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Original Article

Mapping mini-implant anatomic sites in the area of the maxillary first molar with the aid of the NewTom 3G® system

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ABSTRACT – ***Introduction:*** *The goal of our study was to construct a map of the implant sites in the region of the attached gingiva around the maxillary first molars that would be appropriate locations for placement of miniscrews to serve as orthodontic anchorage.* ***Method:*** *We conducted 58 radiographic examinations with the NewTom 3G® cone beam technique. For each interdental space, between upper second bicuspids and first molars (5/6) and between upper first and second molars (6/7), we studied the mesio-distal width and depth of bucco-lingual bone at two different levels, L1 and L2, that corresponded to the lower and upper limits of the attached gingiva in the general population.* ***Results:*** *The widths of the interdental spaces varied very little between L1 and L2 and these variations were comparable. At the level of the 5/6 space, the interdental widths displayed a Gaussian distribution, which made it possible for us to determine the confidence intervals at the two borders of attached gingiva as a function of age: $CI_{99\%}$ on L1 = [2.045; 3.462] from 12 to 17 years or [1.594; 2.519] from 18 to 24 or [1.613; 2.5] from 25 to 48 years and $CI_{99\%}$ on L2 = [2.37; 3.69] from 12 to 17 years or [1.5; 2.613] from 18 to 24 or [1.546; 2.619] from 25 to 48 ans. The interdental depths increased in an apical direction and their variance diminished. Even if the adequacy of the Gaussian law is less reliable in the sagittal plane, we find a greater consistency in depths in the spaces around 5/6 that allows us to establish very precise confidence levels: $CI_{99\%}$ on L1 = [9.213; 10.575] and $CI_{99\%}$ on L2 = [10.295; 11.593].* ***Conclusion:*** *The mesial areas of the first molars constitute reliable zones for implantation of miniscrews with a maximum of 2–2.3 mm for 12 to 17 years old or 1.5–1.6 mm for 18 to 48 years old in width and of a maximum of 9–10 mm in length whether the attached gingival level is strong or feeble. The distal areas of the first molars, because of their great variability, require an individualized radiographic study before any miniscrew can be placed.*

1. Introduction

The introduction of miniscrews in orthodontics revolutionized daily practice by providing "absolute" stability in an anchorage unit. Since Creekmore and Eklund first used these devices in 1983 [1] in the region of the anterior nasal spine to intrude maxillary incisor teeth, the effectiveness of temporary anchorage devices, of which miniscrews are one type, has been demonstrated for a great variety of indications such as the ingression of the anterior teeth, the protraction or distalization of molars, the retraction of anterior teeth, adjustment of the occlusal plane, the non-surgical correction of open bites, and Class II and Class III skeletal malocclusions [13, 20, 22].

Many writers, like Lin and Liou in 2003 [14], Kyung, *et al*. in 2003 [10], Maino, *et al.* en 2003 [17] or Melsen in 2005 [18], have proposed greatly different miniscrews that vary widely in shape, length, and diameter. In sharp contrast with this vast array of mini-implant retention systems, there have been very few studies that have attempted to establish a cartography of the safe zones where practitioners

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can place miniscrews with confidence. This shortage of reliable data is, in part, responsible for the complications practitioners often encounter, such as hypersensitivity, injury to root surfaces, or fracture of alveolar bone that sometimes accompany a faulty placement of miniscrews. We wanted, in our investigation, to contribute to a much-needed anatomic cartography of a region widely used clinically, the maxillary first molar region.

The objective of our study was to obtain a three-dimensional view of the amount of bone in this area that orthodontists could utilize in selecting miniscrews and that would also serve as a guide for oral surgeons in inserting them. Our study differs from others that have preceded it by establishing safe zones only at the level of the attached gingiva using the muco-gingival line as a reference landmark, which greatly simplifies his clinical utilization.

2. Methods and materials

This project was a transverse monocentric descriptive study.

2.1. Material

2.1.1. The sample

We recruited our patients in the order of their arrival at appointments at a Paris radiology office for an X-Ray examination of one type or another of a masticatory system disorder. Our study was both prospective and retrospective utilizing as it did previous radiographs stored in the office's information technology system. We selected only films of dentitions with no inflammation, particularly periodontal nor any other infection or tumor.

Our criteria for selecting patients were the presence in the arch of the maxillary second premolars and second molars as well as first molars that had no restorations extending interproximally so that we could be assured of the integrity of the cemento-enamel junction. In addition, we selected only patients whose lower premolars and molars were in position so that there could have been no over-eruption of maxillary buccal teeth. Sex and ethnicity of patients played no role in our selection of the sample.

After analyzing about one hundred tomographic films, we chose a group of 58 patients whose age ranged from 12 to 48 years with an average of 23 and a half.

2.1.2. Gathering information

We used the Italian company QR's NewTom 3G® machine, making our acquisitions at a setting of 110 kV with intensity of 5 to 20 mA. Our films embraced an anatomic spherical volume 15 cm in diameter. Each patient was examined for 35 s but the actual X-ray exposure time was only 5.4 s, with an emitted dosage of only 1 to 7 mGy for a field of 9. For our reconstructions we used a 1000 × 1000 matrix. We treated the data with the Windows XP® operating system and the Newtom 3G Expert® software and then stored the films with the DICOM 3 format.

We used the same reference plane, the palatal, for all the radiographs in our study.

After the first radiograph of volume, we took axial reconstruction, panoramic, and oblique frontal films for each patient with the aide of a reconstruction program. Then we joined all the tomographic sections we had taken, which, together, were 1 mm thick.

2.2. Methods

2.2.1. Variables measured

We measured the interdental alveolar widths and depths between the upper second premolar and the first molar and between the upper first molar and the second molar.

2.2.1.1. Choice of anatomic landmarks

We selected the space to reconstruct on the film "scout view" with the aid of a box parallel to the palatal plane, centered on the maxilla but including the mandibular arch to be sure there were no missing teeth in this opposing dental arch (Fig. 1a).

