ROOT RESORPTION IN HUMAN PERMANENT TEETH

A ROENTGENOGRAPHIC STUDY

A Thesis embodying original work, submitted as partial fulfillment of the requirements for the Degree of Master of Dental Science in the Faculty of Dentistry, University of Sydney, December, 1965.

O. P. BLACK
## CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>1 - 2</td>
</tr>
<tr>
<td>Review of Literature</td>
<td>2 - 40</td>
</tr>
<tr>
<td>Materials, Apparatus and Methods</td>
<td>41 - 82</td>
</tr>
<tr>
<td>Results and Findings</td>
<td>83 - 114</td>
</tr>
<tr>
<td>Discussion</td>
<td>115 - 149</td>
</tr>
<tr>
<td>Conclusions</td>
<td>150 - 152</td>
</tr>
<tr>
<td>Bibliography</td>
<td>153 - 160</td>
</tr>
</tbody>
</table>
Root Resorption in Human Permanent Teeth

A Roentgenographic Study

Introduction

The process of "Osteogenic Resorption" is a basic physiological phenomenon without which the individual cannot exist. Briefly, it is essential for the maintenance of normal metabolism, for growth, for adaptation to a changing environment, and for the existence of the dentition. The process of resorption as applied to the dentition may be termed "odontogenic resorption." Odontogenic resorption is essential for the shedding of the deciduous teeth, and without this physiological process the permanent teeth could never erupt.

It may be said that the deciduous dentition has a high potential for resorption. This inherent resorptive potential may, or may not be expressed in the normal permanent dentition. The form and the degree which this expression takes varies. It may be general or local.

Minor cemental resorption as found histologically in the permanent dentition, is not pathological, but is an expression of normal physiological movement and function. The prediction of the inherent resorption potential of a patient, particularly an orthodontic patient, would be most useful. Orthodontics is applied, controlled pathological osteogenic resorption. It was Oppenheim (1942) who stated that a tooth cannot be moved within physiological limits.

Orthodontic tooth movement is pathological (in a strict histopathological sense).

Clinically, prediction can only be made by the use of roentgenographs. It has been the aim of this study to try and assess how helpful a roentgenogram is in showing resorption of the roots of teeth and other
supposed osseous changes associated with root resorption.

Review of the Literature

The review of literature has been divided into the following sections, and each section will be dealt with separately. The sections are:

1. The definition of Resorption
2. History of Root Resorption
3. Classification of Root Resorption
5. Incidence and Frequency of Peripheral Idiopathic Resorption before Orthodontic Treatment
6. Incidence and Frequency of Peripheral Idiopathic Resorption after Orthodontic Treatment
7. A brief discussion of the Histopathology of Orthodontic Tooth Movement
8. Roentgenographical Criteria used by the Various Investigators in the Assessment of Peripheral Resorption
9. Histological Assessment of Peripheral Resorption
10. Predisposition to Peripheral Resorption
11. The Aetiology of Peripheral Resorption

1. The Definition of Resorption:

In the literature prior to 1932 there was considerable confusion as to the terminology used to describe this process. Becks and Marshall (1932) who were very prominent in research in this field, reviewed the literature which was available, and concluded that the process should be referred to as "Resorption", as distinct from "Absorption". These workers defined Resorption as "the taking up of products or tissues originating in the body", and defined Absorption as "the taking up by tissues of fluids outside the body." Their definitions may be open to
debate, but this is unimportant. They strongly favoured the use of the
term Resorption, and by and large, this terminology is the one used
today.

2. **History of Root Resorption:**

John Hunter referred to deciduous tooth resorption as early as
1771. Bates, in 1856, in the British Journal of Dental Science,
according to Henry and Weinmann (1951), was the first to observe and
report external resorption of the permanent dentition.

Hopewell-Smith (1930) quotes Kolliher "Handbuch der Gewe-Belehre",
Wurzburg, 1895 (Buchanan's translation of the 3rd Edition), in which the
author refers to the "falling out" of the permanent teeth. The cause
as proposed by Kolliher, is most interesting and is worthy of note. "In
old age, the teeth become denser; the cavity of the pulp gets filled
with a kind of a regular dentine, and even completely obliterated, which
perhaps is the cause of the natural falling out of the teeth."

Miller (1901) reported a case of internal resorption and cited
another case of similar resorption which was shown to him in 1890 by
Kirk. The tooth was an upper right central incisor, where the pulp had
eroded nearly all the dentine from under the enamel and could be seen as
a bright red spot through the enamel.

Mumery (1920)(1926) described this condition, and postulated a
theory for the cause of same. He called this condition "Pink Spot". He
is generally thought to be the first person to have observed this
condition, or at least to have written about it.

According to Stuteville (1938), in 1906, Sanstedt, experimenting
on dogs, reported tissue changes resulting from induced tooth movement.
One of these tissue changes was the loss of root substance, or root
resorption. Sanstedt suggested the term "undermining resorption" as
applied to bone, and this descriptive phrase is still used today.

Ottolengui (1914) discussed root resorption in relation to orthodontic treatment. This paper can be considered as the first serious discussion on root resorption as caused by clinical tooth movement.

In 1927, and again in 1929, Ketcham (1927)(1929) presented his findings of a radiographic review of 385 cases which he had treated in his orthodontic practice. He found the incidence of resorption before treatment to be 1 per cent and after treatment it had increased to 21 per cent. These findings produced a greater awareness in this subject, and to tissue responses in general in relation to tooth movement. Consequently, in the period from 1929 to 1942 there were numerous investigations involving not only the question of apical root loss, but the whole histological process of tooth movement during orthodontic intervention, both in experimental animals and humans.

This work was continued by Oppenheim, Marshall, Stuteville, Becks, Hemley, Rudolph and others, and their investigations, and later investigations will be dealt with in more detail later in the review.

3. Classification of Root Resorption:

Root resorption may be classified in a number of ways. It may be classified on an aetiological basis, or on the position of the resorption, or on severity, etc.; the method does not much matter so long as it is orderly, simple and meaningful.

Zemsky (1929) produced the following classification:-

Over/...
"Group 1:  Deciduous Teeth
(a) In the presence of the germs of permanent teeth
(b) In the absence of germs of permanent teeth

Group 2:  Pulp Disturbances
(a) Granulomas
(b) Cystic degeneration
(c) Root canal therapy

Group 3:  Necrosis of the jaws followed by acute osteomyelitis

Group 4:  Replantation of teeth

Group 5:  Root Resection

Group 6:  Retained teeth
(a) Involvement of the retained tooth
(b) Involvement of the adjacent tooth

Group 7:  Trauma of various types
(a) Poor prosthetic restorations
(b) Malocclusions
(c) Orthodontic treatment

Group 8:  Oral Neoplasms
(a) Benign growths
(b) Malignant growths

Group 9:  Periodontal disturbances (diffuse atrophy)."

This classification is long and involved.

Marshall (1934) devised another classification:

"1.  Non-Infective Type
(a) Normal resorption of growth phenomena
(b) Pathologic resorption arising from malnutrition or metabolic diseases as rickets, etc.
(c) Pathologic resorption due to occlusal trauma
(d) Pathologic resorption due to mechanical trauma of an unknown nature
1. (d) undetermined degree.

2. Infective Type

(a) Local. Pathologic resorption due to infection of the pulp canal of the tooth or from adjacent teeth.

(b) General. Infection of a systemic nature, e.g., tuberculosis, syphilis, etc."

Steadman (1942) quotes Kronfeld as having a classification involving six different types of resorption. Steadman's classification consists of three groups:

"Group 1: Some visible cause of resorption - cysts, neoplasms etc.

Group 2: Non-vital teeth, root filled, implanted, replanted or root resected teeth

Group 3: Vital teeth which show resorption with no visible cause in the x-ray."

Becks (1942) devised his own classification:

"Endogenous - Idiopathic

Exogenous - Infectious

- Pressure atrophy (cysts etc.), trauma and excessive activity

- Inactive type of root resorption."

Most of the classifications are unnecessarily complicated. Consequently, the simple classification proposed by Thoma and Goldman in their text "Oral Pathology" (1960) is probably as simple and as meaningful as would be necessary. They classify the resorption according to position - namely, internal resorption and peripheral resorption. In this investigation we are concerned only with peripheral resorption.
Histopathology of Peripheral Idiopathic Resorption:

A detailed examination of cases exhibiting spontaneous intermittent resorption will usually reveal if the condition is active or passive. Activity is usually associated with the presence of multinucleated osteoclasts. These osteoclasts form bay-like lacunae which in turn cause an irregular outline of the tooth surface. Repair is associated with the passive phase of the condition. The replacement tissue varies. In a great many cases it consists of osteocementum, compact bone or cancellous bone. Other combinations may be found, such as cementum and compact bone, compact bone and cancellous bone, and cementum and cancellous bone.

Thoma and Goldman (1960) found that osteocementum was invariably the replacement tissue that was applied to the resorbed dentine.

Sullivan and Jolly (1957) state that the replacement tissue adjacent to the dentine is usually of a compact nature, and found it to be either cementum, osteocementum or compact bone.

