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Further Investigation of Spreader Loads Required to Cause Vertical Root Fracture during Lateral Condensation

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The roots of 54 extracted human mandibular incisors were instrumented, measured, and then filled with gutta-percha by lateral condensation on an Instron testing machine until vertical root fracture occurred. A spreader load as small as 1.5 kg (3.3 lb) produced a fracture, and 13% of the sample fractured at a load of 3.5 kg (7.7 lb) or less. Computer bivariate correlation analysis revealed significant positive linear correlations ($p \leq 0.05$) between fracture load and root width, canal width, canal taper, ratio of canal width to total root width, and number of accessory cones placed. All specimens had fractures in the faciolingual dimension and 28% also had mesiodistal fractures. In 26% of the sample, the fractures did not extend completely through the root from the canal to the root surface. In 87% of the sample, fractures were noted to extend tangentially from the canal when viewed in cross-section and were often observed at the interface between areas of transparent and opaque dentin.

Vertical root fracture seems to be a clinical problem of increasing significance. It is a difficult problem to diagnose and treat (1). Two common causes are improper post placement and excessive use of force during root canal filling procedures (2, 3). The usual consequences of vertical root fracture are loss of the tooth, or at least loss of the involved root of a multirooted tooth, and the subsequent cost of prosthetic replacement. Thus, prevention of vertical root fracture is desirable. Pitts et al. (4) studied the spreader loads required to cause vertical root fracture during the lateral condensation of gutta-percha. They worked with large single-rooted teeth, maxillary central incisors and canines, in an effort to quantify a safe limit of condensation pressure.

The purpose of this study was to investigate further the subject of spreader loads required to cause vertical root fracture using the relatively thin roots of mandibular incisors. Also investigated were the relationships of fracture loads to the size and taper of the roots and root canals, working lengths, number of accessory cones used, spreader penetration depths, and rates of spreader load increase.

MATERIALS AND METHODS

Specimens for this study consisted of 60 recently extracted human mandibular incisors. These teeth were found to be free of preexisting cracks when viewed through a dissecting microscope (×12) assisted by a fiberoptic light source. Only incisors featuring a straight root and single canal throughout the length of the root were included. All of the specimens were continuously hydrated in water containing a small amount of antibacterial agent (phenol) from the time of extraction through completion of testing and analysis.

Straight-line access to the canals was facilitated by removing the incisal portion of the crowns with a diamond disc. The crowns were sectioned perpendicular to the long axis of the root approximately 3 mm coronal to the level of the cementoenamel junction on the buccal and lingual.

The teeth were radiographed in the mesiodistal (MD) and faciolingual (FL) planes before and after instrumentation (Fig. 1). A reproducible orientation of the specimens in a radiographic jig was achieved by preparing custom acrylic holders for each tooth, allowing them to be accurately placed on the X-ray film. By means of the jig, the teeth were held 2 mm from the film and the X-ray source (50 kVp; Philips Oralix, Stanford, CT) was held 18 inches from and perpendicular to the film, resulting in essentially 1:1 magnification. Postinstrumentation radiographs were individually mounted on a back-lighted X-Y table equipped with digital electronic micrometers. These mounted films were viewed through a ten-power microscope (with crosshair) to measure root dimensions (canal and canal wall widths) at the 2-, 4-, 6-, and 8-mm levels from the apex in both the MD and FL planes (Fig. 2).

Each tooth was hand held in gauze saturated with water during instrumentation. The working length was designated as ¾-mm short of the length that a #10 file

