9-1998

The Relationship of the Incisive Canal to Maxillary Median Diastema

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THE RELATIONSHIP OF THE

INCISIVE CANAL

TO MAXILLARY MEDIAN DIASTEMA

by

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A Thesis in Partial Fulfilment of the

Requirements for the Degree Master of

Science in Orthodontics

September 1998

Each person whose signature appears below certifies that this thesis in their opinion is adequate, in scope and quality, as a thesis for the degree Master of Science in Orthodontics.

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Acknowledgements

I wish to thank various individuals and departments at Loma Linda University for permission to use specimens, particularly the Robert M. Ricketts Research Library and Growth Centre, and the Department of Anatomy. Thanks to the Department of Implantology, School of Dentistry, LLU, for use of their X-ray developers. Thanks to Dr. Dorothy Dechant, Curator, Institute of Dental History and Craniofacial Study, University of the Pacific School of Dentistry for the use of specimens contained in the Spencer R. Atkinson Collection. Some of the radiographs reproduced in this paper were taken on materials in the Atkinson Collection. Thanks to Dr. T. Schisf, department of radiology, University of the Pacific School of Dentistry, for use of radiographic and developing equipment, and X-ray film. Thank you to Dr. Grenith Zimmerman for her assistance in the statistical analysis. I am also grateful to each of the members of my research committee for their time and assistance.

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Abstract

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The purpose of this study was to assess the relationship between the incisive canal and maxillary median diastema, and to identify an imaging method capable of documenting the geometry and dimensions of the incisive canal. The sample consisted of 59 dry skulls, 26 of which had a maxillary median diastema ranging in size from 0.1 mm to 2.8 mm (mean 1.0 mm, SD=0.7 mm). Each skull had all of the permanent maxillary teeth present from first molar to first molar and lacked any apparent non-orthodontic condition that could have caused the diastema. Diastema width and canal diameter were measured directly on each skull. A series of three plane radiographs were taken of each skull - a maxillary modified "lateral" ceph, a special maxillary occlusal, and a central incisor periapical. A total of 18 measurements and evaluations were made on each set of films to describe the incisive canal size, position, orientation, and its surrounding cortical bone.

Incisive canals ranged in size from 2.3 mm to 7.2 mm (mean 3.9 mm, SD=0.9 mm). Analysis of the results failed to confirm a relationship between the size of a diastema and the size of the incisive canal for this sample. However, a weak correlation between size of diastema and the density of cortication around the canal was observed when cortication was evaluated subjectively from the maxillary occlusal radiograph (Spearman's correlation 0.49, $p<0.01$). Additionally, in skulls with a diastema, the central incisor roots were found to be more convergent on average than in those skulls without a diastema ($p=0.03$, mean with diastema –2.5°, SD=5.2°, mean without diastema 0.1°, SD=5.8°).

INTRODUCTION

Maxillary median diastema has long been considered in our culture as an esthetic defect, and closing this diastema is therefore routinely performed during orthodontic treatment. Various studies have found the prevalence of maxillary median diastema to be from 1.6% to upwards of 25%.[1-8] This wide range is due to variations in the population under investigation, the selected sample, and differences in the definition of what constitutes a diastema. The prevalence also varies with the stage of dental development, where a tendency for spontaneous closure is noted with eruption of the permanent lateral and canine teeth.[3,4,8,9]

Many factors have been implicated as potential etiological factors for maxillary median diastema. In a review article, Huang and Creath (1995) listed a number of possibilities, including, enlarged labial frenum, oral habits, muscular imbalances, physical impediments (eg. mesiodens), abnormal maxillary arch structure, and various dental anomalies.[10] Others would add deep overbite, maxillary tooth size deficiencies, and median alveolar cleft. Median diastema is commonly associated with generalized spacing.[7,11-13]

Every orthodontist will have occasion to treat such diastemas. While closing the diastema is not generally difficult, there has been much concern over the stability of the closure.[14-16] The result has been the development of a variety of procedures to help ensure stability - ranging from maxillary midline osteotomy and surgical closure,[15,17] to frenectomy/frenotomy,[13,14] to permanent retention,[18-20] and esthetic restorative options.[16,21,22] A recent postretention study suggests relapse rates may be lower than previously reported.[23] Sullivan (1996) reported 34% of the sample had a measurable relapse (0.3±0.6 mm). An attempt was made to identify potential causes of relapse or pre-treatment predictors of relapse, namely, overbite, overjet, generalized maxillary anterior spacing, maxillary incisor to sella-nasion (degrees), abnormal frenum, and intermaxillary osseous cleft. None of these could be identified as a causative factor or used to predict relapse.

One potential etiological factor for maxillary median diastema, or its associated relapse, that has not yet been investigated in the literature is the proximity of the incisive canal and its associated bony cortex to the roots of the maxillary central incisors. The incisive canal encases a neurovascular bundle and descends through the midline along the intermaxillary suture. It ends at the incisive foramen beneath the incisive papilla just lingual to and between the maxillary central incisors.[24] The canal is surrounded by cortical bone and like other cortical bone structures would be expected to reduce the rate of tooth movement, possibly negating the effect of gentle forces such as the tendency of a diastema to close as the cuspids erupt.

In order to make clinical treatment decisions based on the proximity of the incisive canal to the incisor roots, the clinician must have some means of imaging the canal and its relationship to the incisor roots. Computed tomography (CT scan) is effective for this purpose,[25,26] but this imaging technology is rarely used for patients undergoing orthodontic treatment. When a large incisive foramen is present, it will often be seen on a periapical radiograph of the maxillary central incisors and on a standard maxillary occlusal film.[27,28] But these can only show the medio-lateral relationship – a lateral projection showing the antero-posterior relationship is also needed. Unfortunately, neither the canal nor the foramen are visible on a lateral ceph.

