Radiographic Features of Mandibular Trabecular Bone Structure in Hypodontia

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ABSTRACT

Purpose: Radiographic parameters of mandibular trabecular bone structure between 67 subjects having hypodontia and those without were studied on digital panoramic radiographs.

Materials and Methods: Three regions of interest (ROI) were defined: the ascending ramus, apical of the mandibular molar and mesial of the first mandibular molar. The effects of the presence of hypodontia and the ROI on the mandibular trabecular bone structure were tested for statistical significance by means of multivariate analysis.

Results: Radiographic parameters of trabecular bone architecture were found to differ between various regions of the mandible ($p = 0.000$), but not between the group of hypodontia subjects and their controls ($p = 0.23$). There was no interaction effect between the ROIs and the two groups ($p = 0.79$). For people having hypodontia, some directional parameters of trabecular bone have a reverse correlation with the number of missing teeth. The fractal dimension and the number and perimeter of white segments in the binarized image correlate positively with the number of congenitally missing teeth.

Conclusions: A limited number of parameters of radiographic mandibular trabecular bone structure correlate with the number of missing teeth. However, a markable difference in radiographic parameters of mandibular trabecular bone structure between hypodontia and non-hypodontia subjects could not be demonstrated.

KEY WORDS: congenitally missing teeth, hypodontia, oligodontia, tooth agenesis, trabecular bone structure

INTRODUCTION

Hypodontia is a condition in which one or more permanent teeth are congenitally missing. It is seen as part of a syndrome (ie, in ectodermal dysplasia) or as a nonsyndromic anomaly. Hypodontia can vary widely in severity, from a single missing tooth to the absence of all permanent teeth (anodontia).[1,2] In case of an absent tooth, the deciduous tooth may be retained until a high age.[3]

Dental treatment of severe hypodontia can be comprehensive and usually requires an interdisciplinary approach. Current treatment of severe hypodontia includes the use of dental implants as part of the restorative phase of treatment.[4] Information in the literature with respect to the results of dental implant treatment in syndromic and nonsyndromic hypodontia subjects is scarce, frequently anecdotic, and sometimes conflicting. Some authors show promising results in nonsyndromic hypodontia subjects.[5–7] Garagiola and colleagues[8] report similar implant survival rates in hypodontia subjects with and without ectodermal dysplasia. Others observed compromised overall success rate in ectodermal dysplasia subjects with hypodontia, especially in the maxilla.[9–11] Several possible reasons for the latter observation can be hypothesized. Since crown formation and root development of permanent teeth are considered to be important for the development of the alveolar process, their absence and the subsequent lack of growth stimuli of the jawbone will result in impaired alveolar

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bone volume and, possibly, also compromised bone structure.[12,13]

In addition, mutations in some homeobox genes, among which is the MSX1 gene, have been identified as etiological factors in hypodontia.[14,15] Such genes and molecules bear relevance to the process of both tooth morphogenesis and craniofacial bone formation. Recently, a new gene (LTBP3) has been identified that, when dysfunctional, causes severe hypodontia, short stature, and increased skeletal bone density.[16] Whether or not mandibular trabecular bone structure in hypodontia patients is markedly different from that of non-hypodontia subjects is not known to date.

The present study focuses on differences in radiographic parameters of mandibular trabecular bone structure between persons having hypodontia and those without. Furthermore, it is investigated whether these differences are constant across the mandible. For persons having hypodontia, the relation between the number of missing teeth and the mandibular trabecular bone structure is determined.

MATERIALS AND METHODS

The investigation is set up as a case–control study.

Cases

Sixty-seven subjects who were classified as having "hypodontia," "oligodontia," or "tooth agenesis" were selected from the databases of the Center for Special Dental Care of the University Medical Center, Utrecht in the Netherlands (31 males, 36 females). When no panoramic radiograph was present, when the panoramic radiograph was of poor quality, or when the missing tooth type could not be confirmed, the subject was excluded from the study. The number of missing teeth (third molars excluded) was determined from the panoramic radiographs or intraoral photographs when available. Hypoplastic and/or radiographically apparent, but not (yet) erupted, permanent teeth were considered as being "present."

