partially edentulous patients by cone-beam computed tomography. Methods: Cone-beam computed tomography scan images from 72 patients were selected from database and divided into dentate and partially edentulous groups. The configuration of the ridge anterior to the canal including palatal concavity depth, palatal concavity height, palatal concavity angle, bone height coronal to the incisive foramen, and bone width anterior to the canal was measured. A virtual implant placement procedure was used and the incidences of perforation were evaluated after implant placement in the cingulum position with the long axis along with the designed crown. Results: Comparing with variable values from dentate patients, the palatal concavity depth and angle were greater by 0.9 mm and 4 degrees, and bone height was shorter by 1.1 mm in partially edentulous patients, respectively. Bone width in edentulous patients was narrower than in dentate patients by 1.2 mm at incisive foramen level and 0.9 mm at 8 mm subcrestal level, respectively. After 72 virtual cylindrical implants (4.1 × 12 mm) were placed, a total of 12 sites (16.7%) showed a perforation and three-fourths occurred in partially edentulous patients. After replacing with 72 tapered implants (4.3 × 13 mm), only 6 implants (8.3%) broke into the canal in the partially edentulous patient group. Conclusions: The nasopalatine canal may get close to the implant site and the bone width anterior to the canal decreases after the central incisor extraction. The incidence of nasopalatine canal perforation may occur more commonly during delayed implant placement in central incisor missing patients.

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4 **Abstract**

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6 nasopalatine canal and the difference between the incidences of the nasopalatine canal perforation

7 in dentate and partially edentulous patients by cone-beam computed tomography.

8 Methods: Cone-beam computed tomography scan images from 72 patients were selected from

9 database and divided into dentate and partially edentulous groups. The configuration of the ridge

10 anterior to the canal including palatal concavity depth, palatal concavity height, palatal concavity

11 angle, bone height coronal to the incisive foramen, and bone width anterior to the canal was

12 measured. A virtual implant placement procedure was used and the incidences of perforation were

13 evaluated after implant placement in the cingulum position with the long axis along with the

14 designed crown.

15 Results: Comparing with variable values from dentate patients, the palatal concavity depth and

16 angle were greater by 0.9 mm and 4 degrees, and bone height was shorter by 1.1 mm in partially

17 edentulous patients, respectively. Bone width in edentulous patients was narrower than in dentate

18 patients by 1.2 mm at incisive foramen level and 0.9 mm at 8 mm subcrestal level, respectively.

19 After 72 virtual cylindrical implants (4.1 × 12 mm) were placed, a total of 12 sites (16.7%) showed

20 a perforation and three-fourths occurred in partially edentulous patients. After replacing with 72

21 tapered implants (4.3 × 13 mm), only 6 implants (8.3%) broke into the canal in the partially

22   edentulous patient group.

23   Conclusions: The nasopalatine canal may get close to the implant site and the bone width anterior

24   to the canal decreases after the central incisor extraction. The incidence of nasopalatine canal

25   perforation may occur more commonly during delayed implant placement in central incisor

26   missing patients.

28   Keywords: alveolar bone, anterior maxilla, cone-beam computed tomography, dental implants,

29   nasopalatine canal

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Introduction

43

44   Dental implant restoration has become a very common treatment in dental practices (Chung

45 et al., 2009; Fugazzotto, Vlassis & Butler, 2004; Scheller et al., 1998). In the esthetic zone, the

46 primary goal of implant treatment is to re-establish both esthetics and function (Buser & von Arx,

47 2000). As generally accepted, the implant placement is always based on a restorative-driven

48 philosophy (Garber & Belser, 1995). According to this concept, the three-dimensional ideal

49 implant position has been described (Buser, Martin & Belser, 2004; Funato et al., 2007; Grunder,

50 Gracis & Capelli, 2005; Su et al., 2010; Tarnow, Cho & Wallace, 2000). Mesio-distally, a single

51 implant should be at least 1.5 mm away from adjacent root surface (Buser, Martin & Belser, 2004;

52 Grunder, Gracis & Capelli, 2005). Apico-coronally, the implant platform is supposed to be placed

53 2 to 4 mm apically to the designed mid-facial gingival margin (Buser, Martin & Belser, 2004;

54 Funato et al., 2007). Bucco-lingually, the implant should be positioned slightly palatal to the incisal

55 edge and 2 mm of buccal bone is recommended (Funato et al., 2007; Grunder, Gracis & Capelli,

56 2005). Regarding the optimal implant orientation, placement of an implant axis in alignment with

57 the designed crown is recommended in order to fabricate a screw-retained implant crown and

58 prevent from excessive off-axis loading (Chan et al., 2014).

59   However, in both immediate and delayed implant therapy, the nasopalatine canal (NPC) is

60 often an anatomical limitation for a maxillary central incisor implant placement in an ideal position

61 according to the restorative-driven philosophy. The NPC is a bony channel located posterior to the

62 maxillary central incisors and connects the nasal floor with the oral cavity. The NPC contains the

63 nasopalatine nerve, the terminal branch of descending nasopalatine artery, fibrous connective

64 tissue, fat, and small salivary glands (Keith, 1979; Liang et al., 2009). The relative location of the

65 NPC in the maxilla was previously described by assessing the dimension of the buccal bone plate

66 anterior to this canal in some studies, and a proximity of the NPC to the implant surgical site after

67 tooth extraction was reported (Bornstein et al., 2011; Mardinger et al., 2008; Tözüm et al., 2012).

68 Moreover, placement of implants with invading into the NPC may lead to direct contact of the

69 implant with connective tissue and cause a series of complications, including hemorrhage during

70 operation, short term sensory disturbance postoperatively, non-osseointegration of implant and

71 nasopalatine duct cyst formation (Casado et al., 2008; McCrea, 2014; Mraiwa et al., 2004;

72 Peñarrocha et al., 2014; Takeshita et al., 2013). When the NPC interrupts the central incisor

73 implant placement, more complicated surgical procedure is required and the risk of complications

74 increases.

75   Through examination of computerized tomography images of 30 American patients, Kraut &

76 Boyden studied the volumes of the NPC and bone anterior to the canal and reported that

77 approximately 4% NPC will be detrimental to the implant placement (Kraut & Boyden, 1998).

78 However, the incidence of perforation into the NPC is associated with not only the anatomic

79 morphology, but also the feature of the implant and the three-dimensional implant position. The

80 incidence of perforation into the NPC when a central incisor implant is placed in an ideal position

81 following an optimal axis was not well known yet. In addition, the change of the ridge morphology

82 caused by tooth loss may increase the incidence of perforation has not been assessed. Besides, the

83 feature of the exposure and the risk factors of the perforation have never been analyzed. Whether

84 a tapered implant or a minor adjustment of implant angulation could be beneficial for avoidance

85 of perforation was also not well known.

86   Cone-beam computed tomography (CBCT) has been widely used in clinical evaluation before

87 implant surgery because of the capability of accurate three-dimension imaging, relative low

88   radiation dose and costs (White, 2008). Moreover, virtual implant placement in CBCT scan images

89   could provide an overall evaluation of implant position and the proximity of the implant to the

90   surrounding anatomic structure (Fortin et al., 2003; Katsoulis, Pazera & Mericske-Stern, 2009).