The axial section we used for measurements passes through the entries to the pulp chambers of the first maxillary molar (Fig. 1b).

On each axial section we established a sagittal reference plane C that closely follows the median panoramic section, then we constructed a second transverse reference plane C' centered on the largest mesio-distal width of the first molar and as perpendicular as possible to C. The program then reconstituted all the panoramic sections following the reference C and all the transverse sections following the C' axis (Fig. 2).

We traced a reference plane L on the panoramic section centered on the first molar that passes

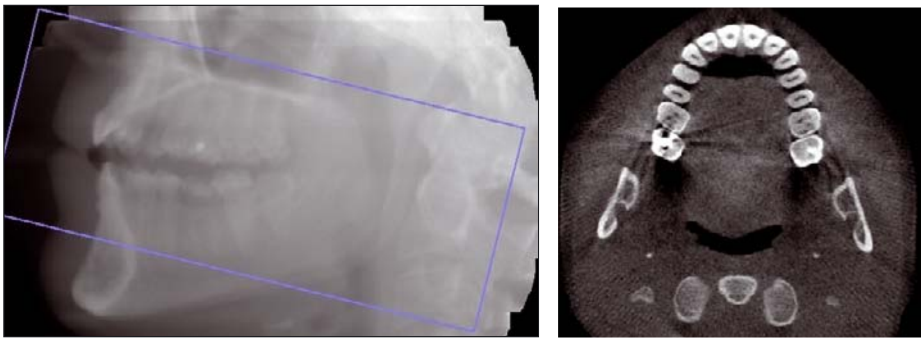

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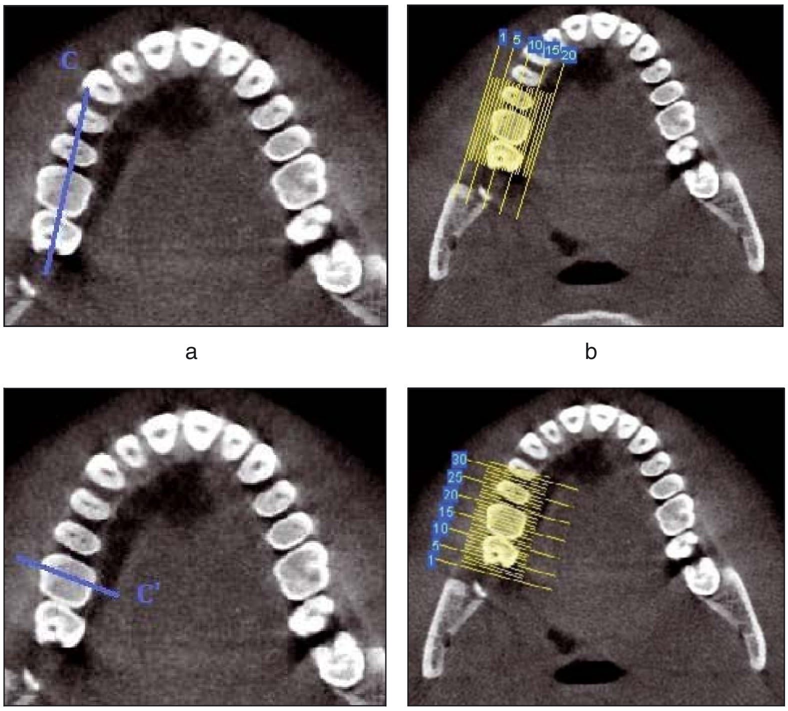
Figure 1
(a) The mode “*scout view*” with the box of working area. (b) The chosen axial section.



a b c d

Figure 2
Axial planes C (a) and C’ (c) and their corresponding reconstruction sections (b and d).

through the interproximal cemento-enamel junctions of the first molar mesially and distally (Fig. 3).

We also designed two reference planes parallel to each other and parallel to the reference plane L, simulating respectively the minimum and the maximum limits of the attached gingiva, calling them L1 and L2. Tenenbaum, *et al.* [23] have shown that the height above the buccal cemento-enamel junctions of the attached gingiva surrounding the first maxillary molar ranges from 2.8 to 4.26 mm. Because the difference between the height of the buccal and proximal cemento-enamel junctions varies from 0 to 1 mm [11], we positioned, with a small margin of security, L1 at 3 mm from line L (Fig. 4a) and L2 at 4.5 mm from line L (Fig. 4b).

With the expectation that oral surgeons will install miniscrews through the attached gingiva at a level quite close to the muco gingival junction, the L1 plane brings into focus the osseous region between premolars and molars used for patients with

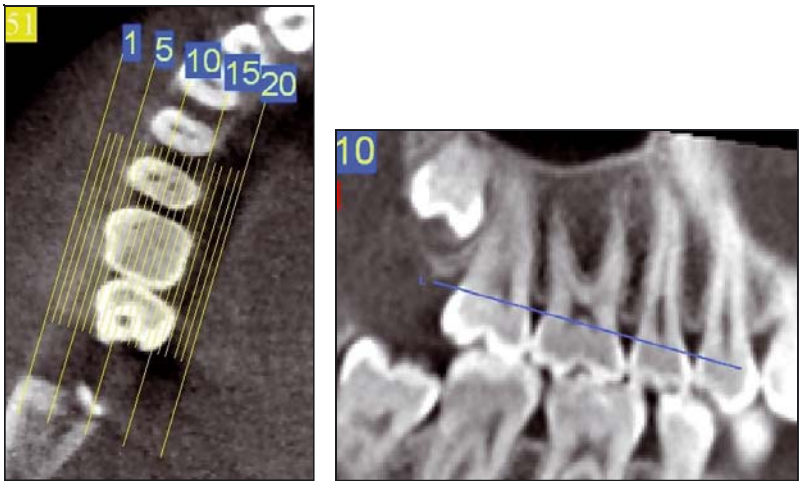


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Figure 3
(a) Choice of the central panoramic section number 10. (b) Tracing of reference plane L.