Controls

A control group of age-matched and sex-matched non-hypodontia subjects was selected from the radiographic database of the Utrecht University Medical Center. The panoramic radiographs were taken in the same month as that of their corresponding matched cases. Each case was matched with a different control.

Panoramic Radiographs and Regions of Interest. Digital panoramic radiographs were acquired with a Planmeca Promax-2 panoramic x-ray machine (64–66 kV, Planmeca Oy, Helsinki, Finland), as part of the anticipated dental treatment. Bone structure measurements were performed at three rectangular regions of interest (ROI) located in the right-hand side of the mandible on all panoramic radiographs. The manually selected ROIs were located: (1) in the ascending ramus, (2) apical of the mandibular molars, (3) between the mesial root of the first mandibular molar, and the anticipated or actual root of the second mandibular bicuspid (Figure 1). Considering ROIs in three typically different regions enables estimation of the relevance of the location. The mean sizes of the ROIs were 140 × 199 pixels, 206 × 65 pixels,

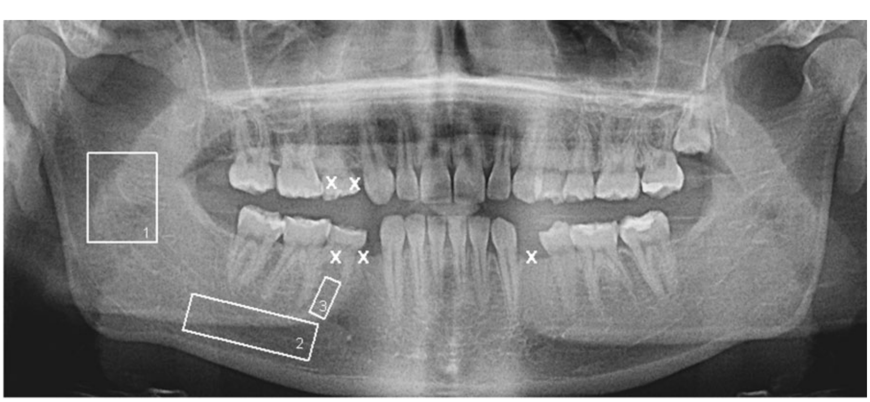

Figure 1 Panoramic radiograph of a hypodontia patient with regions of interest. Congenitally missing teeth are marked with an "x." The right upper and lower first and second bicuspid, and the left lower first bicuspid are congenitally missing. ROI 1 = ascending ramus; ROI 2 = apical of the mandibular molars, and parallel and above the cortical border of the mandible; ROI 3 = parallel to the mesial root of the first molar, stretching from the apex of the mesial root to half way up the root.

and 29 × 62 pixels for regions 1, 2, and 3, respectively. The ROIs were chosen to reflect the possible changes in the alveolar process, in an area far away from the alveolar process (the ramus), which should not be affected by functional effects but only by systemic influences, and in a region in between these two ROIs.

Radiographic Measurement Procedure. The three ROIs were subjected to a sequence of automatic measurement procedures. The procedure of extracting the quantitative data from the radiographic trabecular texture has been described extensively before and is presented here briefly for completeness.[17,18] First, the mean (MEAN) and standard deviation (STDEV) of the gray values were determined in the raw, unfiltered image samples. Subsequently, the image sample was binarized into white and black segments (Figure 2A), and the fractal dimension according to the caliper method (FRACTL), the combined area of white segments (WAREA), and the perimeter of white segments (WCIRC), and the number of white and black segments (WITES and BLAKS) were determined. The measurements WAREA, WCIRC, and WITES and BLAKS were standardized by dividing them by the area of the ROI. Next, the white segments were eroded to a wire frame (Figure 2B) and the total length of the frame (WAXIS), the number of end points (WENDS and WENDS2), and the number of branching points (WFORK and WFORK2) were determined. The black regions were approached in an analogous manner, yielding the parameters BAXIS, BENDS, BENDS2, BFORK, and BFORK2. It is important to mention that the parameters for the white regions and those for the black regions used are not complementary. The measurements on the wire frame were standardized by dividing them by the total surface area of the ROI or by the length of the skeleton (WENDS2, BENDS2, WFORK2, and BFORK2). Finally, the line fraction deviation (LFD) of orientation along 12 directions was measured ranging from 0° (LFD 0) to 165° (LFD 165). The 29 measured geometrical, topological, and directional parameters of the radiographic trabecular bone pattern and the manner of standardization are presented in Table 1. The employed method of measuring spatial orientation of trabecular bone, its validity, and clinical application have been described previously and in more detail.[17–22]