91   The accuracy of computer-guided template-based implant dentistry was analyzed in previous

92   literature (Schneider et al., 2009). The results showed that the mean horizontal deviation was

93   approximately 1 mm at the entry point and approximately 1.6 mm at the apex. Although the

94   reliability may be insufficient to perform a "blind" implant surgery considering the fine anatomic

95   structure around the implant site, CBCT is still one of the most valuable imaging tools in dentistry.

96   Reasonable accurate three-dimensional anatomic information and the relationship between

97   implant and surrounding anatomical structures can be evaluated thoroughly by observing CBCT

98   scans, and the likelihood of complications could reduce afterwards. The aims of this study were to

99   investigate the ridge contour anterior to the NPC and the difference between the incidences of NPC

100   perforation in dentate and partially edentulous patients by CBCT.

101

102   **Materials and Methods**

103

104   **Patient Selection**

105   This study was approved by the Biomedical Ethics Committee of Peking University School

106   of Stomatology (approval ID PKUSSIRB-201519006). The pre-existing CBCT (Vatech CT,

107   Korea) data selected for this study were performed from January 2011 to July 2014 for treatment

108   planning of implant procedures. Appropriate methodology and sample size were determined by a

109   pilot study and power analysis. The sample size was calculated with $\alpha = 0.05$ and power $= 0.90$.

110   It was determined that a sample size of 36 specimens per group (for a total sample of 72) was

111   needed to represent a clinically significant difference in bone width anterior to the NPC.

112   Patients and images selected for this study had to fulfill the following inclusion criteria: (1)

113   Chinese adults with either full teeth of anterior maxillary sextant or missing one maxillary central

114   incisor in this sextant; (2) the present maxillary anterior teeth without obvious crowding or

115   spacing; (3) no deep (> 3 mm) overbite or increased (> 3 mm) overjet in the anterior teeth area;

116   (4) at least two pairs of posterior teeth which could be retained with occlusal contact on each side;

117   (5) complete CBCT scanning of premaxilla and NPC with clear images without scattering artifacts.

118   Patients and images were excluded if: (1) both maxillary central incisor were present but the

119   amount of alveolar bone loss exceeded one third of root length; (2) unhealed extraction sockets

120   and the period after extraction was within 6 months; (3) any socket preservation procedures were

121   performed in the missing maxillary central incisor sites; (4) both maxillary central incisors were

122   missing; (5) alveolar ridge height of implant site was less than 14 mm or the ridge width was less

123   than 3.5 mm at the level of 2 mm below the bone crest. Images were assigned into two groups:

124   dentate and partially edentulous groups. When anterior maxillary sextant presented was classified

125   as dentate group, while the edentulous ridge of missing one maxillary central incisor was classified

126   as partially edentulous group. The distributions of age, gender, NPC shape on sagittal slice

127   (Mardinger et al., 2008) and implant site were well matched between two groups, respectively.

128

129   **Data Reconstruction**

130   All images were obtained using a CBCT machine (Vatech CT, Korea) with standardized

131   routine procedures in the Peking University School of Stomatology by experienced radiologists.

132   The imaging parameters were set at 90 kVp, 7.0 mAs, scan time 24 seconds, resolution 0.15 mm

133   and a field of view that varied based on the region scanned. The scans included in this study were

134   selected from the database and processed with a measurement software program (Ez3D2009

135   Premium Ver. 1.2.1.0) in a password-protected computer. The observer examined CBCT images

136   using monitor at a 1,280 × 1,024 screen resolution under room lighting. The distance between

137   display and the observer was approximately 30 cm. The scans were re-oriented so that the

138   premaxilla was bilaterally symmetric and the long axis of the sagittal CBCT slice was determined

139   following the long axis of the designed crown (connecting the bucco-lingual midpoint at the

140   cemento-enamel junction and the point at the incisal edge) of the maxillary central incisor. The

141   data were reconstructed with slices at an interval of 0.5 mm. The luminance and grayscale were

142   adjusted to obtain clear CBCT views.

143

144   **Configuration of Ridge Anterior to the NPC**

145   The palatal concavity of the alveolar ridge anterior to the NPC was analyzed by examining

146   the sagittal slices (Fig 1 A) and measuring:

147   (1) The palatal concavity depth (PCD), the distance between the deepest point of the buccal

148   plate on the palatal side and a reference line parallel to the sagittal long axis of the central incisor

149   crown and passing through the labial opening of incisive foramen.

150   (2) The palatal concavity height (PCH), the distance between the deepest point of the buccal

151   plate on the lingual side and a reference line perpendicular to the sagittal long axis of the central

152   incisor crown and passing through the alveolar bone crest.

153   (3) The palatal concavity angulation (PCA), the angulation between the line connecting the

154   deepest point of the palatal concavity and the labial opening of incisive foramen and the line

155   parallel to the long axis of the central incisor crown and passing through the deepest point of the

156   palatal concavity.

157   In addition, the height of the alveolar bone coronal to the NPC (BH) was also recorded by

158   measuring the vertical distance between the alveolar bone crest and the line perpendicular to the

159   sagittal long axis of the central incisor crown and passing through the labial opening of incisive

160   foramen in the midsagittal plane of the NPC (Fig 1 A).

161   The minimum width of buccal bone plate anterior to the NPC (BW) was measured in the axial

162   view images at three levels: incisive foramen level, 8 mm subcrestal level and 14 mm subcrestal

163   level (Fig 1 B).

164

165   **Relative Location of the NPC and the Virtual Implant**

166   Seventy-two cylindrical implants (Straumann Bone-Level Implant, 4.1 × 12 mm, Fig 2) and

167   72 tapered implants (Nobel Replace Tapered Implant 4.3 × 13 mm, Fig 2) were placed virtually in

168   the selected maxillary central incisor sites sequentially.

169   In the dentate group, each implant was placed in the midsagittal plane of selected maxillary

170   central incisor mesio-distally. Bucco-lingually, the most lingual point of the implant platform was

171   located at the cingulum of the central incisor. Apico-coronally, the implant platform was placed 2

172   mm below the crestal level. The sagittal long axis of the implant was parallel to the central incisor

173   crown (Fig 3 A-C).

174   In the partially edentulous group, each implant was placed in the center of the edentulous site

175   mesio-distally. Bucco-lingually, the implant platform was also placed at the cingulum region

176   (Chan et al., 2014). The details were present as follows: connecting the most prominent points of

177   the two lateral incisors or the two canines on their palatal side to draw a reference line and

178   measuring the distance between the cingulum of the natural contralateral central incisor at its most

179   palatal point and the reference line, and then the most palatal point of the implant platform was

180   placed labial to the reference line by the same distance. Apico-coronally, the location of the

181   implant platform was the same as that of the dentate group. The sagittal long axis of the implant

182   was parallel to the contralateral central incisor crown (Fig 3 D-F).

183   After each virtual implant was placed, whether the implant penetrating through the interior

184   wall of the NPC was assessed in the sagittal and axial views slice by slice. For the NPC perforation

185   cases caused by cylindrical implants, the position of the implant platform was kept unchanged and

186   the embedded direction was rotated distally and labially by a minor angulation (5 degrees and 10

187   degrees), respectively. The size and the location of each perforation were measured in the sagittal

188   and axial view images, which included its length, depth, area and the distance between the most

189   coronal point of the perforation and the alveolar bone crest (Fig 4).

