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Load and Strain during Lateral Condensation and Vertical Root Fracture

Veera Lertchirakarn, DDS, MDSc, Joseph E. A. Palamara, PhD, and Harold H. Messer, MDSc, PhD

Vertical loads and root surface strains in extracted teeth during lateral condensation using finger and hand spreaders were measured and compared with loads and strains at fracture. Six groups each of 10 teeth were tested: maxillary central incisor, premolar and molar; and mandibular incisor, premolar and molar. Root strains were measured using strain gauges mounted on the apical and middle third of the buccal root surface. Statistical analysis was performed at the 95% level of confidence. The maximum loads and strains generated by finger spreaders were significantly lower than those generated using a hand spreader (D11T). These loads and strains were also significantly lower than the values at fracture. Most fracture lines were in a buccolingual direction, but maxillary premolars with two separate roots and the mesiobuccal root of maxillary molars showed more variation in fracture site. The results suggest that lateral condensation alone should not be a direct cause of vertical root fracture. The use of finger spreaders, however, is associated with lower risk.

A vertical root fracture is a longitudinal fracture of the root, extending throughout the entire thickness of dentin from the root canal to the periodontium. It can be initiated from the crown or at the root apex, or along the root between these points (1). The prognosis of vertical root fracture is unfavorable, resulting in localized bone loss and a deep narrow periodontal defect after the gingival sulcus is involved. At present, management is limited largely to extraction of the tooth or resection of the fractured root (2). The recent report by Selden (3) suggested that the maximum period of success in attempts to manage vertical root fracture was only 1 yr.

In clinical studies, most fractured teeth have been previously endodontically treated (4), suggesting that the endodontic procedure may contribute to vertical root fracture. The stresses originating from the obturation procedure, especially if excessive force is used in lateral condensation, are considered a cause of this complication (5). Saw and Messer (6) suggested that the strains in obturation may be generated by a wedging effect of the spreader within the canal, either by direct contact with the canal walls or transmitted via gutta-percha. Strains generated in association with other obturation techniques may also be high (6).

The applied vertical load during lateral condensation has been found to range from 1 to 3 kg in many studies (6–8). Using extracted teeth, a load as small as 1.5 kg in mandibular incisors (8) and 7.2 kg in maxillary incisors (9) could produce fractures, although the mean load at fracture was in the range of 10 to 20 kg, well above condensation load. A load of 4.9 kg was claimed to be safe and not result in vertical root fracture in the mesial root of mandibular molars (10). Pitts et al. (9) suggested that the spreader load should be limited to 70% of the minimum force required to fracture the root.

The effect of spreader design on vertical root fracture and root distortion using strain gauges was investigated by Dang and Walton (11), who reported that a D11 hand spreader produced more strain than a B-finger plugger in the mesial root of mandibular molars. There is, however, no study to measure and compare the strain occurring during lateral condensation with strain at fracture. The aims of this study were to determine the force and strain occurring during lateral condensation by hand and finger spreader in various teeth, to compare load and strain at fracture in the same teeth, and to calculate the safe limited loads required to avert vertical root fracture in various teeth.

MATERIALS AND METHODS

Teeth Used in the Study

Extracted teeth used in this study were obtained from the Casualty and Oral Surgery Department of the Royal Dental Hospital of Melbourne, and all teeth were extracted for routine clinical reasons. The teeth were stored in isotonic saline solution with 0.05% sodium azide. The root surfaces were thoroughly cleaned and examined at ×20 magnification in a dissecting microscope for any root fracture or crazing. Any tooth found to have fracture, crazing, or gross caries involving the root was excluded from this study. Teeth with immature root apices were also excluded. A radiograph of each tooth was then taken in the labiolingual direction to confirm that the tooth did not have previous root canal treatment, or a calcified or excessively large canal.

Teeth were categorized into six groups each of 10 teeth as follows: *group 1*, maxillary central incisors; *group 2*, maxillary premolars with two separate roots; *group 3*, maxillary molars;

group 4, mandibular incisors; *group 5*, mandibular premolars; and *group 6*, mandibular molars. Each tooth was used for obturation by both hand and finger spreader.