Statistical Analysis. The effects of the presence of hypodontia and the ROI on the 29 variables that measure the radiographic mandibular trabecular bone structure were tested for statistical significance using a 2 × 3 repeated measures analysis of variance design, with the presence of hypodontia and the location of the ROI as independent variables. The relation between the

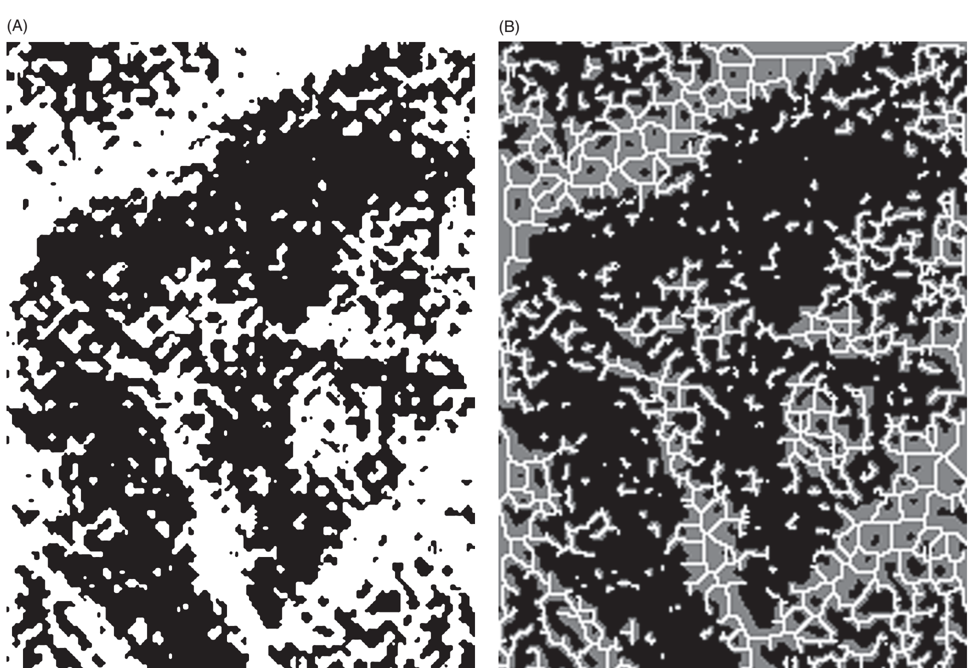

Figure 2 (A) Binarized version of the region of interest. (B) Wire diagram of the white segments.

TABLE 1 Measured Radiographic Parameters of Mandibular Trabecular Bone Architecture