190   All measurements were conducted by two examiners (XJ and WH). The inter- and

191   intraexaminer agreement was determined by comparing two repeated measurements at 20

192   randomly chosen sites taken 1-week apart.

193

194   **Statistical Analysis**

195   All statistical analysis was performed using a statistical package (IBM, SPSS Statistics 19.0).

196   The inter- and intraexaminer agreement was determined using a t test. All measurements were

197   presented as means ± standard deviations (SDs). The occurrence of the NPC perforation was

198   expressed as the number of sites and the percentage of the number of sites divided by the total

199   number of sites. The PCD, PCH, PCA, BH and BW were compared between dentate group and

200   partially edentulous group by Mann-Whitney U test. The chi-square test was used to compare the

201   incidences of perforation between groups, genders and sides. Univariate and multivariate logistic

202   regression analyses were performed to identify risk factors associated with the NPC perforation

203   with the significance level at α = 0.05.

204

205   **Results**

206

207   A total of 703 subjects were screened and 72 subjects (54 males and 18 females) were selected

208   for this study. The mean age was 45.6 years, with a range of 28 to 64 years of age. Each group

209   consisted of 36 subjects. The age, gender and implant site were well matched between the dentate

210   group and the partially edentulous group, respectively. The distribution of NPC shape recorded on

211   sagittal plane did not show statistically significant differences between groups (Table 1). The intra-

212   examiner and inter-examiner agreements were 0.94 and 0.87, respectively ($p > 0.05$).

213   The measuring results of configuration of ridge anterior to the NPC are shown in Table 2. A

214   total of 54 ridges (75.0%) showed a palatal concavity in sagittal views. The mean and SD of PCD,

215   PCH and PCA values were 1.8 ± 1.7 mm, 14.3 ± 7.3 mm and 8.6 ± 6.5 degrees, respectively. The

216   incisive foramen was located at 5.9 ± 2.3 mm below the alveolar bone crest. The mean and SD

217   values of BWs at the incisive foramen level, 8 mm and 14 mm related to the subcrestal level were

218   6.0 ± 1.7 mm, 6.3 ± 1.5 mm and 6.9 ± 1.9 mm, respectively. Results of comparisons of ridge

219   configuration between the dentate group and the partially edentulous group were also listed in

220   Table 2 and shown in Fig 5. There was statistically significant difference between the mean PCD

221   values of the dentate group and the partially edentulous group (1.4 ± 1.4 mm vs. 2.3 ± 1.9 mm, p

222   = 0.036). In addition, the mean PCA values of the dentate group and the partially edentulous group

223   were 6.6 degrees and 10.6 degrees respectively (p = 0.022). The distance between the incisive

224   foramen and the bone crest was significant closer in the partially edentulous group than in the

225   dentate group by 1.1 mm approximately (p = 0.022). At the incisive foramen level, the mean BW

226   was statistically significantly thinner in the partially edentulous group than the dentate group, 5.4

227   ± 2.5 mm and 6.6 ± 1.1 mm, respectively((p = 0.013). Furthermore, the mean BW values measured

228   at 8 mm subcrestal level of the dentate group and the partially edentulous group were 6.7 mm and

229   5.8 mm respectively (p = 0.028). There was no statistically significant difference between groups

230   of the PCH and BW values at 14 mm subcrestal level (p > 0.05).

231   Table 2 also illustrated the comparison results between genders. At the incisive foramen level,

232   the mean BW was statistically significantly greater in male subjects compared with female subjects

233   by 0.8 mm (p = 0.040). In addition, the mean BWs measured at 8 mm subcrestal level of the male

234   and the female subjects were 6.5 mm and 5.5 mm, respectively (p = 0.004). The PCD, PCH, BH

235   values were greater in male subjects, although the statistically significant difference did not exist

236   (p > 0.05).With virtual cylindrical implants (4.1 × 12 mm) were placed, a total of 12 sites (16.7%)

237   showed invading and perforation (Table 3). Three cases of them occurred in the dentate group

238   (8.3%) while other nine cases occurred in the partially edentulous group (25.0%). The incidence

239   of perforation was much higher in the partially edentulous group, although the statistically

240   significant difference did not exist (p = 0.058). With respect to the implant site, the incidence of

241   perforation was statistically significantly higher in the right central incisor site than in the left

242   central incisor site, 33.3% and 4.8%, respectively (p = 0.001). The occurrence of perforation did

243   not show statistically significant differences between genders (p > 0.05). In the axial view images,

244   all the perforations were located at the mesio-palatal site of the virtual implant. Furthermore, the

245   depth and the area of exposure were 0.7 ± 0.6 mm (range = 0.2-2.1 mm) and 1.0 ± 1.3 mm^2 (range

246   = 0.2-4.7 mm^2), respectively. In the sagittal view images, the exposure located at 8.5 ± 3.5 mm

247   below the alveolar bone crest, with a range of 2.3 mm to 12.1 mm, and the length of the exposure

248   was 5.1 ± 3.4 mm, with a range of 1.6 mm to 12.0 mm.

249   After replacing the cylindrical implants with the tapered implants (4.3 × 13 mm), a total of 6

250   implants (8.3%) entered into the NPC, which all belonged to the partially edentulous group (Table

251   3). The incidence of perforation with the selected tapered implant was statistically significantly

252   different between the dentate and partially edentulous groups (p = 0.011). Besides, five out of six

253   perforations occurred in the right central incisor sites, and the statistically significant difference

254   existed between different sides (p = 0.031). The location of the exposure was at the 6.2 ± 3.2 mm

255   below the alveolar bone crest. The length, depth and area of the exposure were 5.4 ± 3.1 mm, 0.8

256 ± 0.6 mm and 1.3 ± 1.7 mm^2, respectively.

257 The numbers of perforation sites was reduced to 4 (5.6%) and 2 (2.8%) by tilting the

258 embedded direction of the cylindrical implant distal-apically by 5 degrees and 10 degrees,

259 respectively. After the embedded direction was rotated labial-apically by the same degrees (5

260 degrees and 10 degrees), the incidence of perforation decreased to 8.3% and 4.2%, respectively.

261 The changes of incidences of perforation, as well as the features of exposure after a minor

262 adjustment of cylindrical implant angulation, were presented in Table 4.

263 The multivariate logistic regression analysis revealed that the PCD was a statistically

264 significant risk factor of perforation (OR 4.332; 95% CI 1.596–11.760; p = 0.004). Implant

265 placement in the left central incisor site (OR 0.087; 95% CI 0.010–0.783; p = 0.029) and BW

266 measured at 8 mm below the alveolar bone crest (OR 0.273; 95% CI 0.111–0.671; p = 0.005) were

267 two protective factors appeared in the last model (Table 5).