Instrumentation

The crown of each tooth was resected 2 mm coronal to the cementoenamel junction to facilitate straight-line access for instrumentation and obturation. The palatal root of maxillary premolars, distobuccal root and palatal root of maxillary molars, and the distal root of mandibular molars were removed 2 mm apical to the furcation to facilitate access for mounting strain gauges. Gauges were mounted on the buccal root of maxillary premolars, the mesiobuccal root of maxillary molars, and the mesial root of mandibular molars. Maxillary incisors were instrumented to a size 40 or 45 master apical file. Other teeth were enlarged to size 30 or 35 master apical file, depending on the size of the initial file. Step-back technique was used, and the canals were flared with Gates-Glidden burs size 2 and 3. During instrumentation, 1% sodium hypochlorite was used for irrigation. After complete instrumentation, teeth were kept in a closed container at 4°C with 100% humidity until obturation.

Strain Gauge Mounting and Strain Measurement during Obturation

Before obturation, the root was prepared for mounting the strain gauges. The labial or buccal surface was chosen as the mounting site because previous studies have shown that the buccal surface is almost always involved in vertical root fracture (6, 8, 12). The root surface was scraped smooth with a scalpel blade. Strain gauges (Micro-Measurements Group, Inc., Raleigh, NC) were trimmed to adapt to root contour. EA-06-125BT-120 type gauge was used for all maxillary teeth and mandibular premolars, and EA-06-230DS-120 gauge was used for mandibular incisors and mandibular molars. The latter gauge type was selected for use in these teeth because it is longer and narrower than the former, allowing it to be better adapted to ribbon-shaped roots. The site for bonding was etched with 37% orthophosphoric acid for 30 s, washed for 30 s, and dried with a stream of air. The back of the gauge was cleaned with chloroform and primed with catalyst before bonding with cyanoacrylate adhesive (M-Bond 200, Micro-Measurement Group, Inc.). The gauges were bonded in a horizontal direction to measure the circumferential root strains at the apical and middle third of the root.

The gauge, solder contacts, and root surface were covered with silicone paste (Dow Corning 3140 RTV coating, Dow Corning Corp., Midland, MI) to a thickness of ~200 μm to protect them from moisture and to simulate a periodontal ligament. The coronal portion of each root was mounted vertically in a 7 mm thick nylon ring, using dental stone (Fig. 1). The ring was then attached to an adjustable metal base so that the root tip was seated in a small depression in the base, which served to stabilize it during obturation. The setup was placed on a 100 N force transducer (Material Test System Corporation, Eden Prairie, MN) that recorded the load applied during obturation (Fig. 1).

The strain gauges and force transducer were connected to a data acquisition board (AT-MID-16E-2, National Instruments Corp., Austin, TX) via a signal conditioning board (SC-2043-SG, National Instruments Corp.). All data were recorded on a computer using process control software (LabVIEW 4.0, National Instruments Corp.). Separate channels were used to make recordings from the two gauges simultaneously. Continuous recording of load and strain was conducted while the canal was being obturated.

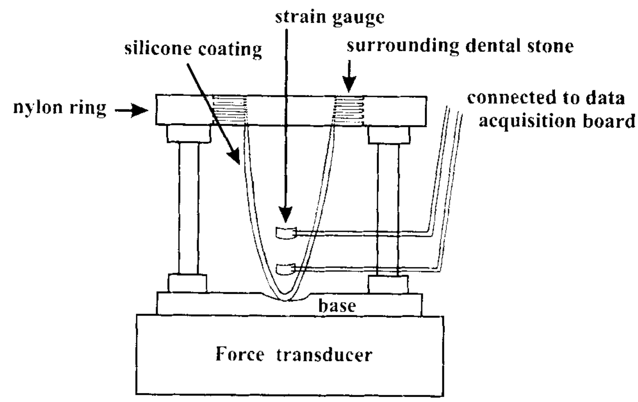

FIG 1. Schematic of the apparatus used to measure load and circumferential strains during lateral condensation, placed on force transducer (front or buccal view).

Obturation

Obturation was conducted by one endodontist in all groups of teeth. Lateral condensation technique: a finger spreader size medium fine (Kerr, Romulus, MI) or a D11T spreader (Hu-Friedy, Chicago, IL) was used with the master gutta-percha cone the same size as the master apical file. Fine-fine accessory gutta-percha cones (Progress, Rudolf Gunz & Co., Melbourne, Australia) were used except for maxillary incisors (medium-fine). Each tooth was used twice for obturation using both the finger spreader and hand spreader. Immediately after the first obturation (randomly allocated to finger or hand spreader), the gutta-percha was removed and the second obturation conducted.