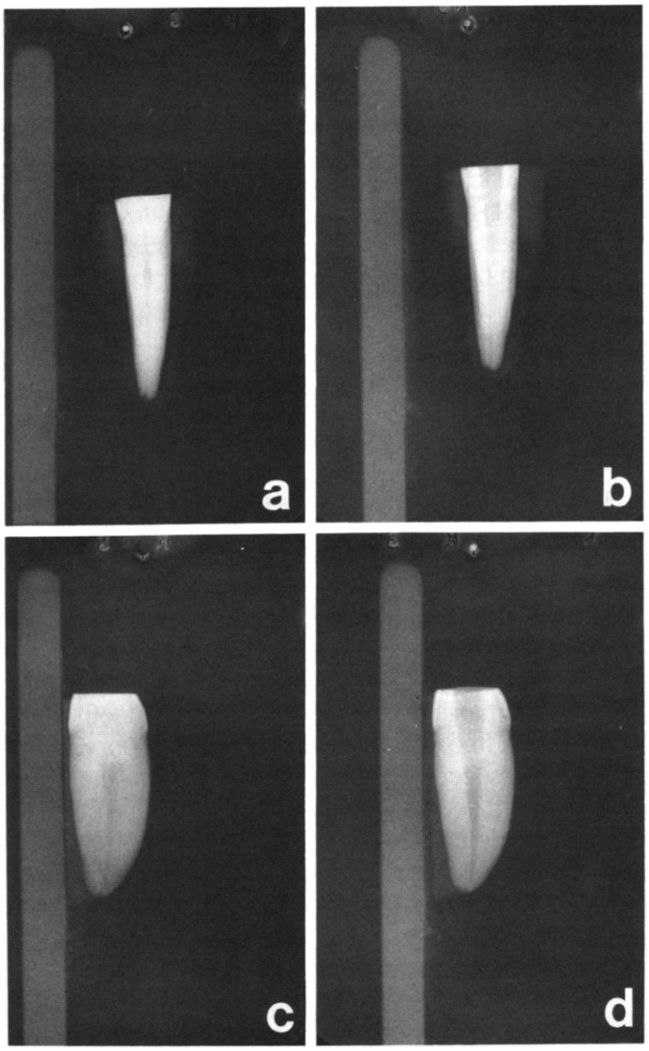

FIG 1. Radiographs of a typical specimen. *a*, Faciolingual view before canal instrumentation. *b*, Faciolingual view after canal instrumentation. *c*, Mesiodistal view before canal instrumentation. *d*, Mesiodistal view after canal instrumentation.

was observed to exit the apical foramen. The apical foramen was always kept patent to a #10 file. Apical preparation began with the first K-type (Zipper, Premier, Norristown, PA) file to bind in the canal at the working length and continued through three sequentially larger K-type files. Each successive instrument in the apical preparation was used in a one-fourth clockwise turn and pull motion until it was loose at the working length. Two milliliters of 5.25% sodium hypochlorite was used to irrigate the canal between each instrument used. Following the use of the #25 file in the apical instrumentation scheme, Gates Glidden burs were used to improve access to the apical preparation and accomplish much of the coronal two-thirds flare. The #2, 3, and 4 Gates Glidden burs were used sequentially to the level where they first began to bind. The stepback phase of canal preparation then began with the next larger size K-type file than the last instrument used in apical preparation and consisted of working four progressively larger K-type files to lengths ½-mm short of the previous instrument length. A Hedstrom file one size larger than the final stepback instrument was then set at a length ½-mm short of the final stepback instrument and was used to complete the flaring of the coronal two-thirds of the root canal preparation. Recapitulation through the apical preparation and irrigation with 5 ml of sodium hypochlorite completed the instrumentation. In 51 of the 60 specimens, the largest instrument used to working length was a #35. Seven specimens were #30, and one each was #40 and #45. Completion of instrumentation was verified by placing a D11T spreader (Premier) in the canal to within 2 mm of the working length. If it fit easily without binding, coronal flaring was considered to be adequate. Radiographs of a typically instrumented and flared canal are presented in Fig. 1 (*b* and *d*).

Subsequent to postinstrumentation radiographs, the roots of the specimens were wrapped in a single layer of lead foil. Next, they were invested in separate acrylic holders to the level of the cementoenamel junction with Duralay resin (Reliance Dental Mfg., Worth, IL), creating artificial sockets (Fig. 3). The holders had been machined from a clear acrylic rod to fit accurately into a prefabricated acrylic base which contained a self-aligning bearing. For each specimen, a plaster index was poured around the exposed crown, allowing the indexed tooth to be separated from its holder. The lead foil was removed, Syringe Elasticon (Sybron/Kerr, Ro-

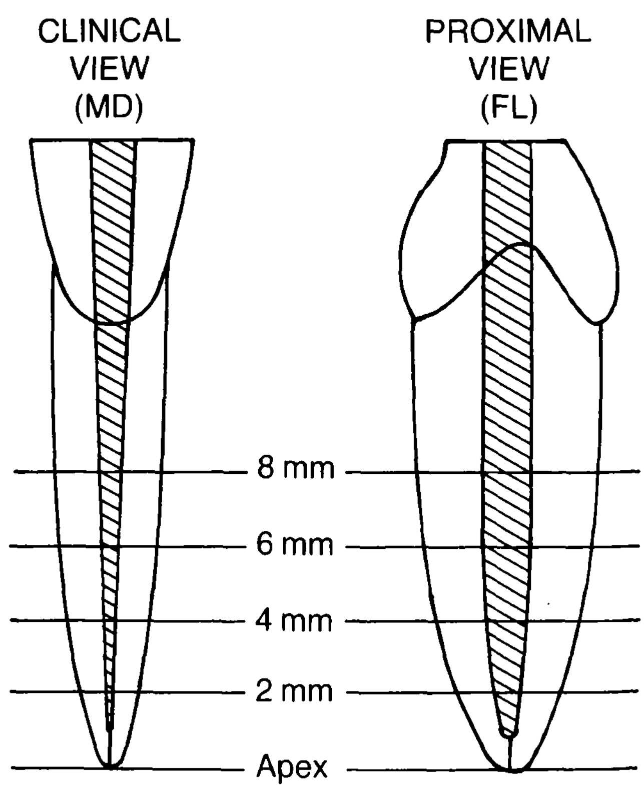

FIG 2. Canal and canal wall widths measured at four levels from the apex in both the MD and FL planes.