The purpose of this study was to investigate the relationship between the presence and size of a maxillary median diastema and the size and cortication of the incisive canal. Imaging methods were of necessity assessed for their ability to image the incisive canal and provide the required data regarding canal anatomy.

Materials and Methods

A. Sample

Dry skulls at Loma Linda University (Loma Linda, CA) and from the Spencer R. Atkinson Collection (University of the Pacific School of Dentistry - San Francisco, CA) were examined. Twenty six skulls with maxillary median diastema (≥0.1 mm) and 33 skulls without diastema were measured and radiographed. Sample criteria specified that the skull must have all maxillary permanent teeth present from first molar to first molar and permanent maxillary cuspids at least half erupted (ie. cusp tip at least half way from alveolar crest to occlusal plane). Those exhibiting maxillary midline pathology, mesiodens, generalized microdontia, or severe periodontal disease were not included. The teeth, especially the maxillary anteriors, are fragile and many are now broken or missing from the skulls. This was permissible provided the mesials of the maxillary central incisors were intact for measurement of a diastema. Information as to the age, gender, or race of the skulls was not available.

B. Direct measurements on the skull

Due to the complex nature of the incisive canal, it was determined to combine direct measurements on the skulls with measurements taken on radiographs. This provided accurate data on canal diameter for the statistical analysis of the canal/diastema relationship, and for evaluation of the potential of the radiographic technique to provide equivalent data.

Two measurements were taken directly on each skull: 1) width of diastema, and 2) transverse diameter of the incisive canal. The width of the diastema was defined as the least distance between the central incisor crowns in the contact area. When present, the diastema was measured with a plastic feeler gauge (constructed of acetate sheets 0.1 mm thick) to the nearest 0.1 mm. The transverse diameter of the incisive canal was measured with needle point dividers. The measurement was transferred to paper by piercing, which was then measured with an electronic digital caliper (Steelex Fine Tools - China). The incisive canal at the incisive foramen is funnel shaped. This measurement was taken at a level where the inner cortical walls approached parallelism, usually 2 to 3 mm up into the canal (Figure 1). All measurements and evaluations were made by the principle investigator (JSC).

C. Radiographic methods and examination

For clinical applications, a radiographic imaging technique for the incisive canal is required. Several methods were investigated. Tomographic examination of two dry skulls, one with a diastema and one without, was conducted with a computer controlled machine that uses a spiral motion for tomography (Scanora Type SBR 1C - Soredex Corporation, Helsinki, Finland). Each skull was held in place and the machine aligned to the incisor/canal

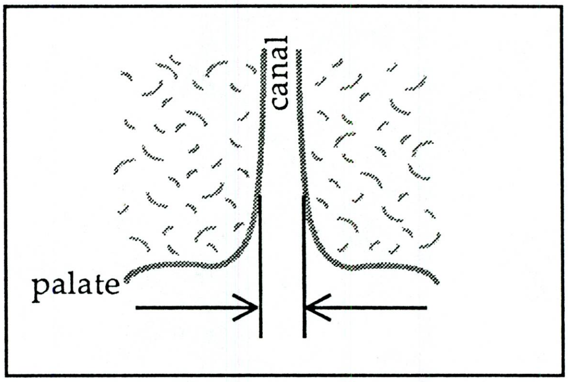


Figure 1. Measurement of the transverse diameter of the incisive canal. Cross-section through the incisive canal and foramen.

area. X-ray energy was attenuated with copper and brass filtration to compensate for the reduced density of the dry skulls which lack the soft tissues, and to yield a radiographic film with suitable density for viewing. Both transverse cuts (eg. through both incisors) and sagittal cuts (eg. through midline) failed to clearly show the incisive canal. As an aid to identify the canal, a 0.012" stainless steel ligature wire was threaded through the canal to pinpoint its location. The wire could be clearly seen in the tomograph, but even when the location of the canal was thus demonstrated it could not be clearly seen or measured. Tomographs were not deemed a useful technique for imaging of the incisive canal.

CT scans have been demonstrated to effectively image the incisive canal.[25,26] This was confirmed by viewing several scans both on film and on computer screen. Today's CT imaging software permits viewing of the hard tissue anatomy in any plane and orientation. However, CT scanning does expose the patient to more radiation and is significantly more costly. It is not indicated for most orthodontic patients.

An alternate method utilized three plane film radiographs to identify and image the incisive canal and its relationship to the central incisors: 1) a "lateral ceph" of the maxilla (designated maxillary ceph), 2) a maxillary occlusal, and 3) a maxillary central incisor periapical. Custom film holding devices were fabricated to hold the film and align the X-ray beam of a standard intraoral dental X-ray unit (Figures 2 and 3).

Maxillary ceph radiograph (Figures 4 & 5). A straight piece of gutta percha was placed in the incisive canal. The skull, with mandible removed, was placed on the film holding device with the occlusal plane essentially parallel with the bite plate. An occlusal film (ANSI size 3.4) was held parallel with the midsagital plane and exposed. This created a lateral ceph projection of the maxilla, with the gutta percha clearly indicating the location and orientation of the incisive canal.