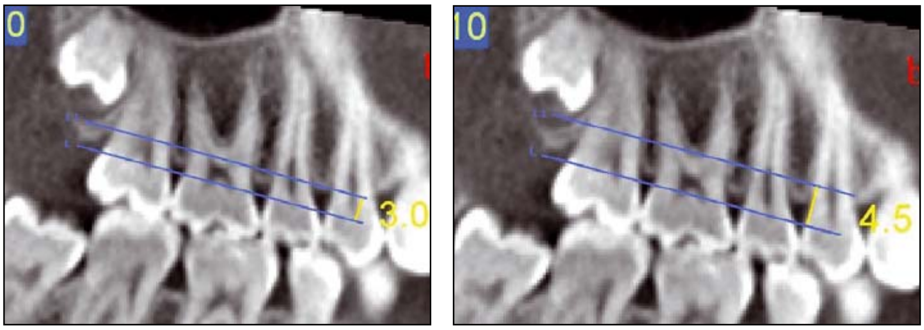

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Figure 4
Materialization of planes L1 (a) and L2 (b) on the panoramic section.

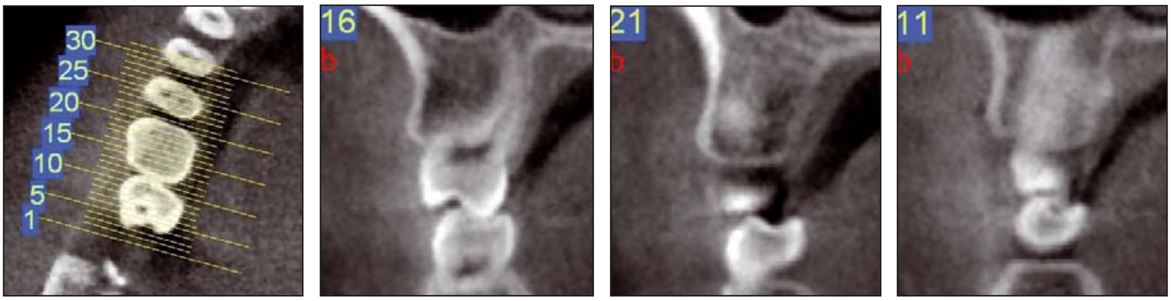
little attached gingiva height (2.8 mm) and the L2 plane depicts the osseous region used for patients with a considerable amount of keratinized gingiva (4.26 mm).

From the ensemble of transverse sections following axis C' that the program reconstructed, we retained three sections: section T1 that is centered on the first molar, T2 that is situated on a point midway between the second premolar and the first molar, and section T3 that is located midway between the first molar and the second molar (Fig. 5).

On section T1 we selected a reference plane H that joins the buccal and palatal cemento-enamel junctions of the first molar. This H plane is characterized by the height at which it is located and the angle it makes with T1 (Fig. 6a).

On sections T2 and T3 we next affixed reference plane H retaining the same height and angulation of section T1 (Fig. 6b and 6c). Plane H symbolizes the cemento-enamel junction and its relationship with sections T2 and T3 makes it an operational reference line for our measurements at the alveolar level of the interdental spaces.

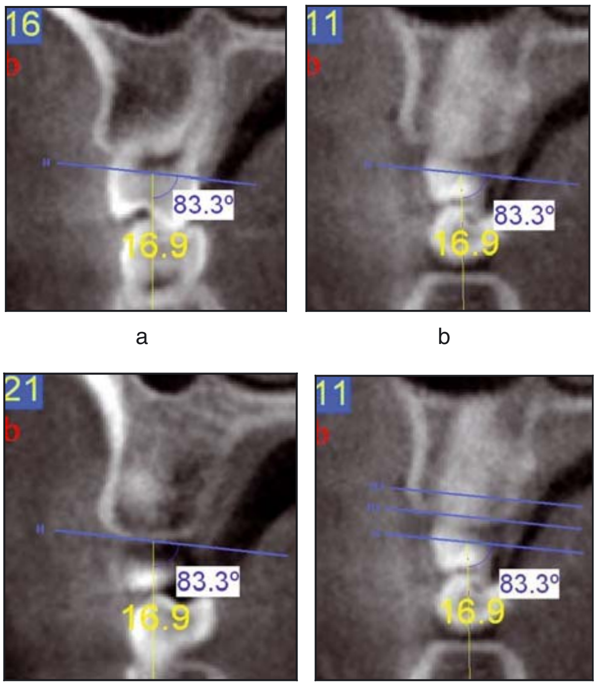
With respect to the reference plane H we defined two other planes parallel to it, planes H1 and H2 respectively 2.5 and 4 mm from plane H (Fig. 6d). Their heights with respect to the buccal-palatal cemento-enamel junction correspond to the heights of lines L1 and L2 in the mesio-distal sense. The 0.5 mm difference between the two heights is caused by a vertical gap between the proximal collar and the buccal collar of the first maxillary molar.



a b c d

Figure 5

(a) In this case, sections 11, 16 and 21 are selected on the axial section. Visualization of sections T1 (b), T2 (c) and T3 (d).



a b c d

Figure 6

(a) The section T1 with plane H situated at 16.9 mm and angulated 83.3^{0}. Plane H is carried onto sections T2 (b) and T3 (c). (d) Planes H, H1 and H2.

2.2.1.2. The amounts measured

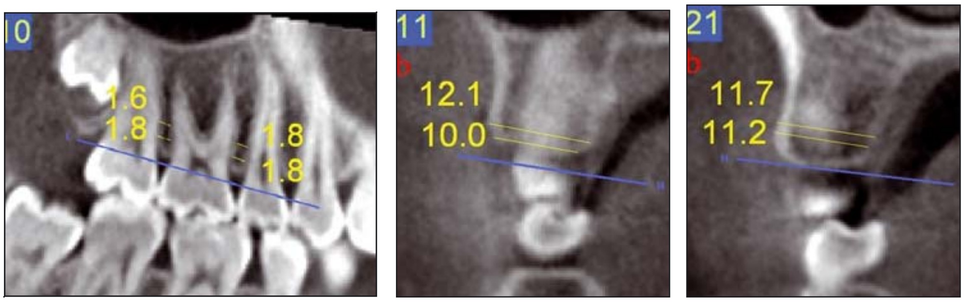
In the sagittal sense, we made our measurements on the panoramic section corresponding to plane C, of each interdental space, the thickness of mesio-distal bone along planes L1 and L2 (Fig. 7a).