268

269 **Discussion**

270 Chan and colleagues used CBCT imaging technique and found that a buccal concavity of

271 ridge always existed anterior to the maxillary central incisor (Chan et al., 2014). The mean value

272 of buccal concavity depth was reported to have mean of 3.42 mm, and it was associated with the

273 occurrence of buccal plate fenestration. However, few studies have provided information regarding

274 the palatal concavity and its relationship with the NPC during implant placement procedure. In the

275 present study, the perforations of the NPC by the virtual implants were located at the labia-distal

276 side only. Therefore, with an obvious palatal concavity, that means the NPC is located relatively

277   at the labial side, may increase the risk of implant entering and damaging the neurovascular

278   bundles within the NPC. In this study, 75% of ridges were present with a palatal concavity. More

279   importantly, the palatal concavity depth was a statistically significant risk factor of NPC

280   perforation. Therefore, not only the location of the incisive foramen, but also the trend of the NPC

281   configuration should be carefully evaluated by CBCT during diagnostic procedure and treatment

282   plan for implant therapy.

283   Bone dimensions anterior to the NPC are important factors for successful implant placement.

284   In previous studies, bone dimensions were measured at crestal, middle, and (or) the most apical

285   point of the canal in the midsagittal plane of the NPC with the reference line perpendicular to the

286   maxillary plane or the sagittal long axis of the canal (Bornstein et al., 2011; Tözüm et al., 2012).

287   A mean bone width of 7.17 ± 1.49 mm has been reported in a multicenter study (Tözüm et al.,

288   2012). However, the implant is rarely placed in the midsagittal plane of the NPC, and also not

289   involving the nasal part of the canal. In addition, the embedded direction may be different from

290   the direction of measurement mentioned above. As a result, the data obtained by previous

291   measuring methods might not reflect the implant condition accurately. In this study, the bone width

292   anterior to the NPC was first measured in the axial view images at three levels: the incisive foramen

293   level, 8 mm below the alveolar bone crestal level, and 14 mm below the crestal level. The incisive

294   foramen level is where the NPC prevents the implant from placement procedure at the early

295   beginning. The 8 mm and 14 mm below the bone crestal levels may represent the middle level and

296   the apex level of the virtual implant selected in this study, respectively. In addition, the measuring

297   direction was perpendicular to embedded direction of implant, that is, the sagittal long axis of the

298   restoration. As a result, the measuring results of the present study would reflect the real implant

299   condition with better accuracy. In the present study, the mean bone width anterior to the NPC was

300   6.0 and 6.3 mm at the incisive foramen level and 8 mm below the alveolar crest level, respectively.

301   The results were slightly narrower than the bone width (7.17 mm) reported by Tözüm et al (Tözüm

302   et al., 2012).

303   The incidence of NPC perforation during the maxillary central incisor implant procedure was

304   evaluated using virtual implant placements in CBCT images. Using a cylindrical central incisor

305   implant (4.1 × 12 mm) placed in the cingulum position with the long axis following that of its

306   restoration, the incidence of NPC perforation was revealed to be 16.7% and significant higher than

307   a previous study reported in using computerized tomography scanning images of American

308   patients (Kraut & Boyden, 1998). The increased versatility of both latest CBCT and software could

309   provide a more accurate and precise measurement of the relationship between implant and

310   anatomical structures. Considering that the incidence of NPC perforation is associated with not

311   only the anatomic morphology, but also the feature of implant and the three-dimensional implant

312   position, the results present in this study may reflect the clinical implant condition more accurately.

313   In addition, different racial sampling may have some effects on the skeletal development. Another

314   study of our research team showed that the mean closest distance between the NPC and the apex

315   of the central incisor root were 3.88 mm in axial CBCT images (unpublished data, Jia X et al.),

316   much closer than the mean distance of 5.22 mm reported by Chatriyanuyoke et al (Chatriyanuyoke

317   et al., 2012). The relatively lower values of the closest distances implied that insertion of implants

318   into the NPC might be more likely to occur in Chinese patients.

319   The absence of maxillary central incisors affected some dimension changes of bony structure

320   and incidences of NPC perforation. The results of comparison between the dentate and partially

321   edentulous group revealed that, the PCD and PCA were statistically significantly greater in the

322   partially edentulous group by 0.9 mm and 4 degrees, respectively, although the distribution of NPC

323   shape recorded on sagittal plane did not show statistically significant differences between groups.

324   Mardinger et al. also found that the bucco-lingual NPC diameter was wider along the degree of

325   ridge resorption (Mardinger et al., 2008). In the present study, it is implied that a closer proximity

326   of NPC to implant site might be presented after tooth loss for a while with wound healed. In

327   addition, bone width anterior to the canal and the bone height coronal to the canal were greater in

328   dentate subjects in the present study by 1.2 mm and 1.1 mm respectively, mainly due to the alveolar

329   bone remodeling after tooth loss (Araújo & Lindhe, 2005; Schropp et al., 2003). Other studies

330   reported similar results regarding the change of bone width after tooth loss as the present study

331   (Mardinger et al., 2008; Tözüm et al., 2012). Considering the ridge modeling after tooth loss,

332   including the change of PCD, PCA, BH and BW as mentioned before, it would be no surprise that

333   the incidence of NPC perforation was significantly higher in the partially edentulous group than

334   the dentate group (25.0% and 8.3% after cylindrical implant placement; 16.7% and 0.0% after

335   tapered implant placement). It is indicated that delayed implant placement in the maxillary central

336   incisor site may require more care to avoid NPC perforation (Table 3). Another thing to keep in

337   mind is that, in this study, one maxillary central incisor was present in the partially edentulous

338   group for reference. Considering that loss of both central incisors may affect the ridge resorption,

339   the potential of NPC perforation during delayed implant placement might increase in patients

340   without both maxillary central incisors.

341   The results showed that the gender influenced the alveolar bone dimensions anterior to the

342   NPC (Table 2). The mean BW values measured at the incisive foramen level and at 8 mm

343   subcrestal level were significantly greater in men compared with women by 0.8 mm and 1.0 mm,

344   respectively ($p < 0.05$). Our results correlates well with some other studies. Güncü et al. reported

345   that buccal bone thickness were greater in male subjects (Güncü et al., 2013). Chatriyanuyoke et

346   al. also found that men had larger amounts of bone between the NPC and the MCIR sockets than

347   women (Chatriyanuyoke et al., 2012). Considering the results of comparisons of anatomic

348   structures between genders, it would not be a surprise that insertion of implants into the NPC was

349   more likely to occur in women, although the difference of incidence was not statistically

350   significant, maybe due to insufficient sample size.

351   Another interesting finding was that the perforation usually occurred in the right central

352   incisor site. The multivariate logistic regression analysis also revealed that the implant site was

353   associated with the occurrence of NPC perforation (Table 5). This corresponds with the results of

354   our preliminary study about the location of the NPC leaning on the right side at both the incisive

355   foramen level and the apical level (unpublished data, Jia X et al.).

356   The location, length, depth, and area of perforation are important information for implant

357   placement. In the axial view images, all the perforations were located at the mesio-palatal side of

358   the implant. However, in the sagittal view images, the perforation could occur at any part of

359   implant (2.3–12.1 mm below the bone crest). The mean distance between the exposure and the

360   crest was 8.5 mm in the present study, which meant that the perforation usually occurred at the

361 mid-root level of the implant. A mean length of exposure of 5.1 mm indicated that the NPC

362 perforation could not be ignored. However, on the other hand, the depth of exposure was only 0.7

363 mm on average, which meant that a tapered implant or a minor adjustment of implant angulation

364 might be beneficial to prevent NPC from being invaded. In this study, tapered implant platform

365 (4.3 × 13 mm) was selected and larger than the cylindrical implant in diameter by 0.2 mm.