Maxillary occlusal radiograph (Figures 6 & 7). Based on measurements of the incisor and canal orientation in the maxillary ceph, the X-ray beam and

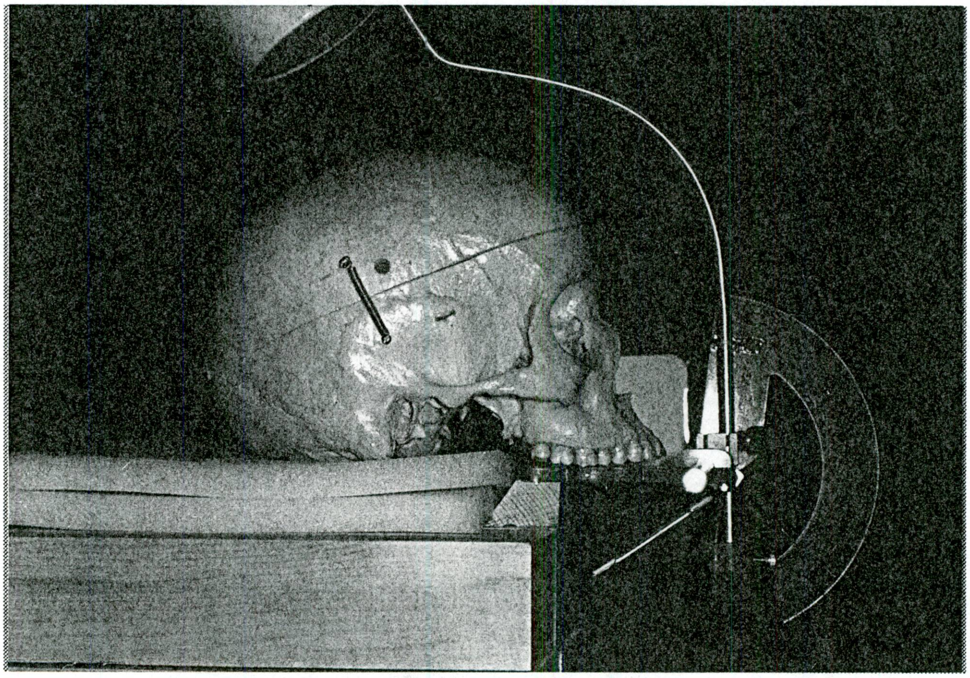


Figure 2. Custom film holding device - lateral view.

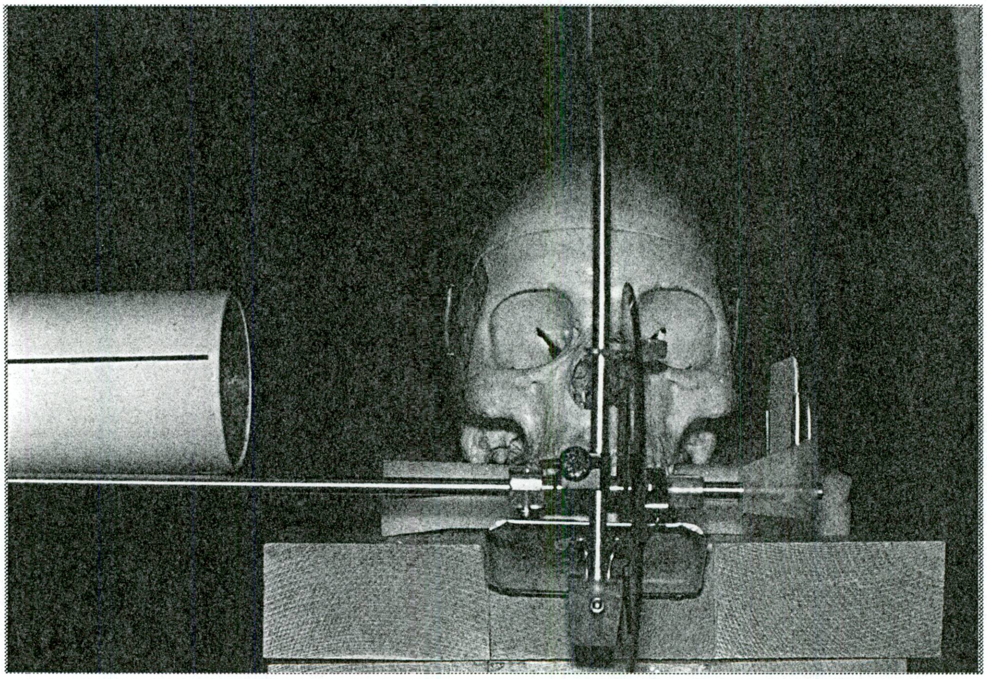


Figure 3. Custom film holding device - frontal view.

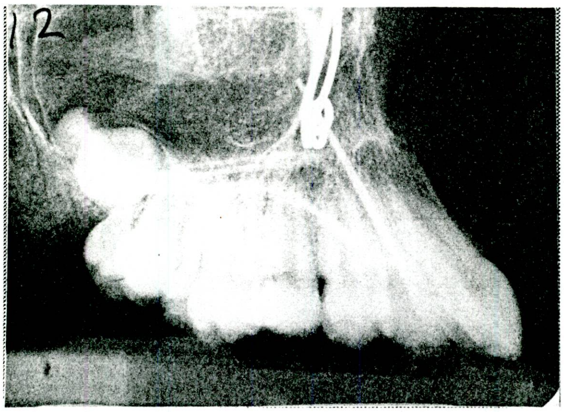


Figure 4. Maxillary ceph showing gutta percha in the incisive canal.

Figure 5. Skull cross-section along the midsagital plane showing the incisive canal.