One can note from mesial to distal respectively:

- l_{11} and l_{12}: the interdental alveolar bone widths on plane L1,
- l_{21} and l_{22} : the interdental alveolar bone widths on plane L2.

In the transverse sense, we took our measurements of the bucco-palatal bone depth along planes H1 and H2 from the oblique frontal sections T2 and T3 (Fig. 7b and 7c). One can note the depth of this bucco-palatal bone from front to rear respectively:

- p_{11} and p_{12} : the interdental alveolar bone depths on plane H1,
- p_{21} and p_{22} : the interdental alveolar bone depths on plane H2.



a b c

Figure 7

(a) Measurements of the interdental distances between 5/6 and between 6/7. Measurement of interdental depths between 5/6 on section 11 (b) and between 6/7 on section 21 (c).

2.2.1.3. The measurement procedure

The measurements we made with the aid of the NewTom 3G® software were precise to the order of the tenth decimal point, after the period, rounded off. The periodontal ligament constituted the anterior and posterior limits for our measurements or, if it was not visible, we used an arbitrary point of 0.25 mm from the root surface. The cortical alveolar bone constitutes the buccal limit and anatomic structures like the floor of the maxillary sinus or the palatal surface of alveolar cortical bone make up the internal limit.

We have, accordingly, in each hemi-maxilla, four measurements for the two interdental spaces between the second premolar and the first molar and between the first molar and the second molar, or eight measurements per patient. Thus our total number of measurements was 464.

2.2.2. Statistical analysis

We used eight variables to evaluate our sample, the widths and the depths of the interdental spaces between the second premolar and the first molar and between the first and second molars. These variables came from 58 randomly selected subjects. We made a preliminary descriptive analysis of our sample utilizing the 464 measurements we had taken. We used the Kolmogorov-Smirnov test to demonstrate the normality of the sample and then the Student's *t* test to determine the 99% confidence intervals of the four variables. With the Kruskall-Wallis nonparametric test, we compared a number of means during our age analysis. Then we sought a mathematical modelization by regression.

We made our statistical analysis using the R® software version 2.9.1 and Tinn R® software version 1.17.2.4. For each test, error risk α was 5%.

3. Results

The ensemble of the statistically described variables is illustrated in table 1.

3.1. The sagittal measurements

The largest interdental width is the space between the second premolar and the first molar on line L2. However, the l_{11} and l_{21}, interdental widths as well as those of l_{12} and l_{22} on the L1 and L2 planes are quite similar on the average with comparable standard deviations (Fig. 8)

In the interdental space between the first and second molars the bone thickness is less than it is elsewhere. On the L2 line there is less interdental bone because the curve of Spee is greatest in the second molar area.

The distribution of widths is illustrated by the density histograms that each has the corresponding Gaussian density showing the close similarity of these two distributions (Fig. 9).

These histograms demonstrate that the widths l_{11} and l_{21} measured in the space between the second premolar and the first molar have a distribution quite close to Gaussian distribution, which illustrates the consistency of these widths that are greater than the distance between the first and second molars. The Kolmogorov-Smirnov adequacy test of Gauss's law with the same mean and the same standard deviation is statistically significant at the 5% confidence

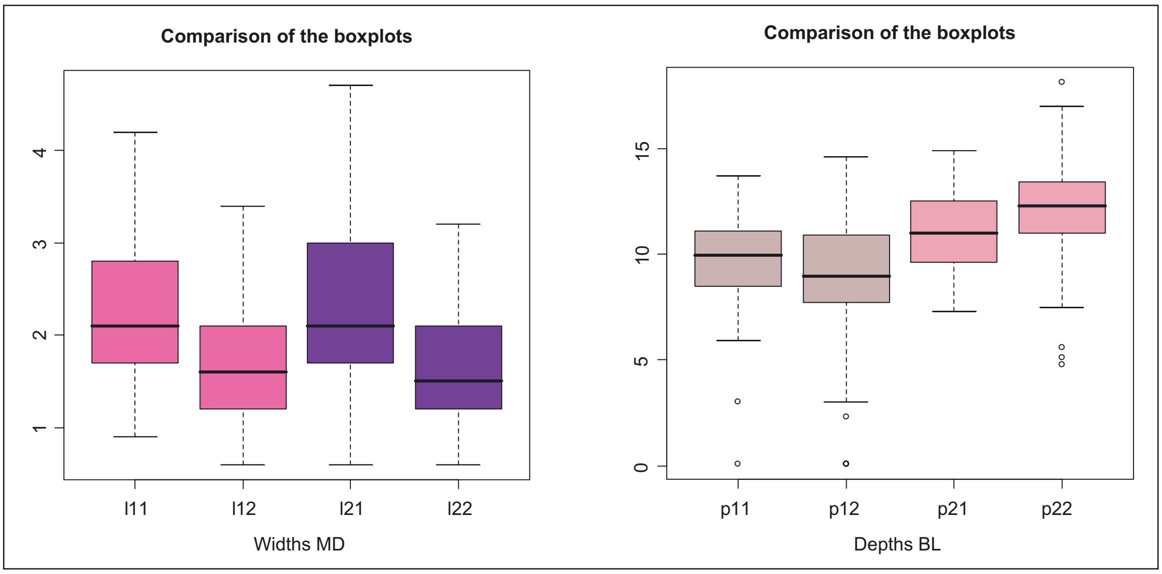


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Figure 8
Graphic comparison of the means and standard deviations of the interdental widths (a) and the interdental depths (b).