A master gutta-percha cone the same size as the master apical file was inserted to the working length. The spreader, either finger or D11T, was inserted to ~1 mm short of the working length, rotated, and withdrawn. An accessory gutta-percha cone was placed into the space created by the spreader, the spreader was reinserted, and the process was repeated until the canal was completely obturated close to the level of the cementoenamel junction. After the second obturation, gutta-percha was removed to the middle third level and vertically condensed with a hot root canal plugger (#5/7, Hu-Friedy).

Fracture Load and Strain Measurement

Fracture was conducted using a D11 spreader tip (Hu-Friedy) for maxillary anterior teeth, and either a medium size (black color) or medium-fine size (green color) finger spreader (Kerr) for the other teeth, to generate stress in the root via the gutta-percha, leading to vertical root fracture. These spreaders were tried in the canal before obturation to ensure that they could not reach the full working length of the canal, but touched the canal wall at least 1 mm before reaching the root apex. The spreader tip was mounted on a servohydraulic testing machine (model 858, Material Test System) that provided the force (applied load) for penetration. The tooth was centered under the spreader on the lower platen, and the

TABLE 1. Vertical loads generated during lateral condensation with finger and hand (D11T) spreader in different groups of teeth

Spreader	Tooth Type					
	Maxillary			Mandibular		
	Incisor	Premolar	Molar	Incisor	Premolar	Molar
Finger	1.1 ± 0.2	1.4 ± 0.2	1.3 ± 0.1	1.0 ± 0.2	1.1 ± 0.2	1.4 ± 0.2
D11T	2.0 ± 0.4	2.3 ± 0.5	2.1 ± 0.4	2.2 ± 0.4	2.3 ± 0.4	2.5 ± 0.3

Data are presented as mean load (kg) ± SD for 10 teeth. All comparisons demonstrated significantly higher loads ($p < 0.05$) for D11T than for finger spreaders.

TABLE 2. Mean maximum root surface strains during lateral condensation using finger and D11T spreader in the apical and middle third areas

Tooth	Strain (μstrain)			
	Finger Spreader		D11T	
	Apical Third	Middle Third	Apical Third	Middle Third
Maxillary incisor	3.6 ± 11.3	7.1 ± 11.9	32.1 ± 26.0	25.6 ± 12.8
Maxillary premolar	7.2 ± 12.5	11.9 ± 15.8	30.4 ± 22.2	32.0 ± 23.6
Maxillary molar	4.2 ± 8.9	15.5 ± 23.4	34.5 ± 15.0	45.8 ± 15.2
Mandibular incisor	<1*	<1*	27.0 ± 17.2	25.6 ± 19.0
Mandibular premolar	6.0 ± 12.9	2.4 ± 7.5	25.6 ± 17.8	18.5 ± 18.9
Mandibular molar	9.6 ± 15.7	11.4 ± 12.2	27.3 ± 24.3	46.8 ± 20.2

Data are presented as the means ± SD. Strain is unitless: 1 μstrain represents a change in dimension of 1 part in 1 million, or 1 μm/meter.
* Less than the detection limit of instrumentation.

spreader was driven into the gutta-percha with a ramped load of 1 N/s until initial fracture of the root occurred. Applied load, displacement of spreader within the canal, and surface strain from both strain gauges were recorded simultaneously. The load was immediately removed as soon as fracture occurred. The initiation of fracture was determined by the displacement transducer. This rapid shut down permitted the detection of a number of incomplete fractures.

Statistical Analysis

Statistical analysis was performed using the SPSS/PC (Chicago, IL) software package. A one-way ANOVA was used to compare the loads generated within the different types of teeth using each spreader type. Post-hoc comparisons among groups were conducted using the Bonferroni test. The paired *t* test was used in each group of teeth to compare obturation load with finger and hand spreader in each group, to compare obturation load with load at fracture, to compare apical strain with middle third strain during obturation, and to compare obturation strain with strain at fracture. All statistical analysis was performed at the 95% level of confidence.

RESULTS

Obturation Loads

The mean maximum loads exerted during condensation using finger spreader and hand spreader (D11T) are presented in Table 1. The mean maximum applied loads with each spreader type were in the range of 1.0 to 2.5 kg, with little variation among the different groups of teeth. The apical load applied during condensation with the hand spreader (2.0 to 2.5 kg) was almost double that encountered with the finger spreader (1.0 to 1.4 kg) and was significantly higher ($p < 0.05$).