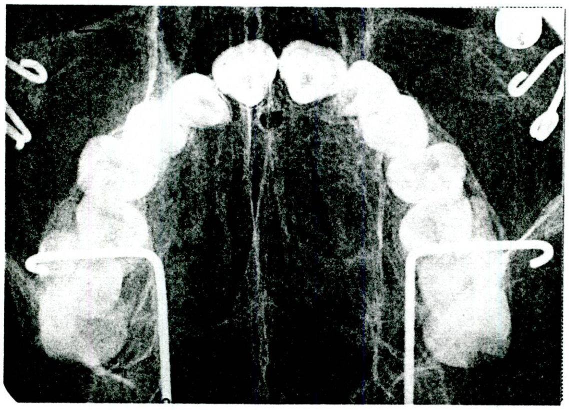


Figure 6. Maxillary occlusal. Note the incisive canal lingual to the central incisors.

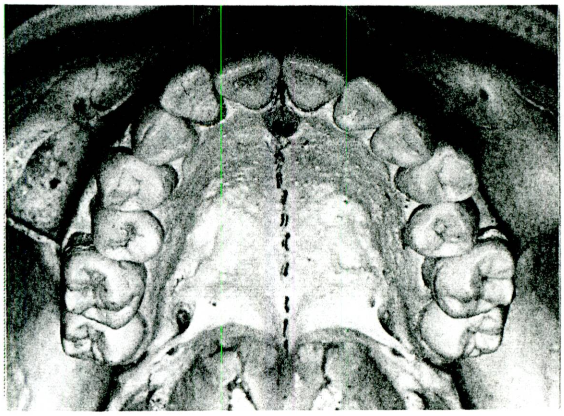


Figure 7. Occlusal view of the maxilla of a skull. Note the incisive canal/foramen.

Figure 8. Incisor periapical. Note incisive foramen between the incisors.

occlusal film were aligned for the central ray to travel approximately down the long axis of the incisive canal. The film holding device held the occlusal film perpendicular to the central ray, not parallel with the occlusal plane (see Figures 2 and 13). This film was exposed without the gutta percha in the canal. Occasionally a second film taken at a different angle was required when the first film failed to show the necessary detail.

Incisor periapical radiograph (Figure 8). The skull, with mandible removed, was placed on the X-ray holding device. A periapical film (ANSI size 1.1) was aligned parallel to the long axis of the central incisors and exposed with the central ray at right angles in the standard manner of the parallel technique.

At Loma Linda University (LLU), Kodak Ultra-speed (D speed) film was utilized. For the Atkinson Collection, Kodak Ektaspeed Plus (E speed) was used. Some skulls had the cranium removed and some did not. Two different X-ray machines were used - one for Loma Linda skulls, the other for the Atkinson skulls. Exposure settings varied accordingly (Table 1). In all cases, the films were processed in an automatic developer on the 4.5 minute setting.

Table 1. Exposure times (in seconds).

	Ceph	Maxillary occlusal		Periapical
		without cranium	with cranium	
LLU*	0.50	0.45	0.90	0.25
Atkinson Collection**	0.45	0.45	0.90	0.25

* 80 kVp, 10mA, film speed D
** 70 kVp, 7mA, film speed E

D. Radiographic measurements (Table 2)

Tracing acetate was placed over the maxillary ceph. Lines were drawn to represent the palatal plane, occlusal plane, long axis of the incisor root, long axis of the incisive canal, and the bite plate of the radiographic film holding device (Figure 9). Four angular measurements (Table 2 - #3,4,6,12), rounded to the nearest 0.5°, were made on each maxillary ceph tracing with a protractor; the remainder (Table 2 - #5,7,8), were calculated using the

Table 2. Data sources and measurements.

	Source	Measurement*
1	Skull	width of diastema
2		transverse diameter of canal
3	Mx ceph	palatal plane to incisor
4		palatal plane to canal
5		palatal plane to occlusal plane
6		incisor to occlusal plane
7		canal to occlusal plane
8		canal to incisor
9		Mx occlusal to palatal plane**
10		Mx occlusal to incisor**
11		Mx occlusal to occlusal plane**
12		bite plate/occlusal plane discrepancy***
13	Mx occlusal	transverse diameter of canal
14		degree of canal cortication - measured
15		degree of canal cortication - subjective
16	Periapical	width of foramen
17		height of foramen
18		CEJ line to inferior margin of foramen
19		angulation of central incisors
20		degree of canal cortication - subjective

* all linear measurements are rounded to the nearest 0.1 mm.
all angular measurements are rounded to the nearest 0.5°.

** angle of central X-ray relative of listed anatomical reference.

*** the angle indicated on the radiograph holding device was with reference to the bite plate of the device. This discrepancy measurement was used to correct the indicated angle to the anatomical references.