Table 1
Descriptive statistics of eight variables.

	Space between 5 et 6				*Space between 6 et 7*			
	l_{11}	l_{21}	p_{11}	p_{21}	l_{12}	l_{22}	p_{12}	p_{22}
Minimum	0.9	0.6	0.1	7.3	0.6	0.6	0.1	4.8
1^{st} *quartile*	1.7	1.7	8.5	9.6	1.2	1.2	7.7	11.0
Median	2.1	2.1	9.95	11.0	1.6	1.5	8.95	12.3
Mean	**2.214**	**2.286**	**9.726**	**10.94**	**1.705**	**1.571**	**8.348**	**11.86**
3^{rd} *quartile*	2.8	3.0	11.1	12.4	2.1	2.0	10.9	13.3
Maximum	4.2	4.7	13.7	14.9	3.4	3.2	14.6	18.1
Standard deviation	**0.819**	**0.962**	**2.304**	**1.854**	**0.571**	**0.612**	**4.045**	**2.498**

level only for these two widths (p-value = 0.5194 for l_{11} and p-value = 0.47 for l_{21}).

For these two variables, in using the Student's t-test we could write the intervals with a 99% confidence level:

- $CI_{99\%}(l_{11}) = [1.927 ; 2.5]$;
- and $CI_{99\%}(l_{21}) = [1.949 ; 2.623]$.

3.2. *The transverse measurements*

The interdental depths increase in the apical direction and their variance decreases.

The greatest interdental depth is located between the first and second molars on line H2. On line H1, one subject had no bone between the second premolar and the first molar while seven subjects had no bone between the first and second molars. That interdental space between first and second molars, on the H1 plane, had less bone depth on average than the space between the second premolar and the first molar and the variance of the measurements was much greater.

The distribution of these widths and their Gaussian rapprochement are illustrated by the density histograms (Fig. 10).

Even though the adequacy of Gauss's law is not as good it is in the sagittal sense, we found a greater consistency of the depths in the spaces between the second premolars and the first molars. The Kolmogorov-Smirnov test is statistically significant at the 5% confidence level only for p_{21}

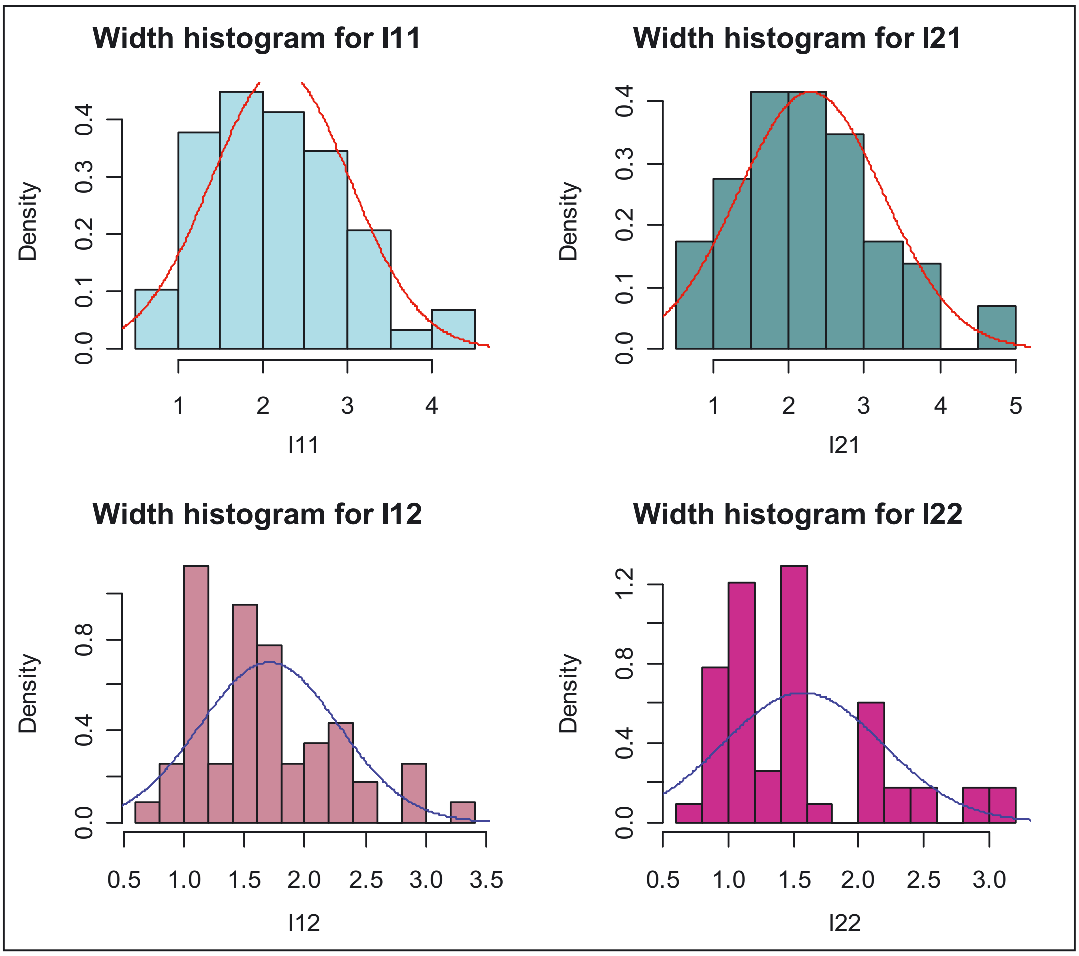


Figure 9
Histograms of the sagittal measurents and the corresponding Normal laws.

(p-value = 0.2281) because of one subject who had no bone at the site of measurement p_{11}. If we eliminate this atypical value, the test becomes statistically significant (p-value = 0.7).

For the depth p_{21}, we write a 99% confidence interval: $CI_{99\%}(p_{21})$ = [10.295 ; 11.593].