Root Surface Strains during Obturation

The strains generated during lateral condensation were measured on the buccal root surface in the apical and middle thirds of the root (Table 2). Overall, strains were low and in many instances close to the detection limits of the strain gauges. No major differences were observed between the mean maximum strains recorded at the apical versus middle third of the root or among the different tooth groups using the same spreader type ($p > 0.05$). However, strains generated during use of D11T spreader were approximately 5-fold higher than those associated with use of finger spreaders ($p < 0.05$). It should be noted that strains were very low for both spreader types.

Loads and Displacement of Spreader at Fracture

The mean and minimum load at fracture are given in Table 3, whereas the distribution of fracture loads for the 10 teeth in each group are shown in Fig. 2. Marked differences in the mean load at fracture were noted among the different tooth types, ranging from 6.2 ± 1.5 kg for mandibular incisors to 17.2 ± 4.3 kg for maxillary incisors. Interestingly, the mesial root of mandibular molars (mean load: 8.1 ± 3.8 kg) was weaker than any other tooth except mandibular incisors. The range of fracture loads within any one group was also large (Fig. 2), varying ~3-fold for all groups.

The minimum load resulting in fracture in individual teeth was <5 kg for all but two groups of teeth and was only 3.4 kg in one mandibular incisor (Table 3). If a "safe-limited load" is set at 70% of the minimum load resulting in a fracture (9), then four of six groups of teeth tested were within ~1 kg of realistic hand-spreader force applied during lateral condensation (Table 1).

Fracture typically occurred when the spreader tip was ~5 mm from the root apex (Table 3). It was not possible to determine whether the spreader tip contacted dentin or was surrounded by gutta-percha when fracture occurred.

TABLE 3. Load at fracture (kg; means ± SD) when a spreader tip was inserted under load into a canal filled with gutta-percha

Load (kg) or Distance (mm)	Tooth					
	Maxillary			Mandibular		
	Incisor	Premolar	Molar	Incisor	Premolar	Molar
Fracture	17.2 ± 4.3	8.7 ± 2.6	11.5 ± 3.6	6.2 ± 1.5	9.7 ± 2.9	8.1 ± 3.8
Minimum	9.1	4.8	6.9	3.4	4.8	4.8
Safe limited	6.4	3.4	4.8	2.4	3.4	3.4
Distance from apex	4.1 ± 1.2	5.2 ± 1.1	2.8 ± 1.1	5.4 ± 1.4	4.6 ± 1.8	4.6 ± 1.7

The mean fracture load for 10 teeth ("Fracture"), the lowest load encountered among the 10 teeth in each group ("Minimum") and the safe-limited load, set at 70% of the minimum load ("Safe limited") are all given. Distance from apex is the distance of the spreader tip from the root apex when fracture occurred (mm; means ± SD).

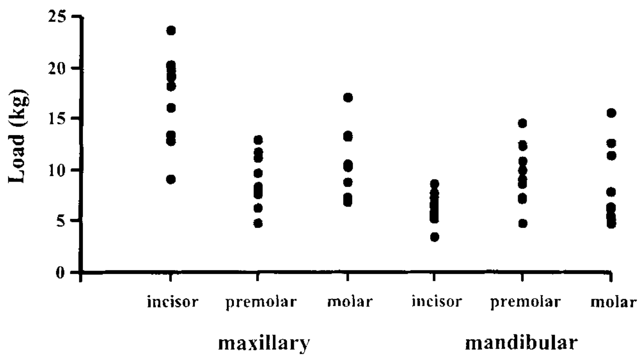

FIG 2. Dot plots of loads (kg) at fracture in various groups of teeth.