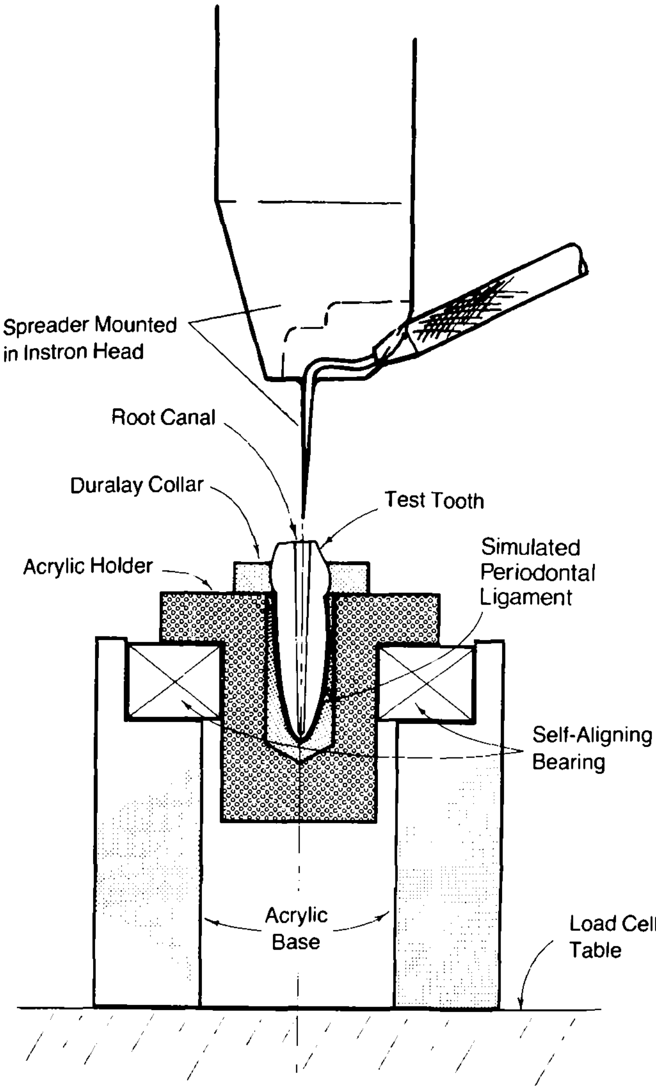

FIG 3. Test assembly containing tooth in artificial socket on load cell table with spreader in moving head of Instron.

mulus, MI) was injected into the socket, and the indexed tooth replaced. This procedure provided the specimen with a silicone substitute for the periodontal ligament. Next, the plaster index was replaced with a Duralay collar, preventing apical displacement of the tooth under load. Such displacement could have resulted in the root being reinforced by the hard acrylic socket and led to unnaturally high fracture loads. The specimen was then placed into the prefabricated acrylic base for testing and the whole assembly placed on the compression load cell table of an Instron testing machine (Instron Corp.) (Fig. 3). The canals were then filled by lateral condensation of gutta-percha using a D11T spreader mounted in the moving head of the machine. The Instron continuously recorded spreader load and penetration depth on moving graph paper (Fig. 4). The Instron was calibrated to stop spreader penetration automatically and precisely 2-mm short of the working length. The surface of the apical portion of the primary gutta-percha cone (Premier) was softened with a quick dip in chloroform and the cone formed to working length to enhance adaptation to the apical canal walls. Adequate forming of the cone was verified by visual inspection. Prior to the final placement of the primary cone, Grossman's new formula sealer (University of Washington Pharmacy, Seattle, WA) was painted on the canal walls with a K-type file one size smaller than the last file used to the working length. Once seated to length, the formed cone was seared off at the canal access with a heated plugger. The spreader was then inserted by the Instron machine to the predetermined depth of working length minus 2 mm at a fixed rate of 5 cm per min. This depth and rate remained the same throughout the experiment. The operator selected penetration sites by moving the test assembly on the Instron load cell table. Because of the oval shape of the orifices, the sites were either buccal or lingual to the master cone. The self-aligning bearing permitted the mounted spreader to stay centered in the long axis of the canal by allowing the specimen to rotate or change axial inclination during spreader penetration.