For the depth p_{11}, we can write a 99% confidence interval by eliminating the atypical subject:

- new mean = 9.895 ;
- new standard deviation = 1.929 ;
- $CI_{99\%}(p_{11})$ = [9.213 ; 10.576].

3.3. *Influence of age*

For the interdental space between the second premolar and the first molar, we refined the analysis by dividing the sample into three age groups: 12 to 17 years, 18 to 24 years, and 25 to 48 years. We depicted the distribution that we obtained for the three age groups in a general age histogram (Fig. 11).

Next we noted the sub-variables of interdental widths and depths with the title “a” for the first age group, “b” for the second, and “c” for the third. For example, for l_{11}, the three sub-variables are l_{11a}, l_{11b} and l_{11c}.

We illustrated the basic descriptive statistics of these sub-variables in table 2.

As the comparative boxplots show, age affects the two widths and the two depths in the interdental spaces between the second premolars and the first molars (Fig. 12). The interdental widths and depths diminish as patients age from 12 to 48, but the Kruskall-Wallis test shows that these differences are not statistically significant for p_{11} (p-value = 0.09) and p_{21} (p-value = 0.24) but also proves that they are

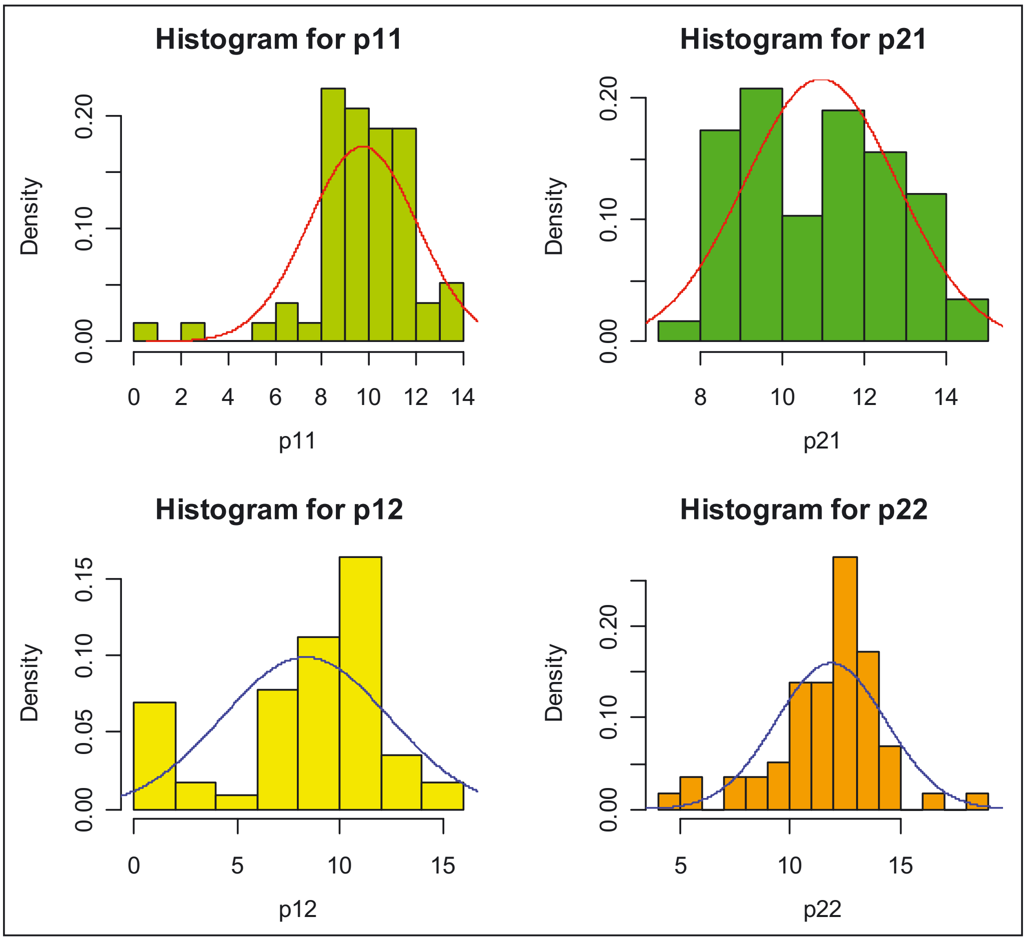
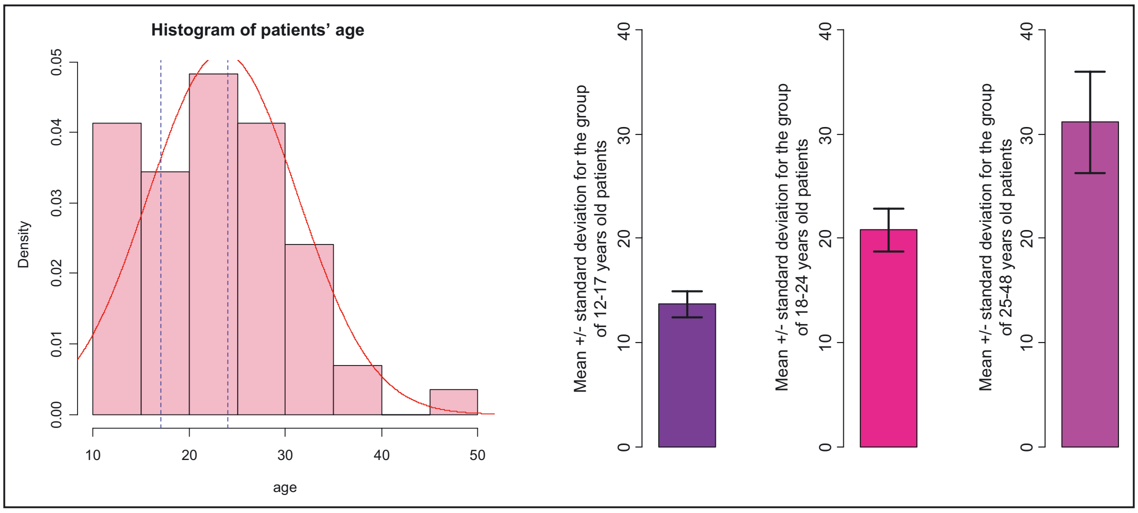


Figure 10
Histograms of the transverse measurements and the corresponding Normal laws.



a b

Figure 11
Histogram of age (a) and its distribution in the three groups (b).