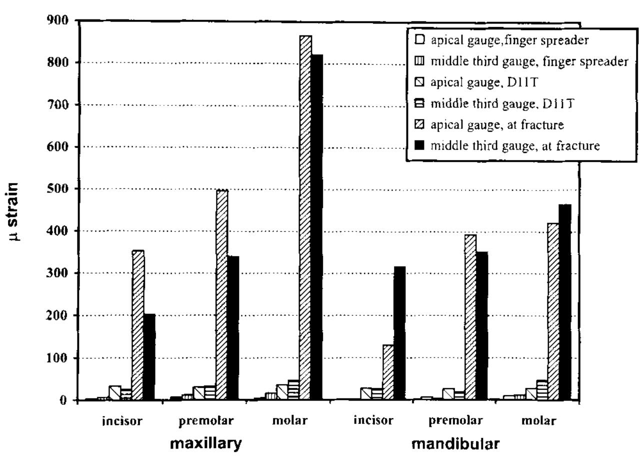

FIG 3. Mean maximum root surface strains (in μstrain), occurring during lateral condensation using finger and D11T spreaders, compared with strains at fracture. Strains were measured using strain gauges mounted on the buccal surface of the root in the apical and middle thirds areas.

Strains at Fracture

The root surface strains at fracture in this study are presented in Fig. 3. No significant difference in the strain at fracture was found between the apical and middle third area in each group of teeth. The strains at fracture were significantly ($p < 0.05$) higher than the strains generated during lateral condensation using both finger and D11T spreaders (Fig. 3), by a very wide margin.

Location of Fracture Line

Most fracture lines in every group of teeth occurred in a buccolingual direction. Eight of 10 maxillary incisors fractured in this direction, whereas one fractured only on the proximal surface and the other fractured both proximally and at the buccoproximal line angle. The mandibular incisors also fractured predominantly in a buccolingual direction (80%), whereas two fractured only on one proximal surface.

Maxillary premolars showed 50% fractured in a buccolingual direction, and four of these five fractured only on the palatal surface of the buccal root. One tooth fractured only on one side of the proximal surface, and another four fractured at the line angle between buccal or palatal and the proximal surface. For the mandibular premolar group, 8 of 10 roots also fractured in a buccolingual direction, one fractured on one proximal surface, and the other root fractured on both buccal and proximal surfaces.

For mandibular molars (mesial root), eight roots fractured in a buccolingual direction and two fractured on both buccal and proximal (distal) surfaces. The mesiobuccal root of maxillary molars demonstrated more variation in fracture line site. There were only three roots that fractured in a buccolingual direction, whereas three showed a fracture line on one proximal surface. Three roots had a fracture line at the buccoproximal line angle, and one on both buccal and proximal surfaces.

DISCUSSION

Endodontic procedures, and especially lateral condensation, have been blamed as a cause of vertical root fracture (5, 13). Some studies have also suggested that lateral condensation creates stresses in the root during obturation, which could lead to subsequent fracture (7, 14). The load and strain generated during lateral condensation were compared with loads and strains at fracture in this study.

The mean maximum applied loads using either finger spreader or D11T hand spreader were in the same range (1 to 3 kg) as previous reports (6–8). These loads were not dependent on the type of tooth being obturated. Hand spreaders (D11) created more strain than the B-finger spreader in straight roots of extracted teeth (11). On the other hand, Murgel and Walton (15) found no statistically significant difference in strain generated by finger and D11 spreader in curved roots (mesiobuccal root of maxillary molars). The results from our study showed that the D11T hand spreader created significantly higher strains than those produced by finger spreaders in all groups of teeth. This was due to the load applied using the D11T spreader being higher than the finger spreaders, whereas in the former study the applied loads were generated by an Instron testing machine at a fixed load of 3 kg.

The mean maximum load and strain generated during obturation in this study were significantly lower than the load and strain at fracture. In particular, the root surface strains during obturation were only a small fraction (1 to 10%) of the strains recorded at fracture. Some fracture lines did not pass through the strain gauges. This suggested that the measured strains in these teeth were lower than actual strains at fracture. Although the mean maximum strains as measured in this study were lower than they could be, the strain at fracture was significantly higher than root surface strains generated during the obturation procedure. These results suggest that lateral condensation should not be a direct cause of vertical root fracture unless condensation forces are excessive or the root is much weaker than normal (e.g. after overinstrumentation) (14, 16). Lindauer et al. (10) and Dang and Walton (11) also demonstrated that the prevalence of vertical root fracture generated by lateral condensation should be very low, using a strain gauge technique with extracted teeth. Vire (17), in an analysis of endodontically treated teeth requiring extraction, concluded that endodontic factors (including obturation) were responsible for only a small proportion of cases of vertical root fracture (only 4.3% of total failure cases). The average elapsed time of this failure was 20.2 months, suggesting that vertical root fracture occurred some time after obturation, or required time for propagation.