When penetration was complete, the specimen assembly was alternately rotated clockwise and counterclockwise in a 45-degree arc before and during removal of the spreader. Medium-fine accessory cones (Sybron/Kerr) matching the taper of the D11T spreader were placed into the channels created by the spreader. All gutta-percha cones used in this study were from the same lot or batch and stored under identical conditions in an effort to eliminate variation in the physical properties. The sequence of spreader penetration and placement of accessory cones was repeated until a root fracture occurred. This was evidenced by an audible "crack" heard through a stethoscope with its tubing attached to the spreader handle and/or a sudden release of the spreader load as seen on the graph (Fig. 4). The load value at fracture, the rate of loading at fracture (slope of the curve), and the distance from full penetration of the spreader at the time of fracture were

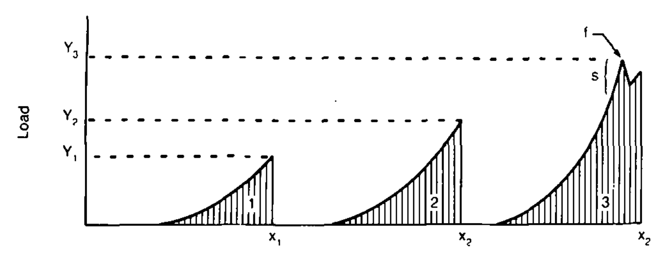

FIG 4. Typical Instron tracing during testing of tooth which fractured after placement of two accessory cones. *1*, first spreader insertion with primary gutta-percha cone seated; *2*, second spreader insertion with one accessory cone placed; *3*, third spreader insertion and root fracture with two accessory cones seated; *x*, maximum spreader penetration; *y*, maximum spreader load; *f*, point of fracture with subsequent stress release; *s*, slope of curve just prior to fracture used to calculate load rate.

all taken from the Instron tracing. Also noted was the number of accessory cones placed before fracture occurred.

Each tooth was then removed from its socket and the root examined under the stereomicroscope with the aid of a fiberoptic light source for evidence of fracture (Fig. 5). After photographing, each root was encased in acrylic and sectioned at the 2-, 4-, 6-, and 8-mm levels from the apex. This procedure was accomplished with a water-cooled diamond disc mounted in a straight handpiece, which was attached to a micrometer-controlled jig. The resulting four cross-sections of each root were examined and photographed under a stereomicroscope using both direct lighting and transillumination (Fig. 6). The fractures were classified as being predominantly in the MD or FL dimension. The relationship of fracture lines to patterns of opaque and transparent (sclerotic) dentin and relative wall thicknesses were noted. Also evaluated were canal shape, whether or not the fracture extended completely through dentin and cementum to the root surface, and whether or not the fracture passed through the apical foramen.

Descriptive and bivariat correlation analysis of the data were performed on a CDC mainframe computer with the Condescriptive and Scattergram subprograms, respectively, of the SPSS system of computer programs (5).

RESULTS

Of the 60 teeth tested, 54 were found to have vertical root fractures. Evidence of fracture was lacking in six teeth. Statistical analysis of the fracture load data of the 54 fractured teeth is listed in Table 1. The smallest fracture load found to produce vertical root fracture was 1.5 kg (3.3 lb) (Figs. 5*b* and 6*b*). Thirteen percent