Table 2
Descriptive statistics of twelve sub-variables.

	l_{11a}	l_{11b}	l_{11c}	l_{21a}	l_{21b}	l_{21c}
Mean	2.754	2.057	2.058	3.031	2.057	2.083
Standard deviation	0.836	0.744	0.776	0.779	0.895	0.936
	p_{11a}	p_{11b}	p_{11c}	p_{21a}	p_{21b}	p_{21c}
Mean	11.19	9.676	8.975	11.86	10.8	10.58
Standard deviation	1.66	1.593	2.776	1.867	1.685	1.896

statistically significant for l_{11} (p-value = 0.05) and l_{21} (p-value = 0.009).

Taking into account the homogenous nature of the age groups, the 99% interval confidence levels for the two depths p_{11} and p_{21} are unchanged.

According to the Kolmogorov-Smirnov test, all the sub-variables l_{11a} (p-value = 0.953), l_{11b} (p-value = 0.9866), l_{11c} (p-value = 0.4771), l_{21a} (p-value = 0.9683), l_{21b} (p-value = 0.3795) and l_{21c} (p-value = 0.5658) are consistent with Gauss's law. By using the Student's t-test, we were able to establish new 99% intervals of confidence for the three age groups:

- $CI_{99\%}(l_{11a})$ = [2.045 ; 3.462] and $CI_{99\%}(l_{21a})$ = [2.37; 3.69] ;
- $CI_{99\%}(l_{11b})$ = [1.594 ; 2.519] and $CI_{99\%}(l_{21b})$ = [1.5; 2.613] ;
- $CI_{99\%}(l_{11c})$ = [1.613 ; 2.5] and $CI_{99\%}(l_{21c})$ = [1.546; 2.619].

So, to operate at the highest safety level, orthodontists and oral surgeons must take the patient's age into account when deciding what size miniscrew to use.

3.4. *Modelization*

There are no linear or non-linear mathematical equations that would make it possible for us to tie all these different variables and sub-variables together in a coherent whole. We tried every conceivable combination of age, width, and depth with no success.

4. Discussion

4.1. *The sample*

The number of subjects we evaluated in our investigation, compared to the sample size of earlier studies that comprised at best 30 individuals, is relatively large, which increases the validity of generalizing our results. However, the standard deviations are also large, which demonstrates the wide dispersion of the population around the mean. The variability is greatest in the mesio-distal sense because of the many different angulations teeth assume and because of the wide differences in root morphology.

Our study also covered a broad age range, from 12 to 48 years. We were careful to recruit half of our subjects from adolescents who had not completed their growth period because this group constitutes an important part of the population whose orthodontic treatment will be conducted with the aid of mini-implant anchorage. Every other study evaluated only young adults and mature adults but no teenagers.

4.2. *The landmarks utilized*

In our study we noted two different possible sites along the height of the attached gingiva because we wanted to take measurements with two limits, upper and lower, both observable clinically in the general population.

We decided to evaluate only implant sites situated in the keratinized gingiva because several recent studies, including Kuroda, *et al.* in 2007 [9] show a success rate of about 90% for miniscrews implanted in the attached gingiva. Placement in the free mucosa is known to cause irritation, inflammation, and more frequent failure. And, worse, in the free mucosa the head of the screw must be buried in soft tissue, which greatly limits its therapeutic usefulness.

The results we have presented in our study are based on a landmark readily recognizable in the mouth, the muco-gingival junction in contrast to other studies that used the alveolar crest or the cemento-enamel junction. We chose this landmark