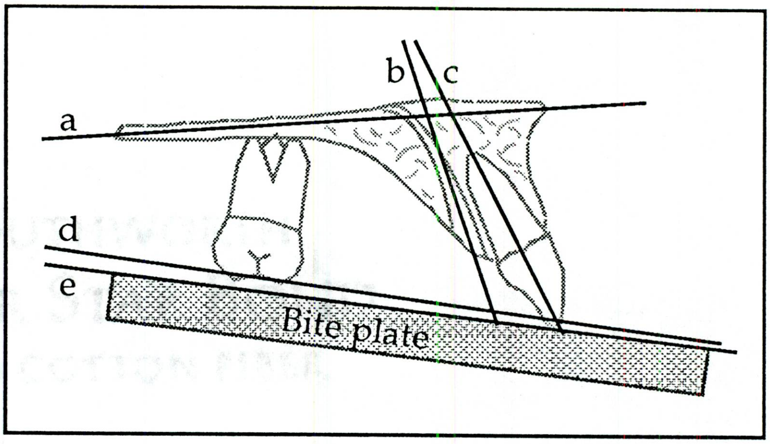
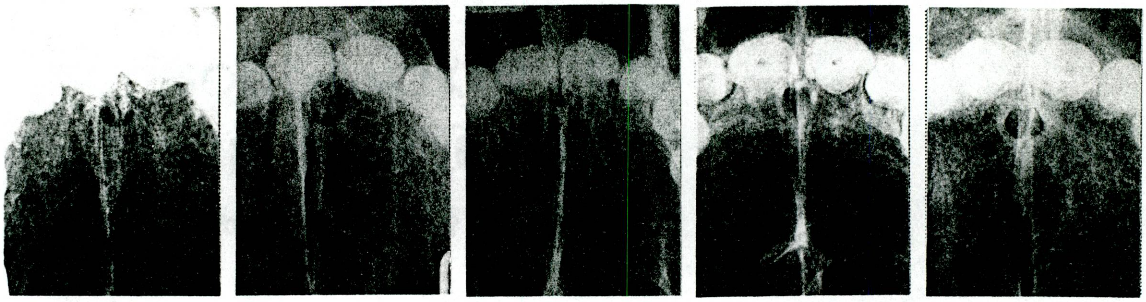


Figure 9. Lines and planes drawn on the maxillary ceph radiograph.
a. Palatal plane.
b. Long axis of incisive canal.
c. Long axis of incisor root.
d. Occlusal plane.
e. Bite plate.

mathematical fact that the three angles of a triangle add up to a total of 180°. The angle indicated on the film holding device was the angle of the central ray relative to the bite plate. This was used together with the bite plate/occlusal plane discrepancy measurement (Table 2 - #12) to calculate the angle of the central ray to the anatomical references (Table 2 - #9,10,11).

The transverse diameter of the incisive canal from inner cortical margin to inner cortical margin was measured directly on each maxillary occlusal film to the nearest 0.1 mm with an electronic digital caliper (Steelex Fine Tools - China). Two measures of the degree of cortication around the



0 1 2 3 4

Figure 10. Reference standards for subjective evaluation of cortication in maxillary occlusal radiographs.

canal were made; one measured, one subjective. The cortical bone surrounding the canal is seen on the radiograph as a radiopaque ring of varying density. The measured cortication is the canal diameter when measured from outer cortical margin to outer cortical margin minus the canal diameter when measured from inner cortical margin to inner cortical margin (ie. measured cortication = outer diameter minus inner diameter). A subjective rating scale for degree of cortication of the incisive canal was created by selecting five reference films ranging from almost no cortication (designated 0) to heavy cortication (designated 4) (Figure 10). Cortication of the incisive canal in each occlusal film was evaluated using this scale.

Cortication around the canal can be described as negligible, mild, moderate, or heavy. Each category can either partially or completely surround

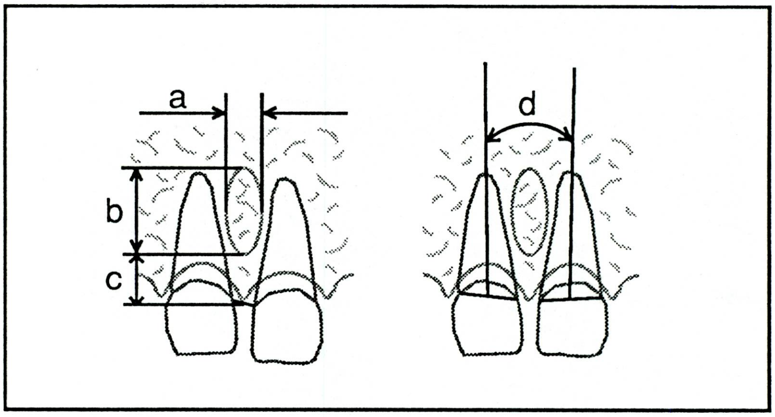


Figure 11. Measurements on the incisor periapical radiograph.
a. Width of incisive foramen.
b. Height of incisive foramen.
c. Distance from CEJ line to inferior margin of foramen.
d. Angulation of central incisor roots.

the canal. In words, the subjective cortication ratings are: 0) negligible cortication, 1) mild partial, 2) mild complete to moderate partial, 3) moderate complete to heavy partial, and 4) heavy complete.

The height and width of the incisive foramen in the incisor periapical radiograph were measured directly with the same digital caliper to the nearest 0.1 mm (Figure 11). A line was drawn from the mesial CEJ of one central incisor to the mesial CEJ of the other. The distance from this CEJ line to the inferior margin of the foramen was measured with digital calipers to indicate the inferior-superior position of the foramen. A line was drawn from the midpoint between the mesial and distal CEJ's of each incisor to the root apex

0 1 2 3 4

Figure 12. Reference standards for subjective evaluation of cortication in incisor periapical radiographs.

to represent the long axis of the root. The angulation of one incisor to the other was then measured with a protractor to the nearest 0.5° (negative values indicate that the roots converge, positive values that the roots diverge). Subjective canal cortication was evaluated against five reference films (Figure 12) in a manner analogous to that used for the occlusal films.