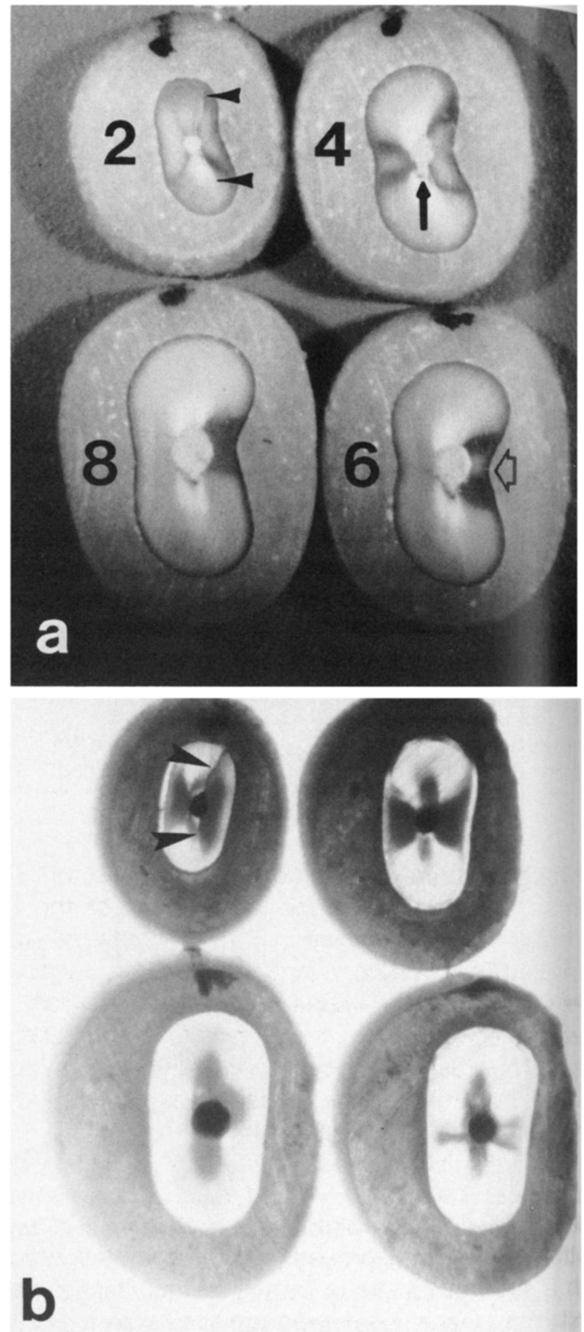

FIG 6. Examples of cross-sections at 2-, 4-, 6- and 8-mm levels. Light band around each section is acrylic coating applied before sectioning. Black marks on each section at 12 o'clock indicate facial root surface. *a*, Photographed under direct lighting. *Arrowheads* in 2-mm section indicate termination of fracture short of root periphery in an incompletely fractured specimen. *Arrow* in 4-mm section indicates keyhole shape of canal. *Open arrow* in 6-mm section indicates root fluting. *b*, Cross-sections of root which fractured at smallest spreader load (1.5 kg) photographed with transillumination. Fracture evident in 2-mm section only (*arrowheads*).

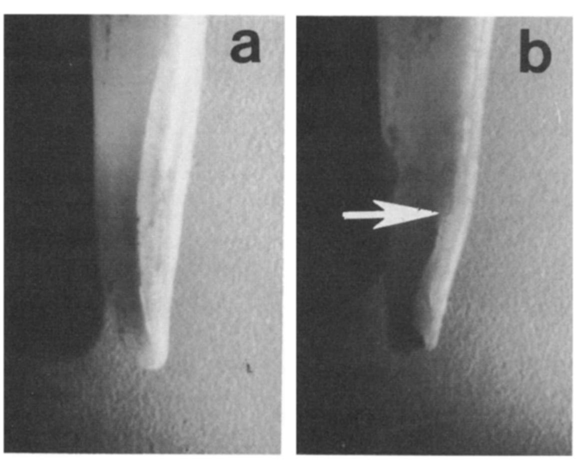

FIG 5. Examples of root fractures in gross specimens under fiberoptic illumination. *a*, Lingual view with fracture not extending to apical foramen. *b*, Buccal view of root which fractured at smallest spreader load (1.5 kg). *Arrow* indicates coronal extent of fracture.

of the sample fractured at loads of 3.5 kg (7.7 lb) or less and 22% fractured at loads of 5 kg (11 lb) or less.

The bivariat correlation analysis provided printed two-variable scattergrams and simple linear regressions of fracture load versus the designated variables.

TABLE 1. Analysis of fracture loads (kilograms)

Low	High	Mean	SD	Median
1.50	13.70	7.08	2.58	6.80

TABLE 2. Summary of significant data

Variables Analyzed against Fracture Load		Pearson's r Value	Significance of r (p)
No. of accessory cones		0.468	0.000
Root width:			
Proximal (FL)	4 mm	0.322	0.017
	6 mm	0.373	0.005
	8 mm	0.371	0.006
Clinical (MD)	4 mm	0.335	0.013
	6 mm	0.307	0.024
	8 mm	0.340	0.012
Canal width:			
Proximal (FL)	6 mm	0.391	0.004
	8 mm	0.347	0.010
Clinical (MD)	2 mm	0.381	0.004
	4 mm	0.269	0.049
	6 mm	0.359	0.008
	8 mm	0.325	0.016
Proximal canal taper (FL)		0.321	0.018
Canal/root width:			
Proximal (FL)	6 mm	0.271	0.048
Clinical (MD)	2 mm	0.287	0.035

Scattergrams are two-dimensional graphs of data points, the coordinates being the values of the two variables being considered. The scattergrams were evaluated for curvilinear tendencies. Since none was noted, polynomial or curvilinear regression was not deemed necessary in pursuit of further bivariat relationships. The Pearson product-moment correlation coefficients (r) were evaluated to determine the strength of the linear relationships.

Significant data derived from the analysis of the linear relationships between fracture load and the other variables studied are provided in Table 2. All r values were positive, which indicates that both variables in each relationship increased together (direct relationship). While the r values do not indicate strong relationships, a high level of significance was found for the correlation between fracture load and the number of accessory cones used ($p \leq 0.01$). Significant positive correlation ($p \leq 0.05$) was also found between the fracture load and (a) proximal and clinical root widths (4-, 6-, 8-mm levels, Fig. 2), (b) proximal (6-, 8-mm) and clinical (2-, 4-, 6-, 8-mm) root canal widths, (c) proximal root canal taper (canal width at 8 mm minus canal width at 2 mm), and (d) the ratio of the root canal width to total root width at two levels (proximal 6 mm, clinical 2 mm).