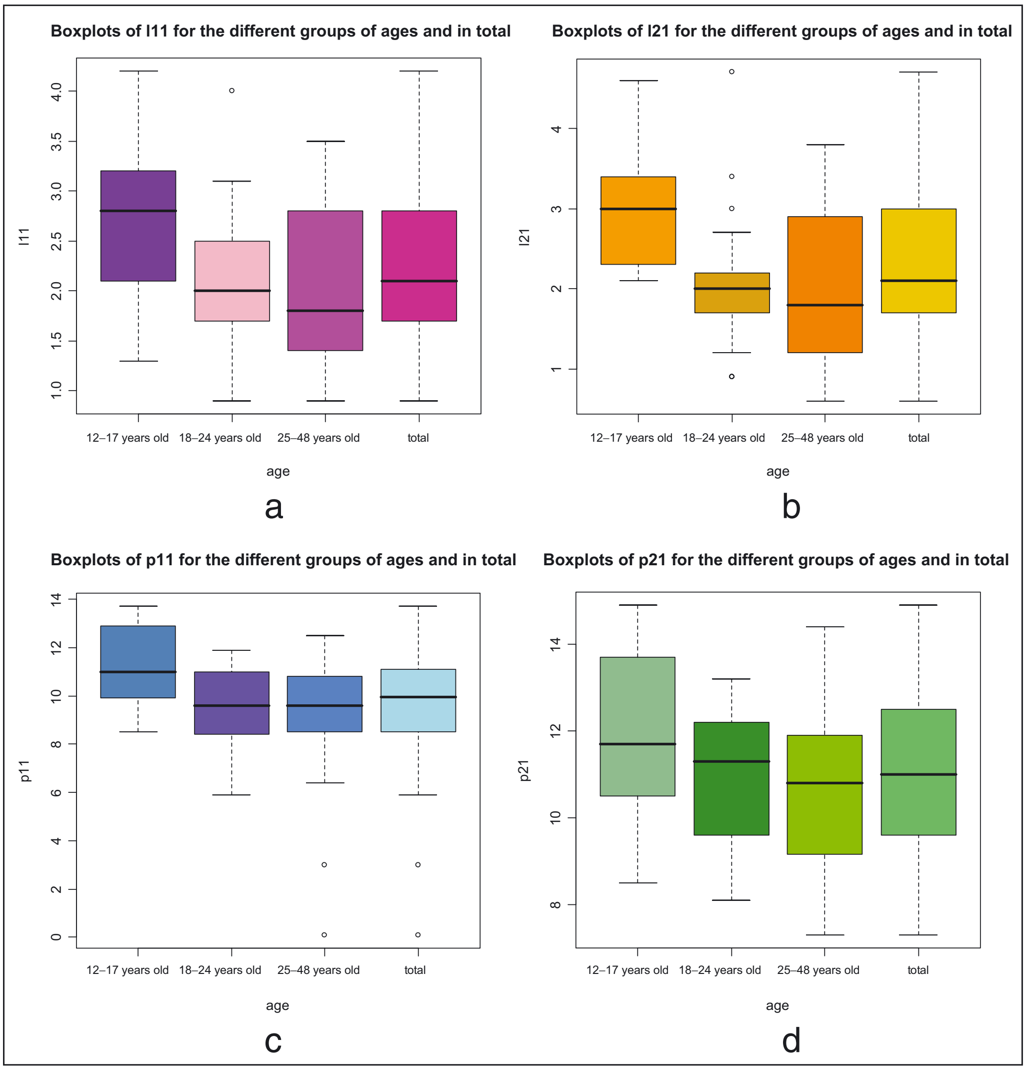


Figure 12
Comparison of the boxplots of the variables l_{11}(a), l_{21}(b), p_{11}(c) and p_{21}(d), according to age.

because practitioners would be able to employ it clinically with facility.

4.3. *The width and length of the miniscrews*

Because one of the objectives of our study was to create a dimensional reference guide to aid orthodontists in their choice of miniscrews, the great variability of the region of the maxillary first and second molars necessitated an individualized preoperative radiographic analysis.

Our study provides no information about the angulation oral surgeons should use to implant miniscrews but, by means of a simple trigonometric calculation, we can derive the maximum screw length for any given angulation.

The author are in total agreement in recommending a 30-40° angulation in the maxilla, which will accommodate a longer miniscrew and diminish the risk of impinging on neighboring roots during implantation.

Our study did not include palatal implant sites [3–6, 12, 21] or infra-zygomatic sites [16].

Taking into account the great number of patients and the Gaussian distribution of the widths measured in the second premolar to first molar interdental space, we were able to establish 99% confidence intervals for that region that would allow a generalization of results:

– In the sagittal sense, we are going consider the inferior borders of the confidence intervals of l_{11} and of l_{21} as the maximum widths of miniscrews that can be used in relation to the height of the attached gingiva. Lindhe [15] estimates that the periodontal space enveloping the tooth occupies about 0.25 mm of space. In calculating our measurements we regarded the periodontal space as a minimal security zone. Poggio, *et al.* [21] suggest that surgeons respect a security margin of 1 mm between the miniscrew and the adjacent root surface to prevent its being injured. But with that great a protective zone the maximum permissible width of a miniscrew that could be used mesial to the first molar would be far too small for patients older than 17. Crismani, *et al.* [2] confirm this conclusion by proving with meta-analysis that miniscrews 1 to 1.1 mm in width have a very low success rate.

Summing up, we can state that all miniscrews less than 2 mm in diameter can be used for patients 12 to 17 years of age whose height of attached gingiva is modest and all miniscrews with widths lower than 2.3 mm can safely be used for those in the 12 to 17 years old group who have a satisfactorily greater height of attached gingiva. For patients 18 to 48 years of age practitioners can appropriately select miniscrews with a maximum width of 1.5 mm no matter what the height of the attached gingiva may be. But in no instance, should surgeons implant miniscrews whose width is less than 1.2 mm.

- In the transverse sense, we chose as a security space a cortical palatal bone thickness of 1.2–1.3 mm as suggested by Hu, *et al.* [6]. Morarend, *et al.* [19] confirm our choice of bi-cortical support in their study that shows that a 1.5 mm miniscrew with bicortical support has an anchorage resistance at least equal to that of a 2.5 mm miniscrew with only monocortical support. The lower borders of confidence intervals of p_{11} and p_{21} constitute the maximum permissible lengths of the bodies of miniscrews that can be used, in function of the level of the attached gingiva. The thickness of the keratinized gingiva determines the height of the collar of the miniscrew. Kim, *et al.* [8] have shown with anatomic dissections that the attached gingiva is 2 mm (1.46 ± 0.6 mm) on the line L1 and up to 1.5 mm (0.98 ± 0.5 mm) on the line L2.

In conclusion, for those patients with a modest height of attached gingiva, the length of the body of the miniscrew must be less than 9 mm and the collar must measure less than 2 mm. For patients with a greater height of attached gingiva, the maximum length of minscrews can be 10 mm and the collar can be at least 1.5 mm in height. But in all cases, to be retained satisfactorily miniscrews must be at least 8 mm long [2].

In spite of the difficulty of making comparisons, we are confident in saying that our results agree well with those previously published by Ishii, *et al.* [7], Deguchi, *et al.* [3], Poggio, *et al.* [21], Hernandez, *et al.* [5] and Hu, *et al.* [6].

5. Conclusion

Areas mesial to the first maxillary molar constitute safe zones for implantation of miniscrews provided they have bodies no greater that 1.5 to 2 mm in diameter depending on the age of the patient and lengths no greater than 9 to 10 mm, depending upon the height of the attached gingiva. Orthodontists and oral surgeons should keep these values in mind in order to avoid damaging any dental tissues. But it is still not possible to establish a comparable standardized osseous guide for this region that would make it practical for practitioners to avoid irradiating their patients with the obligatory pre and post-operative radiographs. And the regions distal to the maxillary first molar, because of their great variability, still require obligatory personalized radiological examinations.

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