Simple parameters			
1	MEAN	Mean of gray values in the ROI	
2	STDDEV	Standard deviation of gray values in the region of interest	
Geometrical parameters of the binarized version of the sample			
3	FRACTL	Fractal dimension	
4	WAREA	Area of white segments	Divided by the area of the ROI
5	WCIRC	Perimeter of white segments	Divided by the area of the ROI
6	BLAKS	Number of black segments	Divided by the area of the ROI
7	WITES	Number of white segments	Divided by the area of the ROI
Topological parameters of the wire diagram of the white segments			
8	WAXIS	Length of struts	Divided by the area of the ROI
9	WENDS	Number of end points	Divided by the area of the ROI
10	WENDS2	Number of end points	Divided by the length of the white skeleton
11	WFORK	Number of furcations	Divided by the area of the ROI
12	WFORK2	Number of furcations	Divided by the length of the white skeleton
Topological parameters of the wire diagram of the black segments			
13	BAXIS	Length of struts	Divided by the area of the ROI
14	BENDS	Number of end points	Divided by the area of the ROI
15	BENDS2	Number of end points	Divided by the length of the black skeleton
16	BFORK	Number of furcations	Divided by the area of the ROI
17	BFORK2	Number of furcations	Divided by the length of the black skeleton
Directional parameters of the binarized version as reflected by the line fraction deviation index			
18	LFD 0	Orientation along 0°	
19	LFD 15	Orientation along 15°	
20	LFD 30	Orientation along 30°	
21	LFD 45	Orientation along 45°	
22	LFD 60	Orientation along 60°	
23	LFD 75	Orientation along 75°	
24	LFD 90	Orientation along 90°	
25	LFD 105	Orientation along 105°	
26	LFD 120	Orientation along 120°	
27	LFD 135	Orientation along 135°	
28	LFD 150	Orientation along 150°	
29	LFD 165	Orientation along 165°	

LFD = line fraction deviation; ROI = region of interest.

number of missing teeth and these 29 parameters was determined using the Pearson correlation. The success of the matching procedure was verified by means of a paired samples *t*-test among cases and their matched controls. All computations were done using the SPSS package version 16.0 (SPSS Inc., Chicago, IL, USA).

RESULTS

The matching procedure was successful, with a perfect match on gender and no statistically significant age difference between cases and controls (respectively, 23.7 ± 10.2 years vs 23.7 ± 10.1 years; paired samples *t*-test, $t_{66} = 0.35$, $p = 0.73$). The cases had 2 to 21 teeth congenitally missing teeth, third molars excluded (mean 9.7, SD 4.5 missing teeth).

Mean values of the radiographic parameters of bone structure among subsets of subjects are presented in Table 2. Multivariate analysis revealed a statistically significant difference in bone parameters among different ROIs ($F_{58,9} = 79.53$, $p = 0.000$), but no differences between the group of hypodontia cases and the controls ($F_{29,4} = 1.28$, $p = 0.23$). Hence, a marked difference in radiographic mandibular trabecular bone structure between hypodontia and non-hypodontia subjects

TABLE 2 Measured Radiographic Parameters of Mandibular Trabecular Bone Architecture among Subsets of Subjects