366 However, the diameter of the tapered implant will be narrowed to 4.1 mm at about 3.4 mm below

367 the implant platform level, and only proximately 2.56 mm in diameter at the implant apical level,

368 narrower than the cylindrical implant by approximately 1.5 mm (Fig 2). Considering the relative

369 shallow depth of exposure after cylindrical implant placement, a significant decrease of the

370 incidence of perforation from 16.7% to 8.3% will be achieved if a cylindrical implant is replaced

371 with a tapered implant (4.3 × 13 mm). A minor change of embedded direction was also beneficial

372 for decreasing NPC perforation percentage from 16.7% down to 8.3% to 2.8% (Table 4). However,

373 before the adjustment of implant angulation, practitioners should keep the proximity of adjacent

374 lateral incisor to the implant site and the existing buccal concavity in mind. The distance between

375 the implant apex and the adjacent root surface should not be too close and should not be less than

376 1.5 mm separation after rotating the implant to the distal, while the buccal plate fenestration is

377 always the major factor to be considered during rotating the implant to the labial.

378   However, neither selected a tapered implant nor a minor adjustment (less than 10 degrees) of

379 implant angulation can avoid NPC perforation successfully in some cases. Therefore, it is

380 recommended to take full analysis of the NPC using CBCT at the time of implant treatment

381 planning with consideration of individual differences. The results in this study suggested that other

382   appropriate features of implant, for example a shorter implant or a narrower implant, or a greater

383   embedded angle that departed from the axis of the restoration might be selected to avoid

384   perforation in some cases. For the cases that the implant may invade into the NPC inevitably, the

385   debridement or the displacement of the neurovascular bundle in conjunction with the guided bone

386   regeneration were proposed to prevent direct contact of implant surface with the neurovascular

387   bundle and to provide adequate bone (Artzi et al., 2000; Peñarrocha et al., 2014; Rosenquist &

388   Nyström, 1992; Verardi & Pastagia, 2012). These methods could significantly improve the

389   condition of implant placement, but more long-term studies with large samples are necessary.

390   The limitation of this study is that the results are based on virtual analysis. When taking the

391   findings of this study for reference, the practitioners should keep some consideration in mind,

392   including the accuracy of CBCT scans, the features of the implant, and the surgical experience.

393   Further clinical trial is required to clarify this issue. In addition, unassisted socket healing cases

394   were adopted in the present study, although alveolar ridge preservation has become a key

395   component of contemporary clinical dentistry (Avila-Ortiz et al., 2014). However, the effects of

396   socket grafting and preservation procedures on the contour changes of the NPC are almost

397   unknown. There is a need to evaluate the impact of specific alveolar ridge preservation procedures

398   on the contour changes of the NPC and perforation incidences during implant placement in future.

399

400   **Conclusions**

401   Within the limits of this study, it can be concluded that the NPC may get close to the implant

402   site after the central incisor extraction, and the bone width anterior to the canal may also reduce.

403 The NPC perforations may occur more commonly in partially edentulous patients for delayed

404 implant placement and in the right central incisor site. The right central incisor site with narrower

405 bone width measured at 8 mm below the crest and a deep palatal concavity are associated with the

406 common occurrence of NPC perforation during implant placement. A minor adjustment of implant

407 angulation or using a tapered implant may be beneficial for preventing from NPC perforation.

408

409 **References**

410 Araújo MG, Lindhe J. 2005. Dimensional ridge alterations following tooth extraction. An

411   experimental study in the dog. *J Clin Periodontol* 32:212-218. 10.1111/j.1600-

412   051X.2005.00642.x

413 Artzi Z, Nemcovsky CE, Bitlitum I, Segal P. 2000. Displacement of the incisive foramen in

414   conjunction with implant placement in the anterior maxilla without jeopardizing vitality of

415   nasopalatine nerve and vessels: a novel surgical approach. *Clin Oral Implants Res* 11:505-

416   510.

417 Avila-Ortiz G, Elangovan S, Kramer KW, Blanchette D, Dawson DV. 2014. Effect of alveolar

418   ridge preservation after tooth extraction: a systematic review and meta-analysis. *J Dent Res*

419   93:950-958. 10.1177/0022034514541127

420 Bornstein MM, Balsiger R, Sendi P, von Arx T. 2011. Morphology of the nasopalatine canal and

421   dental implant surgery: a radiographic analysis of 100 consecutive patients using limited

422   cone-beam computed tomography. *Clin Oral Implants Res* 22:295-301. 10.1111/j.1600-

423   0501.2010.02010.x

424   Buser D, Martin W, Belser UC. 2004. Optimizing esthetics for implant restorations in the anterior

425   maxilla: anatomic and surgical considerations. *Int J Oral Maxillofac Implants* 19 Suppl:43-

426   61.

427   Buser D, von Arx T. 2000. Surgical procedures in partially edentulous patients with ITI implants.

428   *Clin Oral Implants Res* 11 Suppl 1:83-100.

429   Casado PL, Donner M, Pascarelli B, Derocy C, Duarte ME, Barboza EP. 2008. Immediate dental

430   implant failure associated with nasopalatine duct cyst. *Implant Dent* 17:169-175.

431   10.1097/ID.0b013e3181776c52

432   Chan HL, Garaicoa-Pazmino C, Suarez F, Monje A, Benavides E, Oh TJ, Wang HL. 2014.

433   Incidence of implant buccal plate fenestration in the esthetic zone: a cone beam computed

434   tomography study. *Int J Oral Maxillofac Implants* 29:171-177. 10.11607/jomi.3397

435   Chatriyanuyoke P, Lu CI, Suzuki Y, Lozada JL, Rungcharassaeng K, Kan JY, Goodacre CJ. 2012.

436   Nasopalatine canal position relative to the maxillary central incisors: a cone beam

437   computed tomography assessment. *J Oral Implantol* 38:713-717. 10.1563/AAID-JOI-D-

438   10-00106

439   Chung WE, Rubenstein JE, Phillips KM, Raigrodski AJ. 2009. Outcomes assessment of patients

440   treated with osseointegrated dental implants at the University of Washington Graduate

441   Prosthodontic Program, 1988 to 2000. *Int J Oral Maxillofac Implants* 24:927-935.

442   Fortin T, Bosson JL, Coudert JL, Isidori M. 2003. Reliability of preoperative planning of an image-

443   guided system for oral implant placement based on 3-dimensional images: an in vivo study.

444   *Int J Oral Maxillofac Implants* 18:886-893.

445 Fugazzotto PA, Vlassis J, Butler B. 2004. ITI implant use in private practice: clinical results with
446   5,526 implants followed up to 72+ months in function. *Int J Oral Maxillofac Implants*
447   19:408-412.

448 Funato A, Salama MA, Ishikawa T, Garber DA, Salama H. 2007. Timing, positioning, and
449   sequential staging in esthetic implant therapy: a four-dimensional perspective. *Int J*
450   *Periodontics Restorative Dent* 27:313-323.