The process of resorption and repair may be cyclic, or may occur concomitantly but in different parts of the affected area of the tooth. The type of replacement tissue seems to vary with the rapidity of the resorptive process. The more rapid the process, the more primitive and less organised the replacement tissue. This principle may explain the existence of the osteocementum (which is a primitive tissue) in relation to the dentine of the resorbed area of the root, as mentioned previously. The repair tissue may also undergo resorptive changes.

The connective tissue adjacent to the resorptive process varies in composition from loose oedematous tissue to a collagenous type. The cells vary in form - some are long and spindle shaped, some round and stellate. Inflammatory cells are always very closely associated with
resorptive changes; that is, it may be said that inflammation is a primary factor in resorption. The type of connective tissue cell, or cells, responsible for the process of resorption, is unknown. This will be discussed later when dealing with the aetiology of resorption.

Pulpal tissues may be entirely normal. In other cases, the pulp tissue in the region of the lesion shows inflammatory changes, whereas in other cases the pulp may degenerate. The process may encircle the pulp but not affect it. This was mentioned by Thoma and Goldman (1960), Hopewell-Smith (1930), and others. Pulpal tissues usually do not show signs of involvement unless the dentine wall becomes perforated.

In the cases seen by Goldman (1954), Stafne and Slocumb (1944), and Thoma, Sosman and Bennett (1943), it appears that in most instances the resorptive process starts at the periphery. It may be initiated at the site of an accessory canal, as noted by Colyer and Sprawson (1931), but this is not the general rule.

5. Incidence and Frequency of Idiopathic Peripheral Resorption before Orthodontic Treatment:

Resorption of the roots of teeth can occur without any apparent cause. This is known as idiopathic resorption. Seward (1963) states that this is the most common form of resorption.

Idiopathic resorption may be subdivided according to its severity. The severe type usually affects only one or two teeth, and this type of resorption is referred to generally as spontaneous intermittent resorption. This is the nomenclature used by Thoma and Goldman (1960). It is not rare, and may, or may not be progressive. Reference to such cases are readily found in the literature, for example, Thoma, Sosman and Bennett - 29 cases (1943); Stafne and Slocumb - 179 cases (1944); Kronfeld (1949); Goldman - 76 cases (1954); Chambers (1957); Everett and Fabrizio (1960); Swan (1963), and Jaczuk Zbigniew - 6 cases (1964),.
to name but a few.

A lot of such cases go undetected, as the teeth usually do not cause pain, and if they do, or if they become loose, or cause any trouble, they are probably merely extracted and not reported in the literature. In most instances, such teeth are usually detected in routine full-mouth examinations during normal dental procedures. Such teeth are usually periodically x-rayed by the dentist to see if the condition is progressive.

From the orthodontic point of view, this particular type of resorption is important.

Fig. 1 - Showing severe Idiopathic Resorption of Maxillary Canines.
Orthodontically, the cases which show a generalized "mild degree" of resorption are the cases which require extremely careful observation during orthodontic procedures. The term "mild degree of resorption" will be considered later when considering criteria.

Fig. 2 - Indicating mild idiopathic
Resorption of lower Central Incisors
Note the apical foramen is visible.

The incidence of this type of resorption has been observed from roentgenograms by many investigators of patients before orthodontic treatment.
TABLE 1

<table>
<thead>
<tr>
<th>Name</th>
<th>Date</th>
<th>No. of Cases</th>
<th>Age Years</th>
<th>% Resorption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ketcham</td>
<td>1927</td>
<td>385</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1929</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rudolph</td>
<td>1936</td>
<td>739</td>
<td>7-21</td>
<td>5</td>
</tr>
<tr>
<td>Becks</td>
<td>1939</td>
<td>72</td>
<td>-</td>
<td>32</td>
</tr>
<tr>
<td>Rudolph</td>
<td>1940</td>
<td>4,560</td>
<td>7-79</td>
<td>13</td>
</tr>
<tr>
<td>Becks</td>
<td>1942</td>
<td>26</td>
<td>-</td>
<td>8</td>
</tr>
<tr>
<td>Massler and Malone</td>
<td>1952</td>
<td>708</td>
<td>12-49</td>
<td>86.4</td>
</tr>
<tr>
<td></td>
<td>1954</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Caprol*</td>
<td>1961</td>
<td>55</td>
<td>11-70</td>
<td>77.3</td>
</tr>
</tbody>
</table>

*Caprol investigated roentgenograms of anterior teeth only

Males and females seem to be almost equally susceptible to idiopathic resorption. In the 739 cases examined by Rudolph (1940), 74 per cent of females showed resorption and 65 per cent of males.

Massler and Perreault (1954) and Massler and Malone (1954) could not find any significant difference in the susceptibility to idiopathic resorption between the sexes.

It may be said very generally that females do exhibit slightly more resorption than do males.

**Frequency:**

Statistics from a clinical study at the New York University Department of Orthodontics showed there is apparently more resorption of the maxillary teeth than the mandibular ones. Gottlieb (1942) stated that if movement is continued following resorption of the cementum, ankylosis may occur. The following is a table of the frequency of root resorption before orthodontic treatment:
**TABLE 2**

Order of Frequency of Resorption before Orthodontic Treatment

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Bicuspsids</td>
<td>Lower Anteriors</td>
<td>Upper and Lower</td>
</tr>
<tr>
<td>Upper Laterals</td>
<td>Upper Laterals</td>
<td>Incisors showed the most resorption</td>
</tr>
<tr>
<td>Upper Centrals</td>
<td>Premolars</td>
<td></td>
</tr>
<tr>
<td>Lower Molars</td>
<td>Upper Centrals</td>
<td></td>
</tr>
<tr>
<td>Upper Molars</td>
<td>Upper Cuspids</td>
<td></td>
</tr>
<tr>
<td>Lower Bicuspsids</td>
<td>Molars</td>
<td></td>
</tr>
<tr>
<td>Upper Cuspids</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower Centrals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower Laterals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower Cuspids</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6. The Incidence and Frequency of Resorption after Orthodontic Treatment:

Having just reviewed the literature dealing with the incidence and frequency of root resorption before orthodontic treatment, it is now fitting that the incidence and frequency of resorption be studied after such treatment.

The following table summarises published observations:

Over/...
### TABLE 3

The Incidence of Resorption after Orthodontic Treatment

<table>
<thead>
<tr>
<th>Name</th>
<th>Date</th>
<th>No. of Cases</th>
<th>Length of Treatment</th>
<th>% Resorption</th>
<th>Type of Appliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ketcham</td>
<td>1927</td>
<td>385</td>
<td>-</td>
<td>21</td>
<td>Labial Expansion Arch</td>
</tr>
<tr>
<td></td>
<td>1929</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rudolph</td>
<td>1936</td>
<td>439</td>
<td>1 year</td>
<td>49</td>
<td>Labial Expansion (Undergraduate Students)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2 years</td>
<td>74</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1940</td>
<td>513</td>
<td>Age Starting Treatment</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>12 Years:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1 Year</td>
<td>49</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2 &quot;</td>
<td>81</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3 &quot;</td>
<td>97</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4 &quot;</td>
<td>100</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>9 Years:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1 Year</td>
<td>30</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2 &quot;</td>
<td>66</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3 &quot;</td>
<td>86</td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4 &quot;</td>
<td>94</td>
<td>&quot;</td>
</tr>
<tr>
<td>Hemley</td>
<td>1941</td>
<td>195</td>
<td>Av. 2½ yrs.</td>
<td>21.5</td>
<td>-</td>
</tr>
<tr>
<td>Becks</td>
<td>1942</td>
<td>26</td>
<td>6 mths. at completion.</td>
<td>80</td>
<td>Ribbon Arch.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Some active for 4 years</td>
<td>96</td>
<td>Undergraduate</td>
</tr>
<tr>
<td>Phillips</td>
<td>1955</td>
<td>62</td>
<td>12.5 yrs. mean S.D. 4.2 mths.</td>
<td>38.9</td>
<td>Edgewise</td>
</tr>
<tr>
<td>McLaughlin</td>
<td>1964</td>
<td>28 only considered-the Maxillary central incisors(54)</td>
<td>1 yr. 5 mths.</td>
<td>92.5</td>
<td>Edgewise There was (Tweed Technique) a decrease of 8.2% of root substance</td>
</tr>
</tbody>
</table>

With regard to resorption, there is no significant difference between male and females. Phillips (1955) and Hemley (1941) suggest that females may show a slightly higher incidence.

The type of movement is important. Phillips (1955) found that
torquing movements caused the most root loss; that is, there was a fairly high degree of correlation between this type of movement and resorption. The amount of tipping, on the other hand, showed no relation to root loss.