	Group		Location		
Parameters	Cases (n = 67)	Controls	ROI 1	ROI 2	ROI 3
1. MEAN	115.7 (26.8)	124.1 (30.2)	129.5 (31.3)$^{+}$	110.6 (24.0)$^{-}$	119.6 (27.8)
2. STDDEV	19.0 (8.5)	17.0 (8.1)	24.1 (8.7)	15.7 (5.5)	12.6 (5.5)$^{-}$
3. FRACTL	1.496 (0.068)	1.497 (0.070)	1.536 (0.036)$^{+}$	1.512 (0.045)$^{+}$	1.441 (0.070)$^{-}$
4. WAREA	0.469 (0.033)	0.463 (0.035)	0.459 (0.018)$^{-}$	0.459 (0.024)$^{-}$	0.478 (0.049)$^{+}$
5. WCIRC	0.336 (0.021)	0.334 (0.022)	0.322 (0.013)$^{-}$	0.323 (0.016)$^{-}$	0.350 (0.023)$^{+}$
6. BLAKS	0.004 (0.002)	0.004 (0.002)	0.003 (0.001)$^{-}$	0.003 (0.001)$^{-}$	0.005 (0.002)$^{+}$
7. WITES	0.005 (0.002)	0.005 (0.002)	0.005 (0.001)$^{-}$	0.005 (0.001)$^{-}$	0.006 (0.002)$^{+}$
8. WAXIS	0.183 (0.009)	0.181 (0.011)	0.180 (0.064)$^{-}$	0.180 (0.008)$^{-}$	0.185 (0.014)$^{+}$
9. WENDS	0.025 (0.003)	0.025 (0.003)	0.025 (0.019)	0.025 (0.023)	0.025 (0.047)
10. WENDS2	0.136 (0.018)	0.138 (0.020)	0.136 (0.011)	0.136 (0.014)	0.138 (0.028)
11. WFORK	0.018 (0.002)	0.018 (0.003)	0.020 (0.001)$^{+}$	0.018 (0.001)$^{+}$	0.016 (0.003)$^{-}$
12. WFORK2	0.099 (0.012)	0.099 (0.012)	0.108 (0.004)$^{+}$	0.101 (0.005)$^{+}$	0.087 (0.013)$^{-}$
13. BAXIS	0.247 (0.011)	0.248 (0.011)	0.242 (0.006)$^{-}$	0.245 (0.008)$^{-}$	0.254 (0.014)$^{+}$
14. BENDS	0.022 (0.003)	0.022 (0.003)	0.021 (0.002)$^{-}$	0.021 (0.002)$^{-}$	0.024 (0.004)$^{+}$
15. BENDS2	0.089 (0.011)	0.087 (0.012)	0.086 (0.006)$^{-}$	0.084 (0.007)$^{-}$	0.094 (0.016)$^{+}$
16. BFORK	0.022 (0.003)	0.022 (0.003)	0.024 (0.001)$^{+}$	0.023 (0.002)$^{+}$	0.020 (0.004)$^{-}$
17. BFORK2	0.090 (0.011)	0.089 (0.012)	0.098 (0.004)$^{+}$	0.092 (0.006)$^{+}$	0.077 (0.012)$^{-}$
18. LFD 0	0.163 (0.073)	0.161 (0.065)	0.104 (0.025)$^{-}$	0.158 (0.047)	0.223 (0.066)$^{+}$
19. LFD 15	0.144 (0.066)	0.143 (0.063)	0.089 (0.016)$^{-}$	0.132 (0.036)$^{-}$	0.210 (0.060)$^{+}$
20. LFD 30	0.134 (0.059)	0.136 (0.060)	0.091 (0.019)$^{-}$	0.116 (0.026)$^{-}$	0.197 (0.059)$^{+}$
21. LFD 45	0.132 (0.052)	0.130 (0.052)	0.099 (0.026)$^{-}$	0.114 (0.022)$^{-}$	0.181 (0.054)$^{+}$
22. LFD 60	0.131 (0.051)	0.131 (0.054)	0.100 (0.029)$^{-}$	0.116 (0.026)$^{-}$	0.177 (0.058)$^{+}$
23. LFD 75	0.127 (0.050)	0.129 (0.055)	0.096 (0.023)$^{-}$	0.115 (0.024)$^{-}$	0.172 (0.063)$^{+}$
24. LFD 90	0.130 (0.050)	0.135 (0.055)	0.101 (0.025)$^{-}$	0.122 (0.029)$^{-}$	0.174 (0.063)$^{+}$
25. LFD 105	0.136 (0.050)	0.144 (0.052)	0.113 (0.028)$^{-}$	0.127 (0.032)$^{-}$	0.180 (0.061)$^{+}$
26. LFD 120	0.145 (0.052)	0.145 (0.052)	0.109 (0.028)$^{-}$	0.142 (0.042)	0.184 (0.043)$^{+}$
27. LFD 135	0.152 (0.062)	0.148 (0.060)	0.097 (0.022)$^{-}$	0.157 (0.046)$^{-}$	0.197 (0.059)$^{+}$
28. LFD 150	0.156 (0.072)	0.152 (0.071)	0.091 (0.017)$^{-}$	0.157 (0.046)	0.214 (0.072)$^{+}$
29. LFD 165	0.160 (0.078)	0.160 (0.072)	0.094 (0.017)$^{-}$	0.157 (0.046)	0.229 (0.072)$^{+}$

Mean values and standard deviations between brackets. For explanation of the abbreviated parameter names, see Table 1 and Figure 1. There is a statistically significant overall effect of the location of the measurements (ROI, $p < .001$). Contrasts are presented as a statistically significant difference from the mean and denoted with a "+" or a "–." No statistical overall effect of the group (cases vs controls) was observed and contrasts are not presented. LFD = line fraction deviation; ROI = region of interest.

could not be confirmed. No evidence was found for an interaction effect between the ROIs and the two groups ($F_{58,9} = 0.78$, $p = 0.79$).