E. Error of the method

The reproducibility of the linear and angular measurements was assessed by statistical analysis of the difference between two measurements of each parameter. A portion of the sample with diastemas (19 skulls with diastemas from the Atkinson collection) was selected for replicate measurements. Using skulls with a diastema allowed error analysis of all measurements using one set of replicate measurements (ie. if using skulls without a diastema, error in measuring diastema width could not be calculated). The measurement error was calculated using the equation:

$$S_x = \text{square root of } \Sigma D^2/2N$$

where D is the difference between duplicate measurements, and N is the number of pairs of duplicate measurements for each parameter.[29] The errors for the measurements taken directly (but not those that were calculated) for this study are shown in Table 3.

Table 3. Measurement errors.

		Measurement	Error
1	Skull	width of diastema	0.05 mm
2		transverse diameter of canal	0.21 mm
3	Mx ceph	palatal plane to incisor	1.8°
4		palatal plane to canal	0.9°
6		incisor to occlusal plane	1.7°
13	Mx occlusal	transverse diameter of canal	0.22 mm
14		degree of canal cortication - measured	0.19 mm
16	Periapical	width of foramen	0.38 mm
17		height of foramen	1.18 mm
18		CEJ line to inferior margin of foramen	1.05 mm
19		angulation of central incisors	1.8°

For the replicate measurements of the subjective canal cortication, the percentage of concordant evaluations was 79% for the maxillary occlusal and 68% for the incisor periapical. Where duplicate evaluations were different, the difference was never greater than one step of the rating scale.

F. Data analysis

To test for variation within the sample, the sample was divided into groups according to two variables - presence of a diastema, and source of the specimen (LLU/Atkinson). Differences between the groups were analyzed by 2-way ANOVA and Mann-Whitney tests.

Means, standard deviations (SD), maximum and minimum values, and ranges were calculated for each of the parameters. The equivalence of the three measures of incisive canal diameter (Table 2 - #2,13,16) was tested by regression analyses. Correlations between diastema, canal diameter (on skull), the angular measurements on the maxillary ceph, canal diameter (maxillary occlusal), linear and angular measurements on the incisor periapical, and measured and subjective canal cortication were also determined.

RESULTS

A. Sample

Of the total sample of 59 dry skulls, 26 (44%) had a diastema of 0.1 mm or greater; 33 (56%) had no diastema. Of the 19 skulls from Loma Linda University, five demonstrated a diastema (26%), compared to 21 of the 40 skulls from the Atkinson Collection (53%). For the total sample, diastema size ranged from 0.1 - 2.8 mm (mean 1.0 mm, SD=0.7 mm). Incisive canal diameter (from skull) ranged from 2.3 - 7.2 mm (mean 3.9 mm, SD=0.9 mm).

Statistical analyses (ANOVA) revealed differences between the LLU and Atkinson portions of the sample. The LLU skulls had on average smaller incisive canals (p=0.02, mean LLU 3.5 mm, SD=0.5 mm, mean Atkinson 4.1 mm, SD=1.0 mm) and more proclined central incisors (palatal plane to incisor; p=0.002, mean LLU 116.4°, SD=6.3°, mean Atkinson 109.3°, SD=7.3°). The angle of the incisive canal to the palatal plane was the same (mean 108.8°, SD=6.6°), resulting in a greater angle between the canal and the incisor in the LLU sample (p=0.02, mean LLU 6.3°, SD=4.9°, mean Atkinson 1.2°, SD=7.2°).

The only significant difference between the portions of the sample with and without diastema (apart from the diastema) was incisor angulation in the incisor periapical film (p=0.03, mean with diastema –2.5°, SD=5.2°, mean without diastema 0.1°, SD=5.8°). There were no statistical interactions between these two groupings.

B. Radiographic imaging

The maxillary occlusal radiograph as described in this study produced a clear image of the incisive canal for the majority of the skulls. In cases where the canal was very small and/or there was an alveolar cleft (as seen in the incisor periapical radiograph[13]) the canal was difficult to see and measure.

This occlusal radiograph can be taken (clinically) with reference to any of three structures: palatal plane, occlusal plane, or maxillary incisor. A number of parameters relating to orientation of the incisive canal were measured on the radiographs. Descriptive statistics for measurements taken on the maxillary ceph are shown in Table 4. The structure most consistently related to the angle from which the maxillary occlusal was exposed was the root of the central incisor (ie. it has the lowest standard deviation).

Three measures of incisive canal transverse diameter were taken, 1) canal measured on the skull directly, 2) canal diameter on the maxillary occlusal, and 3) foramen width on the incisor periapical (Table 5). These three parameters were strongly correlated - canal diameter (skull) with maxillary occlusal canal diameter (Pearson correlation 0.87, $p<0.01$), canal diameter (skull) with incisor periapical foramen width (Pearson correlation 0.82, $p<0.01$), maxillary occlusal canal diameter with periapical foramen width

Table 4. Descriptive statistics for parameters in the maxillary ceph radiograph.

		Minimum	Maximum	Mean	SD
1	Palatal plane to incisor	93.0°	127.5°	111.6°	7.7
2	Palatal plane to canal	95.0°	123.0°	108.8°	6.6
3	Palatal plane to occlusal plane	1.0°	17.0°	9.2°	3.8
4	Incisor to occlusal plane	43.5°	77.0°	59.1°	7.3
5	Canal to occlusal plane	44.5°	78.5°	61.9°	6.2
6	Incisor to canal	-17.5°	17.0°	2.8°	7.0
7	Mx occl. angle to palatal plane	91.0°	115.5°	103.0°	5.9
8	Mx occl. angle to incisor	-5.0°	17.5°	8.6°	4.3
9	Mx occl. angle to occlusal plane	56.0°	86.0°	67.7°	5.5

Table 5. Descriptive statistics for transverse canal diameter.