TABLE 4
Frequency of Resorption after Orthodontic Treatment

SEE OVERPAGE
TABLE 4

Frequency of Resorption after Orthodontic Treatment

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>96% Maxillary Incisor Loss</td>
<td>Upper Laterals &quot; Centrals</td>
<td>Lower Centrals &quot; Laterals</td>
<td>Central Incisors Lateral Incisors Cusps</td>
<td>Lower Centrals Upper Laterals</td>
<td>Lower and Upper Anteriors</td>
<td>Upper Centrals</td>
</tr>
<tr>
<td>37% Mandibular Incisor Loss</td>
<td>Upper 1st Molars Lower Cusps</td>
<td>Upper 1st Molars Lower Cusps</td>
<td>(Mandibular molars show more resorption than maxillary molars)</td>
<td>Upper Molars Lower Cusps Lower Bicusps</td>
<td>Lower 1st Bicusps Bicusps</td>
<td>Lower 2nd Bicusps</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
After studying Table 4, it became evident that the incisors show the highest frequency of resorption, both before and after treatment. It can also be seen that the frequency of any other group is far from clear - in fact, no other inference can be drawn from Table 4.

It will be shown later that it is quite impossible to try and detect resorption of any multi-rooted tooth (except possibly the lower first molar) from the best possible intra-oral radiograph. It cannot be done. Any such investigation that makes such claims is immediately suspect of extremely subjective assessment of the evidence available. Ketcham (1927)(1929) and Carpol (1961) are the only investigators who restrict their observations to single rooted teeth.

7. A Brief Discussion of the Histopathology of Orthodontic Tooth Movement:

Oppenheim (1942) was one of the early investigators who received recognition for the monumental character of his studies of histological changes occurring with the application of orthodontic force. Since 1911, his investigations performed upon monkeys have provided guides for clinical practice. He published an extensive report (1942) on the histological findings on 15 human teeth which had been moved by various orthodontic forces. In all of the patients reported upon so far, there were resorbed areas of root surfaces, presumably produced by injurious effects of the forces exerted by the appliances on the teeth.

Oppenheim (1942) stated that it is impossible to move a tooth within physiological limits. He cited all the histologic work which had been reported on humans, and pointed out that in all these cases there was evidence of root resorption. These resorbed areas supplied him with evidence that orthodontic forces produced a pathological
process.

Stuteville (1937) also makes a similar statement. The following is a quotation from Oppenheim (1944): "High magnification of the labial crest of a lower incisor subjected to orthodontic force for two days showed that the periodontal membrane was entirely crushed for some distance and transformed into a disorganised mass of tissues without any cells. Some thrombosed vessels were found. The width of the periodontal space on the pressure side was reduced to 0.08 mm. as compared to 0.82 mm. on the traction side - 10 times as much. The bone surface facing the periodontal space was acellular, while beneath the periostium, osteoclastic activity was already under way in two places. The condition of the osteocytes in the pressure area was impaired, many were pyknotic, stained faintly, and some bone lacunae were empty. The cementoid layer and the cementoblasts in the region of the greatest pressure had completely disappeared. The periodontal fibres were torn from their attachment and were difficult to trace. Near the bone surface, they intersected each other in all directions. Numerous haemorrhages were found and the bone surface was covered with many osteoclasts. No indication of any osteoid formation was found. In the apical portion of the traction side a similar condition was found, but to a lesser extent."

This was written in 1944, but it could have been written by Reitan in the 1950's. He found the same picture, but he called the cell-free zones hyalinized areas.

The ideal result of any orthodontic movement is the compression of the periodontal space in the direction of pressure just to the extent that the connective tissue is induced to resorb bone. If the periodontal space is not compressed too much, then a frontal
resorption of the bone occurs. Frontal resorption indicates that
there is resorption of bone while the opposite tooth surface remains
intact. However, if the force is greater in relation to the existing
periodontal fibres, then the fibres are hyalinised. In this condition
the periodontal space is unable to produce resorption. The degree of
resorption has a maximum centre in tipping movements, decreasing
towards the periphery. At some point of that periphery the compression
decreases to a degree where the connective tissue is able again to
resorb. At this perimeter the resorption of the compressed areas
starts inward and resorbs the whole bone at the centre, from the
rear and not from the periodontal membrane. This resorption is called
"rear resorption" in contrast to "frontal resorption", and derives its
name from the work of Gottlieb (1942).

Sanstedt, as far back as 1906 noted a similar change, and he
referred to this as "undermining resorption".

8. Roentgenographical Criteria used by the Various Investigators
in the Assessment of Peripheral Resorption:

Hemley (1941): Intra-oral roentgenograms were taken before
treatment and at least once a year thereafter. He used four grades
in the determination of resorption:

"1. Slight blunting
2. Moderate. Slight to less than one-third of the root
4. Marked. One-third or more."

Hemley (1941) himself says that this is a most arbitrary method
of determining resorption. He used three separate examiners to test
their agreement. A particular case will be cited to provide further
understanding of how the examiners determined resorption for the
particular cases involved.
If one examiner thought there was merely widening of the periodontal space, and another thought there was loss of the root substance of a particular tooth, then it was agreed that this be marked as blunt resorption. The third examiner may have said that there was no loss or widening of the periodontal space, and his view would have been disregarded in the above instance. The examiners were an anthropologist, an orthodontist and a dentist.

Becks (1936)(1939)(1942), and Becks and Cowden (1942): The criteria used was simple, and required only one examiner "1. First degree resorption below the apical one-third.
2. Second degree resorption from one-third to the middle one-third.
3. Third degree resorption — more than two-thirds."

Becks makes no mention of the roentgenographic technique used to produce the roentgenograms that were examined.

Massler and Malone (1954) used the following criteria in their assessment of resorption: "Method of Assessment — the amount of periapical root resorption in the roentgenograms of each tooth was assessed in the following manner:

<table>
<thead>
<tr>
<th>Degree or Type of Resorption</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No evidence of resorption.</td>
</tr>
<tr>
<td>?</td>
<td>Resorption questionable. Root outline intact but there appeared to be minute areas of spotty resorption. Lamina dura is interrupted, and the periodontal membrane widened.</td>
</tr>
<tr>
<td>1+</td>
<td>Root apex definitely blunted and resorbed for at least 1 millimetre to about 2 millimetres. Lamina dura interrupted and periodontal membrane widened about the periapical area of the root.</td>
</tr>
<tr>
<td>2+</td>
<td>Resorption of the root apex for at least 2 to 4 millimetres. Lamina dura interrupted and periodontal membrane widened. &quot;</td>
</tr>
</tbody>
</table>

Contd. Over/...
<table>
<thead>
<tr>
<th>&quot;Degree or Type of Resorption&quot;</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3+</td>
<td>Resorption of root 4 millimetres to one-half of root length.</td>
</tr>
<tr>
<td>4+</td>
<td>More than one-half of root resorbed</td>
</tr>
<tr>
<td>5</td>
<td>Root resorption definitely related to root canal therapy (degree not assessed).</td>
</tr>
<tr>
<td>6</td>
<td>Root resorption definitely related to periapical infection (cysts etc.).</td>
</tr>
<tr>
<td>8</td>
<td>Not diagnosable (roentgenogram of poor quality).</td>
</tr>
<tr>
<td>9</td>
<td>Tooth missing.</td>
</tr>
</tbody>
</table>

One examiner only was used, and he examined the roentgenograms using binocular loops with a X3 magnification. The roentgenograms used in this study were taken in the normal way. Massler and Malone make the following point: "In every instance, each tooth was examined in two films and therefore from two different views. Where only one film and one view of a particular tooth root were available and the resorption could not be seen clearly, the film was discarded and the tooth recorded as not diagnosable."

The roentgenograms used were from routine full mouth roentgenographic examinations. This meant that the examiner could have been comparing views of one tooth taken at different vertical and horizontal angulations. Variation of the vertical angulation must elongate or foreshorten the radiographic shadow so that it is impossible to assess small losses of tooth structure.

The criteria of Massler and Malone will be discussed at length in the following section. The present study was, in part, prompted by an unsatisfactory attempt to apply the above criteria to assessing root resorption.
Phillips (1955): Various methods of study were outlined and followed. Before and after intra-oral x-rays were obtained and examined in a manner somewhat similar to the methods of Hemley (1941) and Becks and Cowden (1942). The criteria used by Phillips is as follows:

2. Moderate: up to approximately one-fourth root loss.
3. Excessive: one quarter root length lost.
4. Questionable: possible traces of resorption not previously identifiable because of distortions due to film placement and difference in x-ray cone angulation."

Phillips used three separate examiners, all of whom were orthodontists. He also takes into account the variation which is produced by differing angulations of the film. He makes the following comment:

"The dividing line between the categories of root loss was difficult in some cases, particularly between the categories 'slight' and 'moderate', since a great divergence of root length appeared on a film because of elongation or foreshortening of root lengths due to different radiographic techniques of film placement and a variance in angulation of the x-ray cone by different operators taking the films."

He took the variation of opinions of the various examiners into account in the following way. In the event that differences in the evaluation of the amount of root loss occurred, the assessment of that tooth was placed in the category of major opinion. If, as sometimes occurred, three different evaluations of root loss were recorded (such as no resorption, questionable, or slight) the average of the three evaluations was tabulated.
Phillips (1955) also tried to make an assessment of the variation of root length of the incisors, namely the upper central incisors from lateral cephalometric head films. He, himself, says that this is a most inaccurate method and does not place much importance upon the results derived from these observations.