451 Güncü GN, Yıldırım YD, Yılmaz HG, Galindo-Moreno P, Velasco-Torres M, Al-Hezaimi K, Al-
452   Shawaf R, Karabulut E, Wang HL, Tözüm TF. 2013. Is there a gender difference in
453   anatomic features of incisive canal and maxillary environmental bone? *Clin Oral Implants*
454   *Res* 24:1023-1026. 10.1111/j.1600-0501.2012.02493.x

455 Garber DA, Belser UC. 1995. Restoration-driven implant placement with restoration-generated
456   site development. *Compend Contin Educ Dent* 16:796, 798-802, 804.

457 Grunder U, Gracis S, Capelli M. 2005. Influence of the 3-D bone-to-implant relationship on
458   esthetics. *Int J Periodontics Restorative Dent* 25:113-119.

459 Katsoulis J, Pazera P, Mericske-Stern R. 2009. Prosthetically driven, computer-guided implant
460   planning for the edentulous maxilla: a model study. *Clin Implant Dent Relat Res* 11:238-
461   245. 10.1111/j.1708-8208.2008.00110.x

462 Keith DA. 1979. Phenomenon of mucous retention in the incisive canal. *J Oral Surg* 37:832-834.

463 Kraut RA, Boyden DK. 1998. Location of incisive canal in relation to central incisor implants.
464   *Implant Dent* 7:221-225.

465 Liang X, Jacobs R, Martens W, Hu Y, Adriaensens P, Quirynen M, Lambrichts I. 2009. Macro-

466   and micro-anatomical, histological and computed tomography scan characterization of the

467   nasopalatine canal. *J Clin Periodontol* 36:598-603. 10.1111/j.1600-051X.2009.01429.x

468 Mardinger O, Namani-Sadan N, Chaushu G, Schwartz-Arad D. 2008. Morphologic changes of the

469   nasopalatine canal related to dental implantation: a radiologic study in different degrees of

470   absorbed maxillae. *J Periodontol* 79:1659-1662. 10.1902/jop.2008.080043

471 McCrea SJ. 2014. Nasopalatine duct cyst, a delayed complication to successful dental implant

472   placement: diagnosis and surgical management. *J Oral Implantol* 40:189-195.

473   10.1563/AAID-JOI-D-12-00011

474 Mraiwa N, Jacobs R, Van Cleynenbreugel J, Sanderink G, Schutyser F, Suetens P, van

475   Steenberghe D, Quirynen M. 2004. The nasopalatine canal revisited using 2D and 3D CT

476   imaging. *Dentomaxillofac Radiol* 33:396-402. 10.1259/dmfr/53801969

477 Peñarrocha D, Candel E, Guirado JL, Canullo L, Peñarrocha M. 2014. Implants placed in the

478   nasopalatine canal to rehabilitate severely atrophic maxillae: a retrospective study with

479   long follow-up. *J Oral Implantol* 40:699-706. 10.1563/AAID-JOI-D-12-00145

480 Rosenquist JB, Nyström E. 1992. Occlusion of the incisal canal with bone chips. A procedure to

481   facilitate insertion of implants in the anterior maxilla. *Int J Oral Maxillofac Surg* 21:210-

482   211.

483 Scheller H, Urgell JP, Kultje C, Klineberg I, Goldberg PV, Stevenson-Moore P, Alonso JM,

484   Schaller M, Corria RM, Engquist B, Toreskog S, Kastenbaum F, Smith CR. 1998. A 5-

485   year multicenter study on implant-supported single crown restorations. *Int J Oral

486   Maxillofac Implants* 13:212-218.

487   Schneider D, Marquardt P, Zwahlen M, Jung RE. 2009. A systematic review on the accuracy and

488   the clinical outcome of computer-guided template-based implant dentistry. *Clin Oral*

489   *Implants Res* 20 Suppl 4:73-86. 10.1111/j.1600-0501.2009.01788.x

490   Schropp L, Wenzel A, Kostopoulos L, Karring T. 2003. Bone healing and soft tissue contour

491   changes following single-tooth extraction: a clinical and radiographic 12-month

492   prospective study. *Int J Periodontics Restorative Dent* 23:313-323.

493   Su H, Gonzalez-Martin O, Weisgold A, Lee E. 2010. Considerations of implant abutment and

494   crown contour: critical contour and subcritical contour. *Int J Periodontics Restorative Dent*

495   30:335-343.

496   Tözüm TF, Güncü GN, Yıldırım YD, Yılmaz HG, Galindo-Moreno P, Velasco-Torres M, Al-

497   Hezaimi K, Al-Sadhan R, Karabulut E, Wang HL. 2012. Evaluation of maxillary incisive

498   canal characteristics related to dental implant treatment with computerized tomography: a

499   clinical multicenter study. *J Periodontol* 83:337-343. 10.1902/jop.2011.110326

500   Takeshita K, Funaki K, Jimbo R, Takahashi T. 2013. Nasopalatine duct cyst developed in

501   association with dental implant treatment: A case report and histopathological observation.

502   *J Oral Maxillofac Pathol* 17:319. 10.4103/0973-029X.119761

503   Tarnow DP, Cho SC, Wallace SS. 2000. The effect of inter-implant distance on the height of inter-

504   implant bone crest. *J Periodontol* 71:546-549. 10.1902/jop.2000.71.4.546

505   Verardi S, Pastagia J. 2012. Obliteration of the nasopalatine canal in conjunction with horizontal

506   ridge augmentation. *Compend Contin Educ Dent* 33:116-120, 122.

507   White SC. 2008. Cone-beam imaging in dentistry. *Health Phys* 95:628-637.

508   10.1097/01.HP.0000326340.81581.1a

General characteristics of tested subjects

1   Table 1 General characteristics of tested subjects

	Total (n=72)	Dentate group (n=36)	Partially edentulous group (n=36)	p value
Age (mean ± SD)	45.6±8.8	45.5 ± 9.0	45.6 ± 8.8	0.906
Gender (n)				
male	54	27	27	
female	18	9	9	1.000
Implant site (n)				
Right central incisor	30	15	15	
Left central incisor	42	21	21	1.000
Canal shapes (n)				
cylindrical	29	17	12	
funnel-like	17	6	11	
hourglass-like	15	9	6	
banana-like	11	4	7	0.290

Ridge configuration and comparison results (mean ± SD)

PCD: palatal concavity depth; PCH: palatal concavity height; PCA: palatal concavity angulation; BH: bone height coronal to the canal; BW: bone width anterior to the canal

1 Table 2 Ridge configuration and comparison results (mean ± SD)

Variable		Dental status			Gender		
	Total (n=72)	Dentate (n=36)	Partially edentulous (n=36)	p	Male (n=54)	Female (n=18)	p
Palatal Concavity							
PCD(mm)	1.8 ± 1.7	1.4 ± 1.4	2.3 ± 1.9	0.036	1.9 ± 1.7	1.6 ± 1.8	0.349
PCH(mm)	14.3 ± 7.3	13.9 ± 7.8	14.8 ± 6.8	0.539	14.9 ± 7.7	12.6 ± 5.8	0.275
PCA(degree)	8.6 ± 6.5	6.6 ± 5.9	10.6 ± 6.5	0.022	8.4 ± 6.3	9.1 ± 7.2	0.758
BH (mm)	5.9 ± 2.3	6.5 ± 1.9	5.4 ± 2.5	0.022	5.9 ± 2.4	5.8 ± 1.7	0.958
BW (mm)							
incisive foramen level	6.0 ± 1.7	6.6 ± 1.1	5.4 ± 2.0	0.013	6.2 ± 1.7	5.4 ± 1.6	0.040
8 mm subcrestal level	6.3 ± 1.5	6.7 ± 1.2	5.8 ± 1.6	0.028	6.5 ± 1.4	5.5 ± 1.4	0.004
14 mm subcrestal level	6.9 ± 1.9	7.0 ± 1.6	6.7 ± 2.1	0.401	7.1 ± 2.0	6.4 ± 1.3	0.141

2 PCD: palatal concavity depth; PCH: palatal concavity height; PCA: palatal concavity angulation; BH: bone

3 height coronal to the canal; BW: bone width anterior to the canal

Frequency distribution of perforation with different implant type

* Statistically significant difference exists between implant sites with cylindrical implant (p = 0.001). ** Statistically significant difference exists between dentate and partially edentulous groups with tapered implant (p = 0.011) . *** Statistically significant difference exists between implant sites with tapered implant (p = 0.031).