These results indicate that, with respect to the statistically significant data, (a) the more accessory cones placed, (b) the wider the root (c) the wider the root canal, (d) the greater the proximal root canal taper, and (e) the wider the root canal in relation to the root width, the greater the tendency for the root to fracture at a higher spreader load value.

The thinner of the two canal walls at each level in both the clinical and proximal dimensions was specifically identified and evaluated. No significant correlation with fracture load existed nor was there a significant correlation of fracture load with the distance of the spreader from full penetration at time of fracture. Fractures occurred at a mean distance from full penetration of 1.5 mm (SD 1.3). The rate of increase of spreader load as reflected in the slope of the curve just prior to fracture (Fig. 4) demonstrated no significant correlation with fracture load. No correlation was noted between the fracture load and working length.

Data from stereomicroscopic examination of the cross-sections are listed in Table 3. All root cross-sections were oblong and 63% demonstrated a fluting or root depression on at least one side (mesial or distal) within the apical 8 mm of the root studied (Fig. 6*a*). Only 7.4% (four specimens) exhibited fluting on both sides of the root. An unpaired t test revealed no significant difference between the mean fracture loads of those roots with and those without fluting. It was determined that 61% of the root canals of the fractured roots were basically round through the 8-mm level. The other 39% of the canals initially exhibited "fins" or narrow FL outpouchings. These fins occurred predominently to the lingual and after instrumentation gave the canals the appearance in cross-section of a "keyhole" (Fig. 6*a*). An unpaired t test revealed no significant difference between the mean fracture loads of those roots with round canals and those without round canals. In only 33% of the sample did the fractures occur through the apical foramen and fractures did not extend completely through the root from the canal to the external surface of the root (incomplete fracture) in 26% of the sample (Fig. 6*a*). In 87% of the roots, fractures were noted to extend tangentially from the canal and in at least one cross-section of every specimen evaluated, a fracture was observed at the interface

TABLE 3. Root cross-section analysis

Observation	No. of Sample	% of Sample
Round canal shape	33	61
Oblong root shape	54	100
Presence of root fluting	34	63
Fracture (Fx) through foramen	18	33
Fx complete (to root surface)	40	74
Fx tangential from canal	47	87
Fx in FL dimension	54	100
Fx in MD dimension	15	28
Fx observed between transparent and opaque dentin in at least one section	54	100

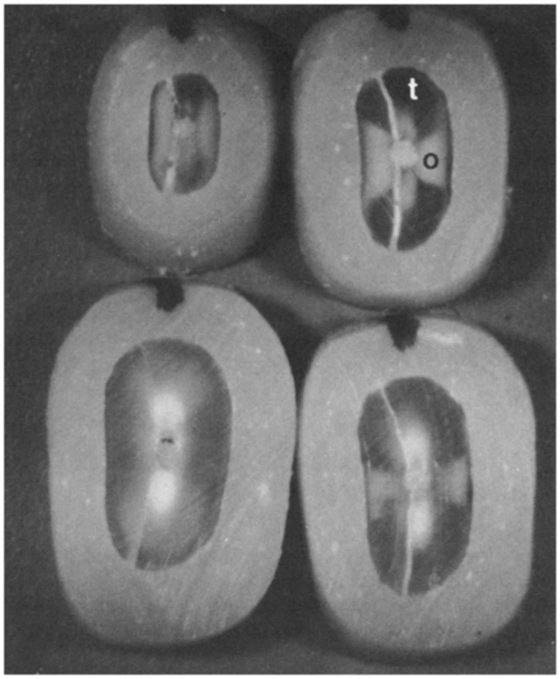

FIG 7. Cross-sections demonstrate fracture between opaque (*o*) and transparent (*t*) dentin.

between transparent (sclerotic) and opaque dentin (Fig. 7). In all 54 specimens the fractures were found primarily in the FL dimension, within the confines of the mesial and distal line angles. However, in 28% an additional fracture was noted in the MD dimension (Fig. 8). This MD fracture presented almost exclusively from the canal into the proximal root depression or fluting (14 of 15 specimens) and often did not appear to communicate with the apical extent of the FL fracture (6 of 15 specimens) (Fig. 9).