However, the number of absent teeth correlated statistically significant with some of the geometrical and directional bone parameters (Table 3). There is a positive but weak correlation with the fractal dimension ($r = 0.31$, $p = 0.01$), and both the perimeter and number of white segments in the binarized radiographic image ($r = 0.33$, $p = 0.006$ and $r = 0.29$, $p = 0.02$, respectively). In addition, a negative correlation can be observed with the directional orientation along 0° and along 165° ($r = -0.24$, $p = 0.05$ and $r = -0.32$, $p = 0.008$, respectively).

DISCUSSION

On hypothetical grounds, a difference in mandibular trabecular bone structure may be present among subjects with and without numerical aberrations of tooth formation. The presence of permanent teeth plays a role during the development of alveolar bone. Some genes and molecules that are known to be involved in tooth

TABLE 3 The Relation between Parameters of the Radiographic Mandibular Trabecular Bone Architecture and the Number of Congenitally Missing Teeth in Hypodontia Patients

Parameters	Pearson's correlation coefficient	*p*-value
1. MEAN	−0.06	
2. STDDEV	−0.10	
3. FRACTL	0.31	0.01
4. WAREA	−0.19	
5. WCIRC	0.33	0.006
6. BLAKS	−0.07	
7. WITES	0.29	0.02
8. WAXIS	−0.13	
9. WENDS	−0.21	
10. WENDS2	−0.15	
11. WFORK	−0.08	
12. WFORK2	−0.16	
13. BAXIS	0.24	
14. BENDS	0.07	
15. BENDS2	0.01	
16. BFORK	0.16	
17. BFORK2	0.06	
18. LFD 0	−0.24	0.05
19. LFD 15	−0.18	
20. LFD 30	−0.13	
21. LFD 45	−0.11	
22. LFD 60	−0.05	
23. LFD 75	0.09	
24. LFD 90	0.02	
25. LFD 105	0.09	
26. LFD 120	0.17	
27. LFD 135	0.06	
28. LFD 150	−0.12	
29. LFD 165	−0.32	0.008

Pearson correlation, $n = 67$ patients.
Significant correlations are denoted.

formation are also relevant to the process of craniofacial development. To our knowledge, no studies have focused on this issue to date, yet it bears clinical relevance, since for the functional and aesthetic oral rehabilitation of subjects with (severe) hypodontia, the placement of oral implants is a common treatment modality. The implants are placed in the alveolar bone and serve to support crowns and bridges, or removable prosthetic appliances; therefore, the quality of the alveolar bone is of paramount importance. The successful application of dental implants relies heavily on the capability of the host bone to achieve and maintain intimate bone-implant contact during initial healing and subsequent implant loading.[23] It remains to be seen whether or not the bone in hypodontia and non-hypodontia subjects is of the same "bone quality" and will respond to implants and functional loading in a similar and favorable manner, and studies investigating this particular subject are lacking.

The term "bone quality" is frequently used in implant dentistry and has been identified as a predictor of implant success.[24] It was originally based on the clinical distinction in macro-architecture of bone, expressed as the relative proportion of trabecular to cortical bone, although the accuracy and efficacy of assessing the quality of jawbone on a radiograph in this manner has been questioned.[25,26] Since then, other aspects of bone, such as its vascularity and mineral density, have gained clinical appreciation in achieving and maintaining osseointegration as well.[23]

Invasive and destructive per surgical diagnostic measures to evaluate aspects of "bone quality," such as laser Doppler flowmetry (vascularity), the assessment of implant insertion resistance torque, and resonance frequency analysis (bone density), have been described.[27–29] Radiographic techniques are used to obtain presurgical structural information about bone in a nondestructive manner. For this purpose, sophisticated radiographic methods are employed in general medicine and implant dentistry alike, including dual x-ray absorptiometry and various forms of computed tomography and magnetic resonance imaging.[30–34] An important advantage of the use of the less sophisticated conventional panoramic radiographs is that they are routinely made in dentistry, and oral and maxillofacial surgery. Therefore, they are easily and widely available.