1   Table 3 Frequency distribution of perforation with different implant type

Group	Implants (number)	Number of Perforations (number and percent)	
		Cylindrical 4.1 × 12 mm	Tapered 4.3 × 13 mm
Dental Status			
dentate group	36	3 (8.3%)	0 (0.0%) **
partially edentulous group	36	9 (25.0%)	6 (16.7%) **
Implant Site			
right central incisor site	30	10 (33.3%) *	5 (16.7%) ***
left central incisor site	42	2 (4.8%) *	1 (2.4%) ***
Gender			
male	54	7 (13.0%)	3 (5.6%)
female	18	5 (27.8%)	3 (16.7%)
Total	72	12 (16.7%)	6 (8.3%)

2   * Statistically significant difference exists between implant sites with cylindrical implant ($p = 0.001$).

3   ** Statistically significant difference exists between dentate and partially edentulous groups with tapered implant

4   ($p = 0.011$) .

5   *** Statistically significant difference exists between implant sites with tapered implant ($p = 0.031$).

Incidence of perforation after implant angulation adjustment

Table 4 Incidence of perforation after implant angulation adjustment

Embedded Direction	Number (Percent)	Location (mm)	Length (mm)	Depth (mm)	Area (mm^2)
Axis of Restoration	12 (16.7%)	8.5 ± 3.5	5.1 ± 3.4	0.7 ± 0.6	1.0 ± 1.3
Distal by 5 degrees	4 (5.6%)	5.4 ± 3.7	5.5 ± 2.0	0.8 ± 0.4	3.9 ± 4.9
Distal by 10 degrees	2 (2.8%)	2.4 ± 0.1	6.6 ± 2.1	1.1 ± 0.2	2.3 ± 0.7
Labial by 5 degrees	6 (8.3%)	6.8 ± 3.7	5.9 ± 3.9	0.9 ± 0.7	1.5 ± 1.9
Labial by 10 degrees	3 (4.2%)	5.3 ± 4.9	8.2 ± 5.1	1.2 ± 0.9	2.4 ± 2.4

Multivariate logistic regression of factors affecting the NPC perforation

NPC: nasopalatine canal; BW: bone weight anterior to the canal; PCD: palatal concavity depth.

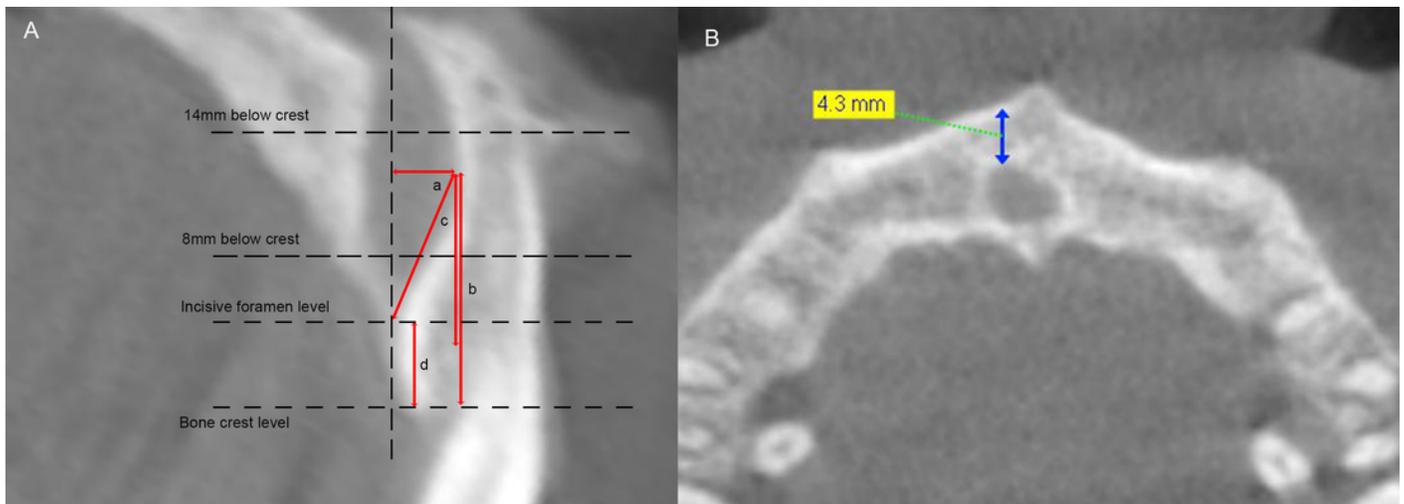
1   Table 5 Multivariate logistic regression of factors affecting the NPC perforation

Variables	β	OR	95% CI	p Value
Left central incisor implant site	-2.446	0.087	0.010 - 0.783	0.029
BW measured at 8 mm below crest	-1.299	0.273	0.111 - 0.671	0.005
PCD	1.466	4.332	1.596 - 11.760	0.004
Constant	1.974	7.200		0.329

2   NPC: nasopalatine canal; BW: bone weight anterior to the canal; PCD: palatal concavity depth.

1

Configuration of Ridge Anterior to the NPC.

A, a = the palatal concavity depth (PCD); b = the palatal concavity height (PCH); c = the palatal concavity angulation (PCA); d = the height of the alveolar bone coronal to the NPC (BH). B, the arrow stands for minimum bone width anterior to the NPC (BW), measured at incisive foramen level, 8 mm and 14 mm below bone crest level, respectively.

2

Features of the selected implants.

a = Straumann Bone-Level Implant 4.1 × 12 mm; b = Nobel Replace Tapered Implant 4.3 ×
13 mm.