DISCUSSION

The most significant findings of this study are that a tooth fractured at a load of 1.5 kg and that 13% of the sample fractured at 3.5 kg or less. The median (6.80 kg) and average (7.08 kg) for this sample fell below the lowest value (7.2 kg) required to fracture a bulky single-rooted tooth in the study by Pitts et al. (4). They anticipated that roots with smaller cross-sectional dimensions would tend to fracture at smaller spreader loads than larger roots. Whether other types of small roots exhibiting such variables as curvature, multiple canals, or accentuated fluting would fracture at significantly different loads from the teeth in this study is not known. Assuming the sample roots were generally representative of the universe of in vivo single-canal lower incisors, the smallest observed fracture load in this study (1.5 kg) could serve as a guideline for limiting clinical spreader forces in an effort to avoid vertical root fracture. A margin of safety would be desirable to allow for potential biological variation. For example, using a

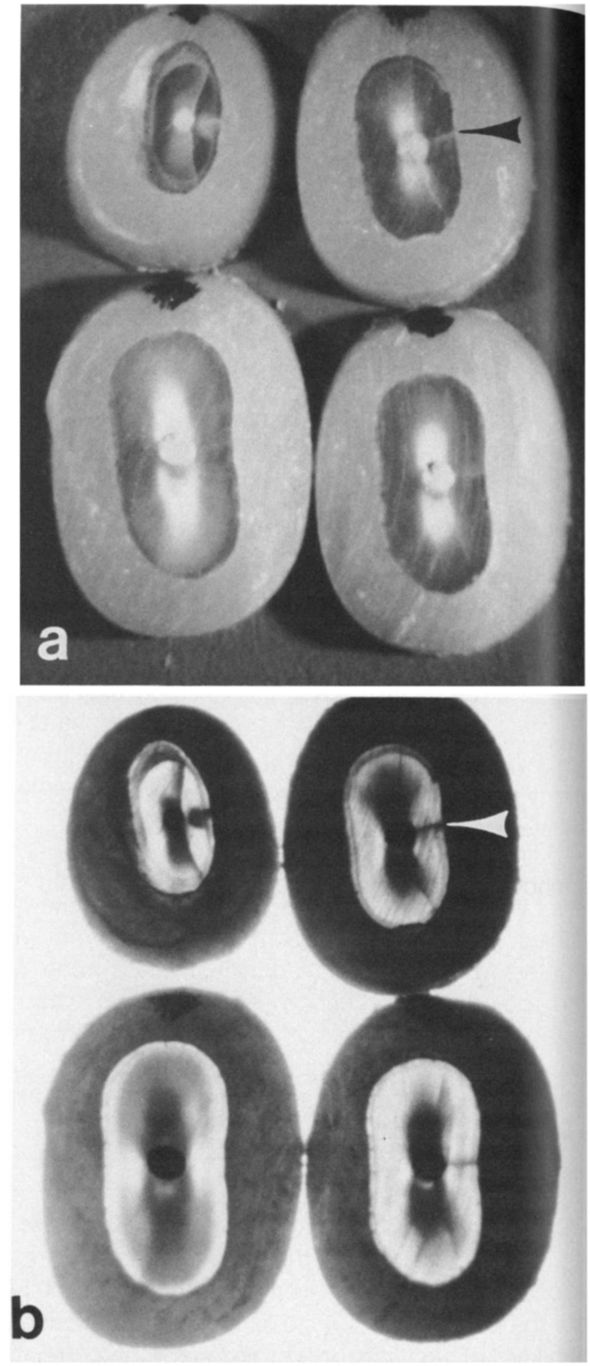

FIG 8. Cross-sections of specimen with fractures in both FL and MD dimensions. *Arrowheads* indicate MD fracture at 4-mm level. *a*, Photographed under direct illumination. *b*, Same sections photographed with transillumination.

safe limit of 70% of the smallest observed fracture load would result in a maximum spreader load of 1.1 kg (2.5 lb). This figure seems small in comparison to the 6.8 kg (15 lb) that has been recommended for use in hand condensation of dental amalgam (6). Fifty percent of the roots in this study fractured below this figure. In fact, according to Phillips (6), the condensation force for amalgam placement should be "as great as possible, consistent with patient comfort." One can readily ap-

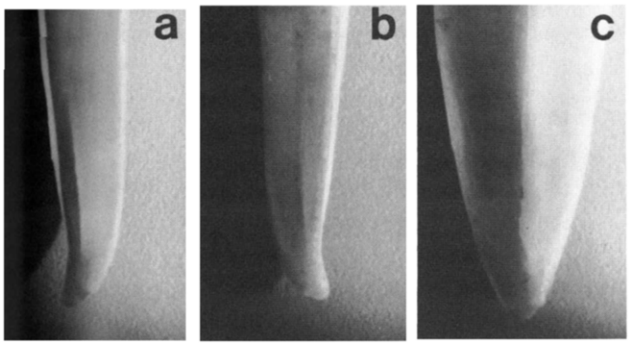

FIG 9. Root with fractures in both FL and MD dimensions. *a*, Facial view. *b*, Lingual view. *c*, Proximal view. Note proximal fracture does not appear to communicate with apical extent of facial and lingual fractures.

preciate the potential danger in applying learned amalgam condensation principles either consciously or subconsciously to the condensation of gutta-percha. Therefore, it seems reasonable that adopting a quantifiable standard for spreader loads would be helpful in an effort to reduce the incidence of vertical root fracture during the lateral condensation of gutta-percha. Such a standard could be taught to practicing dentists and dental students through the use of an easily fabricated teaching model.