Measuring trabecular spatial orientation on panoramic radiographs can be performed in a reliable and reproducible manner.[20] The manual selection of ROI does not introduce large amounts of noise. The technique was applied successfully in the past to study the predictive value of trabecular architecture of jawbone on bone mineral density among osteoporotic and non-osteoporotic subjects.[21] The same measurement technique and parameters of bone architecture were used in the present study with regard to potential differences in mandibular trabecular bone structure among subjects with various degrees of hypodontia (cases) and non-hypodontic subjects (controls).

It was decided to choose the ROIs located in the ascending ramus, apical of the mandibular molars, and between the mesial root of the first mandibular molar, and the anticipated or actual root of the second mandibular bicuspid. The latter position was chosen because the first mandibular molar is seldom absent. It would have been ideal to measure at locations where implant placement was actually anticipated or from which bone grafts were going to be obtained instead. However, controls would then have to be non-hypodontia cases requiring implants at comparable sites as their matched case. Since much effort was put in matching cases and controls on age and gender, this would have been practically not achievable. In addition, radiographs of hypodontia subjects and matched controls that were selected were made around the same date. The latter was considered relevant in order to compensate for possible unregistered alterations in the settings in time of the x-ray device. As a consequence, the data presented in this study should be considered exploratory and relate to mandibular trabecular bone in general at the selected ROI (that are not necessarily relevant to implant dentistry). Translation of the findings to, for instance, histological sections would be speculative.

By means of the used technique, apparent differences of many parameters of the radiographic spatial architecture of mandibular jawbone were apparent between regions located in the ascending ramus, below the molars, and mesial of the root of the first molar. This is not surprising for various reasons. One reason is that the regions that were chosen lie far apart, were located in both basal bone and in the alveolar process, and were both in the vicinity of and far away from teeth. No statistically significant differences within the group of hypodontia subjects and the controls could be demonstrated. However, two directional parameters correlate statistically significantly with the number of absent teeth. It has been shown that the masticatory performance of people with a reduced number of occluding teeth is impaired when compared with subjects with a complete natural dentition.[35,36] Bone structure functionally adapts to the (muscle) forces exerted upon it, and mandibular bone forms no exception.[37] This may contribute to the correlation between some spatial parameters of mandibular trabecular bone and the number of absent teeth that was noted in the present study.

It was observed that subjects with an increasing number of missing teeth also exhibit a larger fractal dimension, which means a larger perimeter and number of white segments in the binarized radiographic image. The fractal dimension is a measure that reflects the contours of the white areas of the binarized sample. When there are many curves, and each curve by itself has ample twists and turns, the fractal dimension can reach the value of 2, like a flat surface. However, when the contour resembles a straight line, the fractal dimension approaches the value of 1. Hence, a higher value for fractal dimension with an increasing number of congenitally missing teeth suggests a coarser contour of the white areas. It is of interest to mention that fractal dimension and bone mineral density were found to be correlated in mandibular bone in a recent in vitro study using cone beam computed tomography imaging.[34] Since the latter radiographic technique is swiftly becoming more widely available and can provide detailed information regarding both anatomical and structural features of bone, its use for in vivo studies on bone texture in larger populations (ie, hypodontia vs non-hypodontia subjects) holds a promise for the near future, but needs further evaluation.

In conclusion, radiographic parameters of trabecular bone architecture differ between various regions of mandibular jawbone. Some directional parameters have a reverse correlation with the number of missing teeth. The fractal dimension, and the number and perimeter of white segments in the binarized image correlate positively with the number of congenitally missing teeth. However, a difference in radiographic parameters of mandibular trabecular bone structure between hypodontia and non-hypodontia subjects could not be demonstrated.

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