Carpol (1961) used the criteria as proposed by Massler and Malone in 1954. The roentgenograms were examined with a X3 magnifying glass and with suitable illumination. His classification is as follows:

0 No resorption

? Questionable resorption; root outline intact but minute areas of spotty resorption or periodontal membrane widening in periapical

1 Apex blunted and resorbed 1-2 millimetres.

2 Apex blunted and resorbed for 2-4 millimetres

3 Apex blunted and resorbed for 4 millimetres to one-half of root

4 More than one-half of the root resorbed

5 Related to infection, trauma etc.

I found it desirable to add one other classification:

L Lateral resorption of greater degree than "?"

Carpol (1961) stated quite emphatically that he used the same criteria as proposed by Massler and Malone, in his article, but it becomes evident by comparing the two classifications that they are not the same. Carpol does not take the interruption of the 'lamina dura' into consideration - this may be merely an oversight on his part, but at least it is a very important omission. He does not score resorption as related to root canal therapy, missing teeth or non-diagnosable roentgenograms of poor quality. He also adds a mysterious "L" which signifies "lateral resorption of greater degree than "?". He does not
elaborate on this point, and what he means by this is not known. Carp pol may have used the same criteria as proposed by Massler and Malone, but in his article it would not appear so.

McLaughlin (1964) compared the root area as shown on roentgenograms of maxillary central incisors of pre- and post-treatment films. He used a polar planimeter to trace the outline of the root for a measure of area. In a preliminary experiment on 35 extracted maxillary central incisors he found that there was a high degree of correlation between the root area (measuring this area from roentgenograms of these extracted teeth) and with the volume of the root. The volume of the root was determined by first cutting the crown of the tooth off with a disc. The most significant point here is not the loss of tooth material, but where the cut was made. He did not follow the dentino-enamel junction, but made his cut as shown in the diagram.
This is most arbitrary, and here his comparison of root area with volume failed. It failed clinically, as well, because in the film there is no way of telling if the root is resorbed on the labial or lingual surfaces. In short, the volume of the root of a tooth cannot be determined clinically. He says that the area, as measured, is a measure of lateral resorption, and believes that root area is a better index of loss of radicular substance than merely the measurement of length of the root. This opinion is justified by the fact that area is a function of length x width.

McLaughlin (1964) was also mindful of the distortion present in clinical x-rays even when the angulation is the same used in exposing the same view at different times. He makes adjustment for this by comparing the length of the crowns in the pre- and post-treatment roentgenograms. Such an adjustment, which he does not describe, is meaningless, as it is not known if the radicular portion is distorted to the same extent as that of the coronal portion. Nevertheless this is the most objective study in the assessment of radicular loss due to orthodontic intervention.

9. **Histological Assessment of Peripheral Resorption:**

An extensive histological examination was made by Henry and Weinmann (1951) of 261 teeth of 12 cadavers. The specimens were taken at the time of autopsy, and were later sectioned in situ longitudinally. One section for each tooth was examined.

The medical history for each case was checked, and it was found that none of these cases had had any disease that might have had any bearing on root resorption.

The results of this investigation are most interesting, and will be dealt with in some detail. Varying numbers of resorption areas
were found on 90.5 per cent of the teeth. If several sections had been available, probably 100 per cent of the teeth would have shown resorption; the average number of resorption areas per tooth was 3.5. This number increased with age, but the areas were smaller.

Henry and Weinmann (1951) also stated that 76.8 per cent of resorption occurred in the apical region, 19.2 per cent in the middle third, and 4 per cent in the gingival third. Another interesting feature of distribution of the areas is that they were more numerous on the mesial and buccal than on the distal and lingual. The authors were of the opinion that this was because of the physiological mesial drift of the teeth. This may be so. It is interesting to note that Weinmann and Schour (1945(a)(b)) found that rats' molars show a greater number of resorption areas on the distal, and these teeth migrate distally. It was also found that 85 per cent of the areas of resorption exhibited signs of repair, and that the size of the areas could be related to severity of the resorption. Here Henry and Weinmann (1951) make the observation that these areas of resorption (not only the severe resorptions) are detectable in a good x-ray. In fact, what they have stated is that the areas which are discernable histologically can be detected in a "GOOD X-RAY". This observation is most questionable, and even more so when the sections they used were in situ and consequently the x-rays must have been taken with the teeth in situ also. This will be referred to in the discussion.

Harvey and Zander (1959) also conducted a histological survey of teeth from a "healthy group" and teeth which were "periodontally affected." They sectioned the specimens transversely and examined every tenth section. Ages for the two groups ranged from 21 to over 50 years, and the material was examined in ten year groups; it was found that resorption did increase with age, and that the periodontally
affected group showed more resorption (91 per cent) than the healthy group (80 per cent). These figures are in accordance with those found by Henry and Weinmann.

10. Predisposition to Peripheral Resorption:

Root resorption in permanent teeth is most clearly associated with infection, trauma and orthodontic tooth movement. However, resorption of the roots of permanent teeth frequently occurs in the absence of these agents, as noted previously. This points towards an innate predisposition of the teeth (in some individuals) to resorption in permanent as well as deciduous teeth.

Resorption potential varies in different individuals. In some cases the teeth appear to be extremely susceptible to resorption so that severe resorptions occur, even in the absence of any demonstrable cause. In others, the teeth appear to be very resistant to resorption so that the roots remain intact even after severe trauma or extensive orthodontic tooth movement. This predisposition is not a new concept by any means. This was the conclusion of Ketcham (1927)(1929); Becks (1936)(1939), and Massler and Malone (1954).

Almost any comprehensive orthodontic textbook refers to such a predisposition; for example, Jarabak and Fizzell (1963) and Graber (1961).

Massler and Malone (1954) completed an extensive clinical survey based on analysis of full mouth x-rays of the dentition of 708 patients containing a total of 13,263 teeth. The patients were from 12 to 49 years of age, and none had received orthodontic treatment. The second portion of the study involved the examination and analysis of full mouth x-rays of 81 patients who had been treated orthodontically. These patients ranged from 12 to 19 years of age. This study is cited
here, as it deals with such a resorptive potential. The summary and conclusions are quoted as follows, and will be dealt with at length in the discussion of this thesis.

"This investigation was designed to study the frequency and the degree of idiopathic periapical resorption in human permanent teeth, as revealed by routine, full-mouth roentgenograms. It was found that:

1. One hundred percent of the persons examined showed some evidence of periapical resorption in one or more of the permanent tooth roots.

2. Eighty-six and four-tenths per cent of the teeth examined showed evidence of some resorption. Only 1.6 per cent of the teeth revealed (roentgenographically) no evidence of resorption. The remaining 12 per cent of the teeth were questionable.

3. An average of sixteen teeth per person showed some evidence of periapical resorption. There were no striking differences between males and females.

4. There were no significant differences between the number of maxillary and mandibular teeth affected. The resorptive pattern was strongly bilateral.

5. The order of susceptibility of teeth to resorptions in this study was consistent with other studies.

6. In only 5 per cent of the teeth was there any evidence as to the cause of the resorption (periapical infection and root canal therapy). In 81.2 per cent of the teeth, no reasons for the resorption were obvious (idiopathic resorptions).

7. The distribution of idiopathic resorptions in unselected cases were as follows:
   (a) 0.71 per cent were mild, the apex of the root being slightly blunted.
   (b) 0.9 per cent showed moderate amounts of resorption (root resorbed for at least 2 mm. to 4 mm.)
   (c) 0.30 per cent were severely resorbed (root resorbed 4 mm. to one-fourth root length).
   (d) 0.11 per cent showed very severe resorption (more than one-fourth of the root resorbed).

8. There appeared to be a significant increase in the frequency of the more severe degrees of resorptions with age."

Contd. over/...
9. The intraoral roentgenograms of eighty-one orthodontically treated patients also were assessed. It was found that the number of teeth resorbed, and particularly the severity of the resorptions, were markedly increased by orthodontic procedures.

10. In a sample of seventy-six cases treated orthodontically, a good prediction as to the degree of root resorption after orthodontic treatment could be made by an analysis of the roentgenograms taken before treatment. This prediction was more accurate when individual teeth were assessed before and after treatment than when the case was assessed as a whole.

11. It is concluded that a definite resorptive potential is resident in the permanent (as well as the primary) teeth of all persons. This resorptive potential varies in different persons and also in different teeth of the same person. The resorptive potential was found to be inherently high in approximately 10 per cent of this sample. This figure correlates well with the approximately 14 per cent of teeth that showed severe degrees of resorptions after orthodontic treatment."

11. The Aetiology of Peripheral Resorption:

How resorption really takes place is unknown. This is a problem which has not been solved to date. Most textbooks of oral pathology and pathology would agree that it is brought about by what is known as osteoclastic activity. The osteoclast was first described and named by Sir Charles Tomes in 1859. There is some disagreement in the literature as to the nature of the connective tissue cell which closely approximates the resorbing bone (Howship's Lacuna).