The finding that the thicker the roots, the greater the tendency to fracture at higher loads is consistent with clinical expectation and tends to validate the experimental model. Using photoelastic models, Harvey et al. (7) determined that increasing canal taper allowed greater distribution of stresses during lateral condensation. This is consistent with the finding in this study. Increasing taper in the proximal dimension tended to increase the spreader load required for fracture. The tendencies for roots to fracture at higher spreader loads in specimens exhibiting wider root canals, or exhibiting wider root canals in relation to total root width, may be related findings. Flow or creep of a greater mass of gutta-percha in larger canals might allow for wider stress distribution and, consequently, require greater spreader loads to fracture the root. The tendency in this study for the root to fracture at a higher spreader load when more accessory cones had been placed prior to fracture may be explained in two ways. The larger the root canal, the more cones that may be placed before stresses begin to build, resulting in more gutta-percha mass and better stress distribution. Also, the greater the root strength, the greater the number of accessory cones required before stresses sufficient to fracture the root are reached. As seen in the results, this strength may in part be defined by root width and canal taper. Certainly, biological variation in such characteristics as degree of calcification and dentin tubule orientation could play a role.

Caution should be exercised in interpreting the influence of root canal taper, canal width, and the ratio of canal width to total root width upon the fracture load. The tendency in this study was for an increase in these dimensions to increase the load at which the root fractured. However, the canals in this study were not "overinstrumented" or excessively flared (Fig. 1). The average values for MD canal width/root width at the 2-, 4-, 6-, and 8-mm levels were 0.32/1.57, 0.47/1.93, 0.65/2.16, and 0.78/2.30 mm, respectively. The same values for the FL dimension were 0.36/2.83, 0.60/37.6, 0.85/4.25, 1.03/4.57 mm, respectively. There must be a point at which increased canal width and taper begins to weaken the root and beyond that point further enlargement could lead to weakening of the root and a tendency to fracture at a smaller spreader load.

Pitts et al. (4) noted that fractures occurred through the thinnest canal wall in 52% of their sample. No correlation of fracture load with the thin wall in either the FL or MD dimension was elicited in this study. In fact, only 15 specimens exhibited fractures in the MD dimension, where the thinnest walls of the root were located. The predominantly FL orientation of the fractures found in this study is consistent with clinical findings (8).

In the roots exhibiting fractures tangential to the canal (87%), the fracture was located at the interface of transparent and opaque dentinal patterns in at least two levels of the cross-sections 94% of the time (Fig. 7). Transparent or sclerotic dentin is more calcified than opaque dentin (9), and the interface between the two may be predisposed to initiation or propagation of fractures. However, Pitts et al. (4) found that there was no association of fracture lines with these interfaces. The particular geometry of the root type used in this study may predispose the root to fractures tangential to the canal and the location of dentinal pattern interfaces may have been coincidental. In either case, these dentinal patterns may be observed on the bevelled root surface during apicoectomy, and a fracture existing at an interface may be difficult to identify (1).

Twenty-six percent of the roots in this in vitro study had incomplete fractures. Clinically, signs and symptoms of pathosis would not be expected until a fracture extended completely through cementum to the periodontal ligament. Perhaps an incomplete vertical root fracture eventually becomes complete due to forces of stress release and function. Consequently, vertical root fracture might not be detected clinically until long after the fracture was initiated. Pitts and Natkin (1) described a case in which clinical signs of vertical root fracture first occurred 2½ yr after suspected fracture initiation.

Six of the original 60 teeth tested did not demonstrate fractures upon examination subsequent to testing. Testing on all teeth was stopped when changes were seen in the Instron tracing suggestive of fracture. It was policy to halt testing and remove the tooth for inspection upon any sign of fracture. This prevented continued condensation in an already fractured root which would lead to invalid fracture load values. The misleading tracings could have been the result of a sudden small shift of the socket assembly within the self-aligning bearing.

CONCLUSIONS

1. Vertical root fractures were found to occur in single-canal mandibular incisors under simulated clinical conditions at spreader loads as small as 1.5 kg (3.3 lb).

2. Thirteen percent of the sample fractured at a load of 3.5 kg (7.7 lb) or less.

3. Statistically significant positive linear correlations were found between fracture load and root width, canal width, canal taper, ratio of canal width to total root width, and number of accessory cones placed.

4. All fractured specimens had FL fractures. Twenty-eight percent also had MD fractures.

5. In 26% of the teeth, the fractures did not extend completely through the root from the canal to the external surface of the root and in only 33% did they occur through the apical foramen.

6. In 87% of the teeth, fractures were noted to extend tangentially from the canal and were often observed at the interface between areas of transparent and opaque dentin.

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