4.1 mm

4.1 mm

a

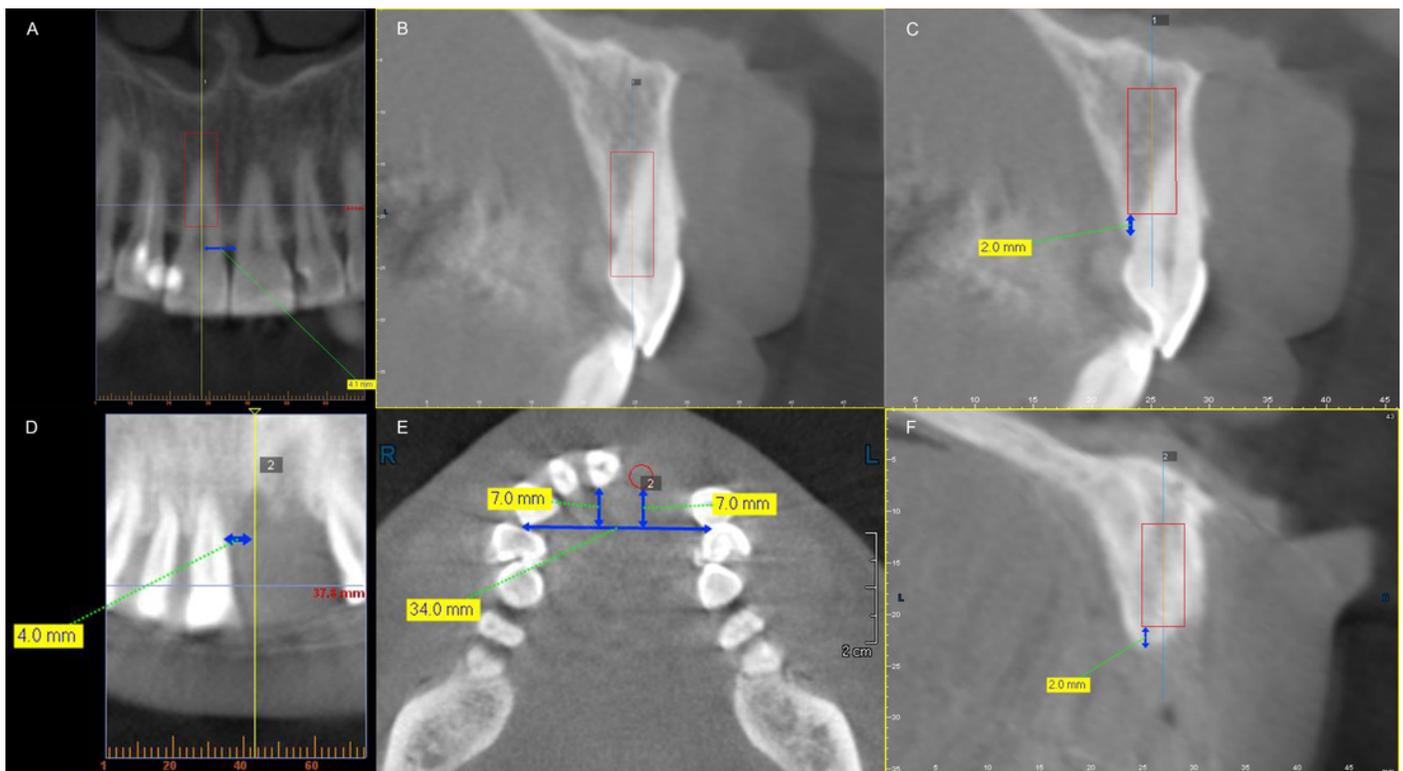
4.3 mm

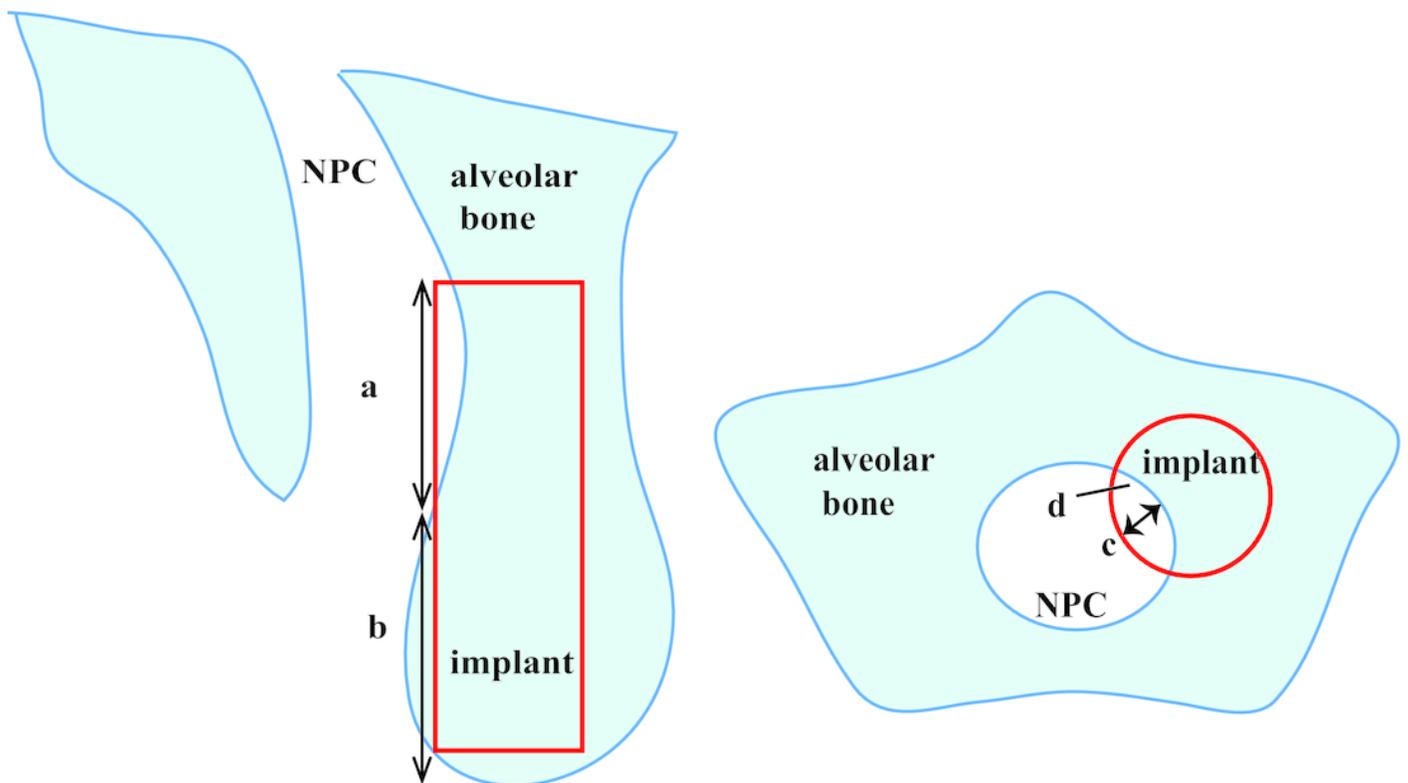
2.56 mm

b

3

Three-dimensional location of virtual implant in dentate patients (A, B, C) and partially edentulous patients (D, E, F).

A and D, mesio-distal location in dentate and partially edentulous group; B and E, bucco-lingually, the implant platform was placed at the cingulum of the future restoration in both dentate and partially edentulous group; C and F, apico-coronally, the implant platform was located 2 mm below the alveolar bone crest in both groups.

Description of nasopalatine canal (NPC) perforation in both sagittal slice and axial slice.

a = length of exposure; b = distance between the alveolar crest and the perforation (location of perforation); c = the depth of the exposure; d = the area of the exposure.

Comparison of ridge configuration anterior to the nasopalatine canal (NPC) between dentate and partially edentulous patients.

The red line stands for the ridge contour of partially edentulous patients.