Hopewell-Smith (1930) thought that the plasma cell of Unna was the most odontolytic cell, and he did not believe that it was necessary to have giant multinucleated cells present to have resorption.

Bullivant and Jolly (1957) described the presence of plasma cells in their article. The presence of plasma cells is most interesting, and their presence may point to the auto-immune response of Burnett. It has been pointed out that the dentine, cementum and bone are all protected by a resorption-resistant highly organic layer (Orban(1936))
and if this layer should be thin and weak because of hereditary factors or systemic disease (predisposition to resorption), then the connective tissue cells (be they osteoclasts, histiocytes, multinucleated giant cells or plasma cells), will produce resorption, but just how is unknown. With regard to the osteoclasts it must be remembered that co-existence is not causation.

The presence of inflammatory changes, slight or gross, is the most constant feature of any form of resorption. The following authors mention inflammation in their writings:-

Mummery (1920); Hopewell-Smith (1930); Applebaum (1934); Becks (1936); Aisenburg (1937); Soifer (1937); Stafne et. al. (1944); Warner and Orban (1947); Kronfeld (1949); Goldman (1954) and Sullivan and Jolly (1957).

Such inflammatory changes have been induced by experimental methods by Orban, according to Warner and Orban (1947) using diathermie, and by Obertsztyn Andrezej (1963), by painting dogs' teeth with autopolymerizing resin. The important feature is that this inflammation which was induced experimentally, was accompanied by resorption of the teeth involved. Damage to the protective layer and subsequent connective tissue attack is in keeping with the thought of Sullivan and Jolly (1957) in their excellent article.

Orthodontically the damaging or predisposing factors may be listed as:

i. Heredity

ii. Systemic diseases or dietary conditions

iii. Physical trauma

iv. Appliances: (a) Magnitude of forces (b) Rigidity of appliance (c) Age at commencement of therapy (d) Duration of treatment.
i. **Heredity:**

It has been mentioned earlier that certain individuals are predisposed to resorption and the orthodontic implications for such people were discussed. Now it is not inconceivable that this tendency to radicular loss may be inherited.

Ritchie (1964) and Baer, Brown, and Hamner (1964) presented several cases of hypophosphatasia in children. This condition is definitely hereditable. In these patients the serum alkaline phosphatase is at a very low level and their deciduous teeth are lost with little or no resorption. It is known today that serum alkali phosphatase is necessary for the production of mucopolysaccharide ground substance of the connective tissue. It may be because of the lack of this ground substance in the connective tissue that the periodontal attachment of these teeth is very weak, and that they are extruded or shed very easily and would subsequently need little or no resorption. On the other hand, it may be due to the fact that because of the low level of the alkaline phosphatase that resorption cannot proceed normally. There is little known about the activity of alkaline phosphatase, and it will be discussed further when dealing with the systemic diseases involving liver dysfunction.

ii. **Systemic Diseases:**

Becks (1936) examined many patients suffering from various endocrine disturbances. He found that those patients suffering from hypothyroidism exhibited a marked tendency to radicular loss.

Carpol (1961) examined patients he knew to be suffering from hypothyroidism and found that these patients were no more susceptible to root resorption than the normal individual.
Mueller and Rony (1930), and Mueller (1931) examined a patient showing progressive root loss, and found this patient to be suffering from liver dysfunction. The alkaline phosphatase was extremely high.

Mueller and Rony (1930) also examined the same patient in 1931, and confirmed their earlier diagnosis of liver dysfunction with a high alkaline phosphatase level and associated root resorption.

Whitehead (1960) described a patient with what he termed as "idiopathic resorption", and this patient exhibited a high alkaline phosphatase level.

In the Orthodontic Clinic of the United Dental Hospital of Sydney a patient was examined and found to have marked loss of the upper left canine root (see Fig. 1). This patient was subsequently tested for liver function by Professor Steinbeck (Associate Professor of Medicine, University of New South Wales), and was found to have a slightly increased alkaline phosphatase level, but this was not thought to be significant. The level was much higher than that of an adult but it was not excessively high for a child.

On this basis, several patients have been referred to Professor Steinbeck at the Prince Henry Hospital for a thorough medical examination, in particular, those patients have been subjected to tests for liver and thyroid function. Up to date there has not been any indication that liver dysfunction, or the alkaline phosphatase level, could have anything to do with root loss - in fact, in the patients so far referred, the only thing which most of them have in common is some form of ectodermal dysplasia.

Patients suffering from Paget's disease and acromegaly usually have an increased alkaline phosphatase level. These patients often exhibit some form of radicular loss. The patients suffering from Paget's disease frequently show root resorption followed by
subsequent hyperoementosis.

Marshall (1935) has suggested that alkaline phosphatase may operate in a reverse manner at a lowered pH. This is mentioned for interest sake only, but speculative, when you consider that the most constant feature of resorption is an inflammatory change. With such a change the pH is lowered. The area is hyperaemic, and hence the level of alkaline phosphatase may be increased locally.

Stafne and Slocumb (1944) do not think that resorption is associated with any particular systemic disease whatsoever.

It is hoped that the liaison with the Medical profession will be greatly increased in the future, and that a large number of cases exhibiting severe idiopathic resorption can be collected, say with the help of the Australian Dental Association, and closely studied both medically and dentally.

Of the cases presented in the literature, very few have been given a thorough medical examination, and it is felt that this sphere, and the sphere of artificial production of liver damage and hence an increased alkaline phosphatase level in small animals should be investigated with the view to the study of root resorption.

**Diet:**

Marshall (1930)(1931)(1932), after extensive work with monkeys, believed root resorption to be due to dietary factors.

Ketcham (1927) also believed diet was the contributory factor.

iii. **Physical:**

**Trauma:** During normal mastication etc. there is movement of the tooth in the socket. Picton (1964) has shown that the tooth is depressed and mesially displaced in its socket. This constant displacement accounts for what is often termed "cemental resorption."
It is physiologically a wear and tear resorption. The fact that the tooth is moved mesially could explain why Henry and Weinmann (1951) discerned more cemental resorption on the mesial than on the distal surface.

An extension of the effects of the forces of mastication is seen most graphically if one or a small group of teeth should be taking a very large share of the masticatory forces. Namely, the tooth or teeth are in traumatogenic occlusion. It is well known, and well accepted that such a tooth or teeth often show radicular and alveolar bone loss, or both. "It is known that trismus of the masticatory musculature may initiate resorption."

Seward (1963) and Sullivan and Jolly (1957) refer to the burrowing resorption of Pedler. As this type of resorption starts in the gingival crevice and often on the buccal aspect, Seward (1963) conjectured that it may be initiated by a blow.

iv. (a) Magnitude of Forces:

Oppenhein (1944) came to the conclusion that application of light forces is correct, and preferable in orthodontics.

Schwarz (1932) stated that the force which produced the most favourable type of tooth movement did not exceed the blood pressure of the capillaries (15-20 mm of Hg) which would be a force of 20-26 grams per sq.cm. of tooth surface. This is experimental evidence, and is based on light spring pressure on premolars of dogs.

Smith and Storey (1952(a)(b)), working on mandibular canines to which were applied springs delivering known forces, found that there was optimal movement when light forces were applied. They found this force to be between 150-250 gms. for the mandibular canine.
With forces less than 150 gms., there was little movement of the canine. When the forces were between 400-600 gms., the canine did not move, but the anchor teeth did. This behaviour is because of the hyalinization of the periodontal space (Reitan (1950)(1951)), the principle of undermining resorption (Sanstedt (1906)), and the area of the roots involved.

Begg (1956)(1961), realised the importance of this behaviour, and devised the principle of "Differential Forces".

The "Optimum Force" varies from patient to patient and from tooth to tooth. It depends on age, sex, general health at the time of movement and the surface area of the tooth or teeth involved, according to Smith and Storey (1952(a)(b)).

Godfrey (1965) has pointed out from the measurements by Jepsen (1963) of root surface areas, that the surface area of the maxillary central, lateral and canine (650 sq. mms) is almost equal to that of the mandibular second premolar and first molar (638 sq. mms.) This is an important clinical observation. It should be noted that force to a tooth is translated into pressure between the root of the tooth and its socket (pressure is force per unit area). It is more correct to speak of an optimum pressure as referred to by Schwarz (1932) earlier.

Reitan (1957)(1960) is clearly of the opinion that excessive force will produce root resorption. He also makes that point that in tipping of a tooth, that it acts as a lever which results in considerable force being applied at the apex. Most orthodontic tooth movement is of a tipping nature. Reitan (1963)(1964) found that very favourable torquing movements of upper first premolars was achieved by a force of 50 gms. Even at this light pressure, minor root resorption was observed.
Johnson (1941)(1947) realised that light force was all that was necessary, and devised a technique using twin wires of eleven thousandths of an inch (.011 in.) In recent years there has been a re-awakening of the principle of the use of light forces. This has given birth, as it were, to various light wire techniques. Such techniques have been devised by Begg (1965) and Jarabak and Fizzell (1963). They use light wire (.014 in. and .016 in.), but it is sometimes doubtful if it is "light force". This is being studied by Lee in Melbourne, and it is to be hoped, by many other researchers as well.