		Minimum	Maximum	Mean	SD
1	Canal diameter from skull	2.3 mm	7.2 mm	3.88 mm	0.88
2	Mx occl. canal diameter	1.8 mm	8.4 mm	4.03 mm	1.29
3	Periapical foramen width	1.9 mm	8.9 mm	4.39 mm	1.16

(Pearson correlation 0.76, $p<0.01$). Regression analysis yielded the following prediction formulas for canal diameter on the skull:

Canal diameter = 0.591 Mx occl. canal diameter + 1.5 mm.

Canal diameter = 0.618 periapical foramen width + 1.169 mm.

For each skull, three measures of degree of incisive canal cortication were determined. For the maxillary occlusal, there was a weak correlation between measured cortication and subjectively evaluated cortication (Spearman's correlation 0.49, $p<0.01$). There was a weaker correlation between the measured cortication in the maxillary occlusal and the subjectively evaluated cortication in the incisor periapical (Spearman's correlation 0.28, $p<0.05$). There was no significant correlation between the two subjective measures of cortication.

C. **Anatomy of the incisive canal** (Figures 5 & 7)

The incisive canal is located behind and between the maxillary central incisors, in the union of the two halves of the maxilla. It is approximately round at the incisive foramen. Superiorly it narrows like a funnel. The canal may or may not visibly extend to the floor of the nasal cavity. Many times the canal divides into left and right canals midway between the incisive foramen and the floor of the nasal cavity, one portion in each half of the maxilla.

D. Relationship of diastema to canal

There were no meaningful correlations between the size of a diastema and the diameter of the incisive canal when measured by any of the three methods - directly on the skull, on the maxillary occlusal film, or on the incisor periapical film.

There were no significant correlations between diastema and any parameters measured on the maxillary ceph. However, larger canal diameters were weakly associated with higher incisor to occlusal plane angles (Pearson correlation 0.40, $p<0.01$), higher canal to occlusal plane angles (Pearson correlation 0.27, $p<0.05$), and slightly inversely associated with occlusal plane to palatal plane angles (Pearson correlation -0.33, $p<0.05$).

For the maxillary occlusal film, diastema was very weakly associated with the subjective measure of canal cortication (Spearman's correlation 0.30, $p<0.05$), but not the measured degree of cortication or the canal diameter.

In the periapical film, an inverse relationship of diastema with both canal cortication (Spearman's correlation -0.32, $p<0.05$) and height of incisive foramen (Pearson correlation -0.27, $p<0.05$) was observed.

Discussion

Statistical differences were noted between the LLU and Atkinson portions of the sample. However, these differences did not affect the technique for taking the maxillary occlusal radiograph, nor the relationship of canal diameter or degree of cortication to the presence or size of a diastema.

When the sample was divided into two portions based on the presence or absence of a diastema, there was a significant difference in incisor root angulation between the two groups ($p=0.03$, mean with diastema –2.5°, SD=5.2°, mean without diastema 0.1°, SD=5.8°). On average, those skulls with a diastema also had incisor roots that were more convergent (ie. negative angulation[30]). However, in the present study, correlation analysis failed to reveal any linear relationship between incisor angulation and size of diastema.

Computed tomography is the gold standard for imaging the hard tissues of the body. But plane films are cheaper, easier, and require less radiation dose to the patient.[31] CT scanning has the advantage of accurately portraying the spacial relationship of the canal to the incisor root from CEJ to apex in all three planes of space. Tomographs can also theoretically provide this information with a properly selected series of cuts. In addition, they are more convenient and less expensive than CT scans. But as tested in this study, they were not adequate for imaging the incisive canal and so were dropped from the protocol. The maxillary occlusal radiograph technique as presented does show canal diameter and cortication, but does not permit reliable measurement of the distance between the canal cortex and the incisor root (see below). As a result, this technique does not provide an accurate representation of antero-posterior relationships, nor of the absolute distance between the canal and the root surface.

During the initial testing of the maxillary occlusal method of imaging the incisive canal, successive films were exposed at different angles (Figure 13). Several of these adequately portrayed the size and cortication of the incisive canal, but the apparent distance between the canal and the incisor roots varied significantly. For this reason, measurements involving the antero-posterior dimension, such as the distance between the canal and the incisor roots, are not considered reliable in the maxillary occlusal film. Therefore in this study, measurements on the maxillary occlusal were restricted to the transverse dimension (ie. transverse canal diameter) and degree of cortication.

The technique described for acquiring the maxillary occlusal radiograph allows some latitude in the orientation of the film and X-ray beam (ie. angle of exposure). But the acceptable range is smaller than the observed anatomical

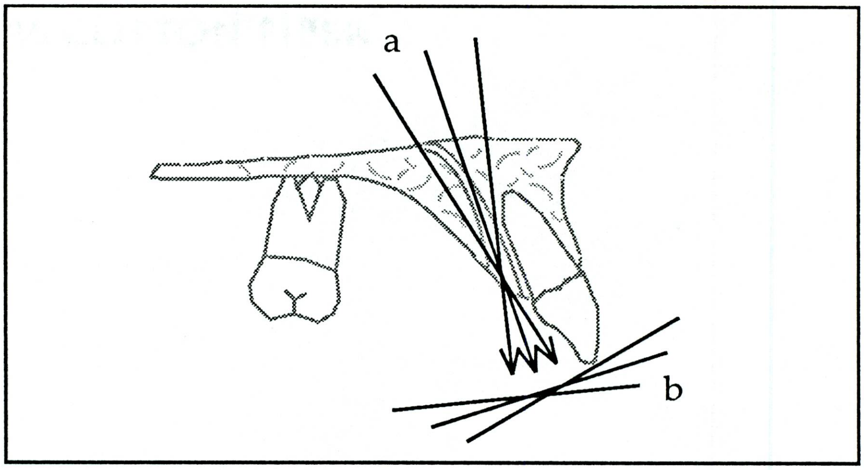


Figure 13. Maxillary occlusal radiographs taken from several different angles. Note that the central ray is always perpendicular to the film.
a. X-ray beam - central ray.
b. X-ray film.