Although lateral condensation should not be a direct cause of vertical root fracture, this procedure has been suggested to result in incomplete root fracture. This may be because dentin has sufficient elasticity to permit separation without complete vertical root fracture (12). These incomplete fractures may become high stress concentration areas, when force is applied during the restorative procedure or from occlusal stresses during mastication. Then, the crack may progressively propagate from root canal wall to outer root surface. The relationship between a localized defect in a material and stress concentration has been well documented in the engineering literature related to material failure. Vertical root fracture has also been reported in nonendodontically treated intact teeth, predominantly the mesial root of mandibular molars (18). The fractures were confined to the root and extended in a buccolingual direction, in teeth with marked occlusal wear. This report suggests that occlusal stress may be a major contributor to vertical root fracture, particularly in the presence of other factors that weaken the root.

The mean load at fracture for the different tooth groups in this study showed considerable variation, with the maxillary incisor requiring the greatest load (17.2 kg) and the mandibular incisor the lowest load (6.2 kg). Overall, the values were similar to those reported previously for similar tooth groups (6, 8, 9). A possible explanation for the different loads at fracture for the various tooth groups may be the variation of root morphology and thickness of root dentin. The anatomical and biological variation of tooth structure may influence a range of mechanical properties (19).

There was also a considerable range in the fracture loads within any one tooth type, and the lowest value recorded for any one tooth in each group was typically only one half of the average fracture load. Given that only 10 randomly selected teeth were tested for each tooth type, the minimum value could easily be exceeded if teeth with narrow roots or wide canals were specifically included. Pitts et al. (9) suggested that the spreader loads should be limited to 70% of the minimum force observed to cause vertical root fracture to provide a margin of safety. The safe limited loads in this study are presented in Table 2. The mandibular incisor is the most susceptible to vertical root fracture. The safe limited load for this tooth is only 2.4 kg, which is higher than in Holcomb et al.'s study (8), but still well within the range of condensation loads encountered with a hand spreader.

Since the prognosis of a tooth with vertical root fracture is very poor (3), endodontists should use instruments that are as safe as possible. When the safe limited loads (Table 2) and obturation load from this study are considered, the finger spreader is likely to result in a very low risk of vertical root fracture. The finger spreader should be the instrument of choice for lateral condensation, especially in mandibular incisors, overinstrumented roots, or in teeth with a thin dentin wall (e.g. apexification cases). In addition, Walton (20) suggested that the more flexible and less tapered finger spreaders are safer than the stiff, conventional hand spreader.

The mean distance of the spreader tip from the root apex in the fracture experiment ranged between 2.8 and 5.4 mm short of the root apex. This result suggests that many of the fractures occurred as a result of stresses transmitted via gutta-percha. It also suggests that the high stress areas are in the apical third or between the apical and middle thirds. This implies that vertical root fracture may initiate in these areas and then propagate both apically and coronally.

Most fracture lines in the present study were in a buccolingual direction. Similar observations have been reported by other studies (6, 8, 12). The sites of vertical root fracture that may be difficult to diagnose clinically are on the proximal surface and the lingual or palatal surface of the buccal root or mesiobuccal root. Four of 10 fractures in the buccal root of maxillary premolars were confined to the palatal surface of the buccal root. For maxillary molars, 30% fractured on only the proximal surface. If this pattern occurs in a clinical situation, it is very difficult to diagnose the cause of failure. This may be a reason that most vertical root fracture studies have reported a low prevalence in maxillary premolars and molars (4, 5).

Although the dentin thickness in the buccolingual direction is greater than in the mesiodistal direction, most vertical root fracture lines presented in this direction. The reason for these fracture characteristics is not clear, but is presumably related to stress patterns in the root. Further study is necessary to gain insight into the pathogenesis of vertical root fracture and hence its prevention.

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Dr. Lertchirakarn is a postgraduate student, Dr. Palamara is a research fellow, and Dr. Messer is professor of Restorative Dentistry, School of Dental Science, University of Melbourne, Victoria, Australia. Address requests for reprints to Dr. Veera Lertchirakarn, School of Dental Science, University of Melbourne, 711 Elizabeth Street, Melbourne 3000, Australia.

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The Way It Was

Ever wonder why smallpox was "small"? It was to contrast it with syphilis, the great pox, which having just ravaged a previously unexposed 16th century population caused numerous extensive cutaneous lesions.

Lewis Pallid