Oppenheim (1944) also stated that intermittent treatment was preferable to continuous treatment. He advised that orthodontic tooth movement should be performed slowly to give time for the compensatory formation of the osteocytes. This allows deposition of osteoid tissue on the traction side, and thereby reduces the possibility of relapse. Oppenheim further stated that only light forces are able to produce an abundance of the primary osteoclasts which alone can be considered the real helpers in the movement of teeth.

Oppenheim (1944), along with Orban (1936), Schwarz (1932), Stuteville (1938), Jarabak and Fizzell (1963), and others, believed excessive forces produced by orthodontic appliances are the main cause of root resorption.

Stuteville (1938) maintained that the much feared injuries which are supposed to be caused by orthodontic appliances are more theoretical than real. It has been shown that "necrotic" areas of the periodontal space will be repaired, and that a resorbed area of the root will be repaired by secondary cementum. However, the bounds of safety can be overstepped, because it has been clearly demonstrated that better treatment results can be obtained by analysing the
orthodontic forces which are used, and giving the supporting tissues time to react to these forces before an appliance is readjusted. The rapid movement of teeth with auxiliary springs causes multiple root resorptions where the springs are active to a distance greater than the thickness of the periodontal membrane, and where the teeth are in occlusion.

These findings are in accord with the observations of Oppenheim that resorption will repair, provided sufficient time elapses between appliance adjustments, and the supporting tissues are allowed to return to normal.

According to Orban (1957), Coolidge measured the periodontal membrane space of a large number of teeth. He found the average width to be 0.21 millimetres. The space is widest at the crest and narrowest near the middle, then wider in the apical region. The force should be active, though less than 0.21 millimetres when the teeth are in occlusion if injuries to the teeth and the supporting tissues are to be avoided.

Stuteville also stated that the forces which act on the tooth due to interference of the inclined planes during mastication are responsible for most of the extensive injuries. These forces are involved in "jiggling" the tooth. Jiggling results when an appliance, such as an auxiliary spring, moves a tooth in one direction and the incline plane of an opposing tooth moves it in the opposite direction whenever the teeth are brought into occlusion.

Oppenheim (1944) stated that once movement is begun, if the correct diagnosis is made there will be no need to change direction - changing direction increases the dangers of root resorption.

Phillips (1954) found that the number of teeth involved and the
degree of tooth involvement can be attributed to the magnitude of the forces during treatment.

(b) Rigidity of Appliance:

Ketcham (1927) believed that immobilisation of the teeth as caused by the appliance was a factor in producing resorption. Jarabak and Fizzell (1963) go further and state that appliance rigidity is a major factor. They then state that this is one of the disadvantages of the edgewise mechanism. The discussion by Jarabak and Fizzell which follows this comment has nothing to do with the rigidity of the appliance. They immediately begin to discuss lingual movement of the roots of the teeth (Torquing), which is in no way connected with appliance rigidity except that, for successful torquing with any fixed appliance, the crowns of the teeth can be held as rigidly as possible. The reason why Jarabak and Fizzell (1963) find and show cases with more root loss during the edgewise mechanism than with the light wire technique, is more likely to be due to the magnitude of the forces involved than simply to appliance rigidity.

(c) Age at Commencement of Therapy:

Rudolph (1940) stated that the incidence of root resorption increases as the age at which treatment is started increases. Massler and Malone (1954) agree with the above statement.

Massler and Perreault (1954) are of the opinion that young adult females show a higher resorptive potential than do young adult males.

Reitan's studies (1954) suggest the importance of age as a factor in root resorption. He stated that it is important to consider the age of animals used for experiments of short duration. He found that it takes a considerably longer period of time before apposition and
and resorptive changes become manifest in older animals. The supporting structures in young dogs usually exhibit an inner bone surface covered by osteoid lines, and cell proliferation starts more readily than in older animals.

The difference in tissue reaction between young and older animals is primarily related to the changes caused by growth in the young animals. On the other hand, decreased growth activity in the older animals could cause a delay in their tissue reactions. Young individuals, aged 11 to 13 years, frequently exhibit a maximal tendency to cell proliferation in the periodontal space. Hence in an interpretation of the findings made from such material, it should be considered that the older individuals may react somewhat differently and could possibly be more susceptible to root resorption.

Phillips (1955) studied a group of 62 whose ages ranged from 10.75 yrs. to 18.5 yrs. (mean age being 13.7 yrs.) They were treated with the edgewise appliance, but he did not find any correlation between the amount of apical root loss and the age of the patient at the inception of treatment.

(d) Duration of Treatment:

Rudolph (1940) clearly demonstrates that the duration of treatment is related to tooth resorption (See Table 3).

Becks (1942), merely states that he does not believe that the duration of treatment is important in the production of root resorption.

Phillips (1955) states the amount of time that the bands were cemented ranged from 5 to 24 months, that is, an average of 12.5 mths. He was unable to show that the duration of treatment was significant in increasing the amount of apical loss.
Jarabak and Fizzell (1963), on the other hand, demonstrated most definitely that resorption does increase with the duration of active treatment.

**Conclusions on Aetiology:**

All men who have studied the problem of root resorption agree that excessive force is probably the main cause of resorption during treatment, but often fail to agree concerning the role of other factors involved in the problem. The length of treatment period, the age at the inception of treatment, the distance the teeth are moved through bone, sex, endocrine imbalance, dietary factors, type of appliance, heredity, etc., are questions which remain and require additional study before their role, if any, in the problem of resorption is determined.

Another area of accord amongst the various investigators is their agreement that the extent of root resorption induced by orthodontic treatment is rarely of clinical significance. On the contrary, the benefits of orthodontics to the dentition and the individual outweigh many times the harm done by root resorption.

The amount of the suspensory apparatus lost is small, as has been shown by Phillips (1955). The functional life of the tooth showing apical root loss is not significantly affected.

**TABLE 5**

Causative factors in radicular resorption listing the Authorities for and against

SEE OVERPAGE
<table>
<thead>
<tr>
<th>Systemic Factors other than Hypothyroidism</th>
<th>Age at Inception of Treatment</th>
<th>Magnitude of Forces</th>
<th>Hypothyroidism</th>
<th>Duration of Treatment</th>
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<td>Against</td>
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MATERIALS, APPARATUS AND METHODS

Materials:

Three adult mandibles were used. They were chosen from a batch of dried specimens because they appeared to be anatomically normal with well formed alveolar processes supporting full complements of natural teeth.

One mandible was used in a pilot study of simulated resorption of single rooted teeth. It was also used to study the effects of changing the horizontal angulation of the central ray to the film, and the effect of artificially producing a hole of known size in the mesial or distal wall of a socket on what is radiographically known as the "lamina dura". It was on the basis of this study that the other mandibles were sectioned, mounted and radiographed with the aid of positioning devices.

Prior to preparing the other mandibles for the various tests, the areas that were to be examined, indicated by the pilot study, were radiographed. By this means the condition and formation of the alveolar bone and the roots of the teeth were determined.

The mandibles chosen were sectioned in the following manner:

The direction of the cut was first marked on the mandible with a grease pencil. The cut was made using a tungsten carbide flat fissure No.1 bur in an air rotor.

Over/...
Fig. 3: showing the mandible, marked with a grease pencil where the cut was to be made.

Specimen 1:

This specimen was prepared to study simulated root resorption. The cut was made bilaterally passing through the sockets of the first premolars. The three sections so formed were then mounted in a radiographic positioning device.

Over/...
Specimen 2:

This specimen was prepared to study what is radiographically interpreted as the "lamina dura". The right canine and the left second premolar were sectioned from this specimen. In sectioning these areas from the specimen, care was taken to section widely, as it was proposed to study the effect of changing the horizontal angulation of the specimen to the central ray. If the section were narrow, then the edges could confuse the subsequent radiographs. These sections were also mounted in a radiographic positioning device.

"Prepared" Specimens:

Other sundry test materials were used:

1. A block of wood in which a half inch hole had been bored using a conventional wood drill. The dimension of the block is $1\frac{3}{4}" \times 1\frac{3}{4}"$.

2. Moulds were made of two brass wedges of varying size with a 50/50 mixture of plaster of paris and sawdust (see Figs. 5 and 6 - wedges). Such a mixture was used because this made the mass more radiolucent and the subsequent film therefore had greater contrast.

The mould was made in the following manner:

a) A cylinder of soft wax of 1" diam. was formed.

b) The respective wedge was luted to a sheet of similar wax.

c) The wax cylinder was placed over the wedge, care being taken that the wedge was in the centre of the cylinder. It was then luted in that position.

d) A vacuum mixture (Whip-Mix) of plaster and sawdust was then vibrated about the wedge.