variation in the relationships of the incisor, palatal plane, and occlusal plane (Table 4 - #7,8,9). The clinician using this technique would not have the advantage of a radiopaque marker to show the position and orientation of the canal. This must be inferred from the surrounding structures. Based on measurements from this sample, the structure to which the angle of exposure is most consistently related is the long axis of the root of the maxillary cental incisor (ie. the Mx. occlusal angle to incisor has the smallest standard deviation, Table 4 - #8). The orientation of the incisor to the occlusal plane can be determined from a standard lateral ceph. On average, alignment of the central ray 8° to 9° more perpendicular to the occlusal plane than is the central incisor will give the best results.

It is difficult to measure the diameter of the incisive canal directly on the dry skull. The canal is funnel shaped, and measuring it is like trying to assign a single value to the diameter of a funnel (Figure 1). The error in the measurement of canal diameter was essentially the same for both the skull and maxillary occlusal, about 0.2 mm. On the periapical, foramen width is more difficult to see and to measure, and has twice the measurement error, about 0.4 mm.

Using the regression formulas, canal diameter for the skull can be predicted from both the maxillary occlusal and the incisor periapical (see page 25). For canals of average diameter (around 4 mm), all three methods of measurement yield essentially the same value. In reality, there is probably no need to convert a radiographic diameter to the value that would be measured on the skull - the radiograph giving all the necessary information regarding canal diameter and cortication. Because the regression formulas are much the same, but the measurement error in the maxillary occlusal is half that in the incisor periapical, the maxillary occlusal technique for measuring the incisive canal diameter appears to give the most accurate representation of the physiologic canal size and degree of cortication.

The only parameter found to significantly correlate with the presence and size of a diastema was the subjective evaluation of canal cortication on the maxillary occlusal radiograph. The relationship is statistically significant ($p=0.02$), but the amount of variation in diastema that can be explained by the cortication of the canal is small, only 8.9% ($r^2 = 0.089$). This could hardly be used to predict the presence of a diastema. There was no correlation between diastema and canal diameter. Apparently, differences in the morphology of the incisive canal are not a significant etiological factor for maxillary median diastema.

It is difficult to explain the inverse relationship observed between diastema and the parameters in the periapical film, namely height and width of the foramen. This is the opposite of the expected relationship. The correlations are very weak when statistical analysis is performed on the sample as a whole. The same correlation analysis performed on the portion of the sample having a diastema failed to show any significant correlations. Also, when data outliers (as identified by scatter plots) were removed from the sample, no significant correlations were found.

The measured and subjective cortication in the maxillary occlusal were weakly correlated (Spearman's correlation 0.49, $p<0.01$). This may be explained by the observation that the measured cortication in the maxillary occlusal gave a linear measure of cortical bone thickness independent of bone density. Yet, a wide variation in bone density was observed, and formed the basis of the subjective rating scale. For example, the cortex could be thin but dense, or wide but less dense. This will affect the measured and subjective evaluations in opposite ways. In relation to diastema, the subjective measure was more relevant.

The size and range of diastemas present in this sample is smaller than in some other studies.[14,23] Possibly a sample with more severe diastemas would have shown a stronger relationship between the incisive canal and diastema.

As noted, direct measurement of the distance between the canal and the incisor root was not reliable. It is conceivable that when the distance from canal to root approaches some minimum, canal diameter or cortication may correlate more directly with the size of a diastema. Of the techniques discussed, only CT scanning allows this measurement. The transverse distance between the incisor roots and thus their proximity to the canal is modified by orthodontics - decreasing with diastema closure, but increasing with distal root angulation. Likewise, where the incisors are retracted, the antero-posterior distance between the roots and the canal will decrease. Knowing the canal-to-root measurement prior to orthodontic treatment would allow prediction of this dimension in the final occlusion based on a visualized treatment objective (VTO). The predicted dimension could possibly be used as a predictor of diastema relapse potential. This presents several areas of potential investigation: the incisor root/incisive canal proximity for skulls/patients with and without diastema using CT scanning, diastema relapse rates based on post-treatment incisor root/incisive canal proximity, and diastema relapse rates in cases with and without diastema initially where the incisors were retracted.

CONCLUSIONS

The maxillary occlusal radiograph, obtained by the technique described in this study, is able to image the incisive canal and permit accurate measurement of its transverse diameter and density of cortication. However, measurements involving the antero-posterior dimension were not found to be reliable, thus preventing an accurate measurement of the actual distance between the incisive canal and the incisor root. Only CT scanning successfully permits accurate measurement of the distance from the incisive canal to the incisor root. Tomographs were not found useful.

Analysis of the results failed to confirm a relationship between the presence or size of a maxillary median diastema and the size of the incisive canal in the human skulls examined. There is a weak correlation between the size of a diastema and the degree of cortication around the incisive canal, when cortication is evaluated subjectively from the maxillary occlusal radiograph. It was found additionally that skulls with a diastema often presented with a more negative angulation of the maxillary central incisors.

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