The soft wax form was used to allow almost free expansion of the mixture on setting. In this way the mixture adjacent to the wedge was not compressed by the setting expansion. This characteristic of setting expansion was verified by Earnshaw (1965). A cylindrical form was
chosen so that, when the mould was rotated on the positioning device and radiographed, there would be relatively the same mass of material surrounding the wedge-shaped cavity.

Fig. 4: Plaster-Sawdust moulds.

Note: They are mounted on a perspex base to which a pointer is attached.

Brass Wedges:

The dimensions of the brass wedges are \( \frac{1}{4}'' \times \frac{1}{4}'' \) and \( \frac{1}{4}'' \times 3/8'' \). These dimensions are at the base of the wedge. Wedge shapes were used for a specific reason, and so were the sizes varied. This will be discussed later.

Over/...
Fig. 5: showing brass wedge $\frac{1}{4}'' \times \frac{1}{4}''$
Fig. 6: showing brass wedge $\frac{1}{4}'' \times \frac{3}{8}''$
4. **A Sheep's Femur**: In which a wedge of bone had been removed from the head of the femur. The wedge of bone was removed at right angles to the long axis of the head (See Figs. 51 and 52).

5. **X-ray Film and Processing:**

Kodak radiatized intra-oral film and Kodak blue band medical x-ray film was used.

The contrast range of Kodak radiatized intra-oral x-ray film was obtained by direct communication with Kodak (Asia) Pty. Ltd., Research Department, Coburg, Victoria - "The contrast of Kodak radiatized dental x-ray film is \(1.8 \pm 0.05\). This contrast is measured between densities 0.5 (above gross fog) and 2.5 (above gross fog.) The contrast quoted is for the film processed for three minutes in KRX at 20°C, but this film is relatively insensitive to small process variations."

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**Processed in KRX at 20°C for 3 minutes**

**Kodak Radiatized Dental Film**

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**Fig. 7:** Density against contrast
Fig. 8: Reflectivity against density at contrast $1.8 \pm 0.05$

**Apparatus:**

Two machines were used in this study:

1. For the study of simulated resorption, a standard Phillips dental x-ray machine was used.

2. For the study of the "lamina dura" a Stanford medical x-ray machine was used.

Both machines were set at 65 kilovolts and 10 milliamperes for the entire study. This was the setting used by Roveda (1964) and is approximately the setting that most dental machines employ, with the exception of the Phillips Oral-X which is set at 50 kilovolts and 7 milliamperes.

The exposures used were determined by trial and error until a
film of good contrast and density was obtained. Using the Phillips x-ray machine for the simulated resorption, the exposure for the lower anteriors was one second, and for the premolars 1.3 seconds. The exposure using the Stanford medical machine at a target-film distance of 12 inches was 1.5 seconds which was the same exposure for both the canine and the premolar.

**Magnifying Lens:**

A large stand magnifier with an aspheric distortionless lens was used to view the films. This lens gives a magnification of X5.

**Viewing Box:**

The source of illumination in the viewing box was provided by a bar-type 20 watt blue fluorescent tube.

**Vertical Drill Press:**

The drill was used to make progressively larger holes in the mesial wall of the right canine socket (See Fig. 35).

**Positioning Devices:**

**Simulated Resorption:** The specimens were set in cold-cure acrylic. The axes of the tooth sockets were set perpendicular. The surface to be set in the acrylic was vaselined so that the specimen could be removed from the acrylic if this should be desired later. Then a film holder for each specimen was prepared from sheet perspex to the dimensions of a Kodak radiatized intra-oral film of adult size and of the child's Kodak radiatized intra-oral film. The adult film-holders were fixed to the posterior specimens so that the film was as close as possible to the lingual of the area being examined. This close adaptation of the film to the area being examined was only possible because
the mandible was sectioned.

It was found, in trying to position the film holder in the intact mandible, that it could not be done without first bending the film holder. This is undesirable. Also this positioning problem was one of the determining factors why the second premolar was chosen to be examined.

Fig. 9: demonstrating the mounting of the right posterior specimen.

Note the perspex film holder
Fig. 10: demonstrating the mounting of the left posterior specimen.

Note the positioning rod

Positioning of the anterior film holder was more difficult, and a compromise was adopted. Because of the curvature of the mandible in the incisor region, the film-holder, and subsequently the film, would have had to be bent to be closely applied to this region. This would be undesirable radiographically, as it would produce distortion of the image. The small film was used in this region for obvious reasons. The sides of the holder were made as thin as practicable in an attempt to place the film as close to the lingual area as possible. It was then fixed in that position.

The position of the film holders can be seen in Figs. 9, 10 and 11, and the position of the tooth, or teeth, in relation to the holder
can be seen in the subsequent roentgenograms.

![Diagram]

Fig. 11: demonstrating the mounting of the anterior specimen

Note: The child's radiatized film was used in this region, and is shown in the film holder.

A device was then constructed and attached to the mounted specimen so that the angulation of the central ray and the target film distance would be constant for all exposures. This was made from \( \frac{1}{8} \)" brazing rod. A piece of brazing rod was heated, flattened and curved so that it could be held in between the cone of the Phillips dental x-ray machine and the housing of the tube. Then to this curved section, a suitably fashioned rod was soldered (See Fig. 11). This straight section was fashioned at one end so as to clear the rolled lip on the back of the cone. This allowed the curved section to fit between the cone and the housing.
The target film distance was then adjusted to 9-inches. In the machine used, the distance from the target to the tip of the cone is 8-inches, so that the specimen was placed with the tip of the cone 1-inch from the film. One inch is approximately the distance of the tip of the cone from the film in clinical practice.

The angulation and the vertical position of the central ray in relation to the specimen was determined by trial and error, until the length of the image was equal to that of the tooth being examined. This comparison was made by direct measurement. The vertical position was found to be most important, and this was clearly demonstrated by the roentgenogram of the premolars. The vertical position was chosen where the image of the buccal and lingual cusps coincided, and the image of the incisal edges of the anteriors were clear-cut. The rod was then fixed to the mounted specimen when these requirements were met.

This device is simple, but it does allow the same exposure to be taken of the same area at the same vertical angulation of the central ray with a reasonable degree of accuracy.

The plaster-sawdust mould was mounted on a perspex disc so that the pointer which was fixed to the disc was at right angles to the base of the wedge (See Fig. 4). The right canine and the left premolar were also mounted on perspex discs of 1-inch diameter using cold cure acrylic. Pointers had been previously attached to these discs and the specimens were mounted so that the centre of the socket was directly over the pivotal point of the disc, and perpendicular.
Fig. 12: showing the right canine and the left premolar mounted on perspex discs. A pointer is attached to the disc. The right canine also shows the position of a heavy spring (see Discussion).

The base on which the specimen was to rotate was made from $\frac{1}{2}$" sheet perspex. A protractor was screwed to the base so that the edge of the protractor was parallel to the edge of the base. A hole was then drilled (which was the same diameter as the wire protruding from the base of the specimen), through the protractor and the base at that point where the $90^\circ$ calibration of the protractor meets its base-line. A film holder was constructed to the size of a Kodak radiatized adult intra-oral film. It was placed $\frac{1}{4}$-inch from the specimen to allow the specimens to be rotated freely. It was realised at the time of placing the film that the further the film was from the specimen, the greater would be the magnification of the image. A $\frac{1}{2}$-inch was the
minimum distance. A wire frame was made so that the slotted box which was to hold the film could be removed easily and repositioned accurately. The holding device was placed so that the film was at right angles to the 90° calibration on the protractor.

The target film distance was fixed at 12-inches, that is, the distance from the focal spot on the Stanford medical x-ray machine to the film. This greater target film distance was chosen to gain the benefits of the long cone technique. This distance was fixed by attaching two ½" brazing rods to the base. The rods were arranged so that the device could be placed in the same position in relation to the tube of the machine, and hence the position of the film was the same throughout the entire study.

Fig. 13: showing the plaster-sawdust mould and device in position in relation to the tube
Fig. 14: showing the lower left premolar and the device in position in relation to the tube. (This device allowed the specimen to be rotated a known amount in relation to the film and the source of radiation.)
Fig. 15: The specimen is at $90^\circ$ to the film as shown by the pointer.

Note: The photo was taken at an angle, and this gives the appearance of the tooth being off centre in relation to the pointer.
Fig. 16: Indicating the specimen rotated at 80°.
Fig. 17: Indicating the specimen rotated at 70°.
Method:

Simulated Resorption - In Vitro:

1. Using the positioning device the lower anteriors and right and left premolars were radiographed.

2. Areas of simulated resorption were formed in the lower anteriors by the use of a No. 1/2 round bur and a No. 1 round bur, and in the premolars by etching the surface with hydrochloric acid. The method of controlling the depth of cut of the bur was by holding the specimen flat, and the bur was held parallel to the surface being cut. In this way the shaft acted as the stop. (See diagram below).

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The acid etching was done by first completely coating the root of the tooth in wax. The wax was then removed from the area to be etched, and the root placed in the acid. Etching with acid produces an area of resorption with a similar macroscopic appearance to that of natural resorption. The coronal areas were etched for one hour, and the apical areas for 45 minutes. The positions of the areas of simulated resorptions were carefully chosen. Figs. 18 to 34 show where these areas are located.
Fig. 18: Indicating the positions where areas were placed in the central incisors. This will be seen better in the photographs of the individual teeth.
Fig. 19: Lingual of lower right central incisor. Area of loss produced by No. 4 round bur.
Fig. 20: Labial of lower right central incisor
Fig. 21: Mesial of lower right central incisor. Areas of loss produced by No. ¼ round bur
Fig. 22: Distal of lower right central incisor. Area of loss produced by No. ½ round bur
Fig. 23: Lingual of lower left central incisor. Area of loss produced by No. 1 round bur
Fig. 24: Labial of lower left central incisor
Fig. 25: Mesial of lower left central incisor. Area of loss produced by No. 1 round bur.
Fig. 26: Distal of lower left central incisor. Areas of loss produced by No. 1 round bur
Fig. 27: Mesial of lower right lateral incisor.
Area of loss produced by No. 1/2 round bur
Fig. 28: Mesial of lower left lateral incisor.
Area of loss produced by No.1 round bur
Fig. 29: Lingual of lower right second premolar. Areas of loss produced by etching.
Fig. 30: Distal of lower right second premolar. Areas of loss produced by etching on the lingual aspect are visible.
Fig. 31: Lingual of lower left second premolar. Areas of loss produced by etching on the distal are visible.
Fig. 32: Buccal of lower left second premolar. Areas of loss produced by etching on the mesial are visible.
Fig. 33: Mesial of lower left second premolar. Areas of loss produced by etching.
Fig. 34: Distal of lower left second premolar. Areas of loss produced by etching.

Note: The areas are positioned in what was thought to be the tangential area (see Discussion)
The centrals and the premolars are radiographed, both labio-lingually and mesio-distally.

The teeth were then replaced in the dried specimen and radiographs taken using the same exposure as previously. The fact that the same exposure was used is important, as this gives radiographs of similar densities which can then be compared. Radiographs of dissimilar densities cannot be compared, as was shown by Degering (1962)(1964).

**In Vivo:**

Lower first molars and lower premolars that were to be extracted were radiographed. The extraction was performed. The root of the extracted tooth was then drilled in a similar manner as were those of the lower anteriors in the dried specimen. This was done under sterile conditions.

The positions of the small holes can be seen in Figs. 42 and 44 to 47. The extracted tooth was then placed back in the socket and radiographed using the same exposure. This portion of the investigation was undertaken at Boys' Town, Engadine.

**Lamina Dura (in vitro):**

A block of wood with a 1/2-inch hole was radiographed.

The wedge-shaped cavity in the plaster-sawdust mould was radiographed at different horizontal angulations to the film.

The femur of a sheep was radiographed, both before and after a wedge of bone was removed from the head of the femur (see Figs. 51 and 52).

The specimen of the lower right canine was radiographed at different horizontal angulations to the film, with and without the
canine in the socket (see Figs. 54 and 53).

The specimen of the lower left premolar was radiographed at different horizontal angulations to the film, with and without the premolar in the socket (See Figs. 56 and 55).

The lower right canine socket was radiographed, in which progressively larger bur holes had been made in the mesial wall of the socket (with and without the canine in place (See Figs. 58 to 61).

To overcome the problem of access and the depth to which the hole was made, it was decided to approach the mesial wall of the canine through the lateral socket, or at least what was the lateral socket. The distal wall of the lateral socket was removed exposing the mesial wall of the canine socket. Central trabeculae which were attached to the wall of the canine socket were also removed. A stone key was made for the specimen, from which the specimen could be removed and repositioned accurately. This key was positioned in a vertical drill press, as shown in Fig. 35. A series of progressively larger holes were made, and subsequently radiographed at each stage.
Fig. 35: Showing right canine socket in the vertical drill press.

Through the hole in the mesial wall of the canine socket, a strong spring was fashioned to hold the canine hard up against the distal wall of the socket. The specimen so prepared was radiographed at varying horizontal angulations of the specimen to the film.
Fig. 36: The lower canine can be seen mounted on the positioning device with the spring actively holding the canine against the distal wall of the socket.

Progressively larger holes were made in the distal wall of the lower right first premolar socket. Radiographs were taken at each stage using the same exposure as was used previously.

The gingival break was begun with a No. 1 flat fissure bur, and the size progressively increased until a No. 7 flat fissure bur was used. The apical break was made beginning with a No. ½ flat fissure bur and continued until a No. 6 flat fissure bur was used.
Fig. 37: Indicating the distal wall of the lower right first premolar.

Note: It is cribriform nature.
RESULTS

Simulated Resorption (in vitro):

Radiographs were taken of the lower centrals and premolars removed from the specimens.

Fig. 38: Radiographs of prepared lower central incisors. (The left incisor with areas prepared by No. 1 round bur are uppermost in the figure. This print is disappointing, as the areas are not as clear as they are in the radiographs).

Lower Right Central:

Labio-Lingual View: All areas which were produced with the No. ½ round bur are visible. The area on the mesial appears to be incorporated in the tooth. This is because of the position and shape of the tooth.

Mesio-Distal View: Only the area on the lingual is visible.
Lower Left Central:

Labio-Lingual View: All areas which were produced with the No.1 round bur are visible.
Mesio-Distal View: Only the area on the lingual is visible.

Fig. 39: Radiographs of prepared lower second premolars. (The left premolar is uppermost in the figure).

Lower Right Premolar:

Labio-Lingual View: The lingual areas are not visible.
Mesio-Distal View: The lingual areas are visible.

Lower Left Premolar:

Labio-Lingual View: All areas are visible.
Mesio-Distal View: All areas are visible (they are visible as shadows).
Fig. 40: Radiographs of lower incisors and premolars in situ before preparation.
Fig. 41: Radiographs of lower incisors and premolars in situ after preparation

Lower Right Central Incisor:
The mesio-apical area is slightly visible, as seen in Fig. 41. The mesio-gingival and disto-central areas are not visible.

Lower Left Central Incisor:
The disto-apical and the mesio-central areas are visible. The disto-gingival area is not visible (see Fig. 41).

Lower Right Lateral Incisor:
Mesio-central area is not visible

Lower Left Lateral Incisor:
Mesio-centro-lingual area is not visible
Lower Right Premolar:

The lingual areas are not visible

Lower Left Premolar:

The mesio-gingival area is visible. The mesio-apical, disto-gingival and disto-apical areas are not visible. This radiograph may be confusing because of the trabecular pattern. The before and after radiographs must be studied very closely.

Lower Right First Molar: Simulated Resorption (In Vivo)

Distal Root: The No.1 round bur hole is visible. This bur hole is larger than those made previously. It was made at right angles to the surface, and is the depth of the whole head of the bur.

Fig. 42: Distal of the distal root of the lower right first molar.

Note: There appears to be two prepared areas. There is only one, in a gingivo-lingual position.
Fig. 43: Radiographs of the lower right first molar both before and after preparation (See Fig. 42). The prepared area can be seen.

Note: There is a slight shadow showing on the distal root in the pre-extraction radiograph.

Lower left first Premolar:

This tooth was rotated, as can be seen from the radiograph.

Using a No.1 round bur the areas were prepared, as described in the Method. They are not visible in the radiograph.
Fig. 44: Mesial of lower left first premolar, indicating prepared area.
Fig. 45: Distal of lower left first premolar indicating prepared area.
Lower Right First Premolar:

This tooth was rotated, but the No. 1 round bur holes gingivally, and the No. \( \frac{1}{2} \) round bur holes apically, as shown in Figs. 46 and 47, were positioned to be tangential to the central ray. These areas are not visible in the radiograph.

Fig. 46: Mesial of lower right first premolar indicating prepared areas.
Fig. 47: Distal of lower right first premolar indicating prepared areas.
Fig. 48: Radiographs of lower left and right first premolars, both before and after preparation. Pre-extraction radiographs are uppermost in this Fig. The prepared areas, as shown in Figs. 44, 45, 46 and 47 are not visible in the radiographs.
Lamina Dura (in vitro):

Photographs for each section of the study will be presented, and the subsequent results given for each.

Fig. 49: Radiograph of a piece of wood. Note the outline of the cavity.
In Fig. 49, the cavity is surrounded by a white line. This is the "Mackie Line" produced by what is known as the "Eberhard Effect", or more recently, it is known as the "Adjacency Effect" or "Edge Effect". The production of this line and its significance in relation to the 'lamina dura' will be considered in the Discussion.

Fig. 50: Serial radiographs of a plaster-sawdust mould of a wedge-shaped cavity (at various angulations). Starting at the top left-hand corner of the figure, the angulations are: 0, 5, 10, 20, 30, 40, 45, 50, 60, 70, 80, 87.5 and 90 degrees.
It can be seen that there is a Mackie Line effect in 0, 87.5 and 90 degrees. With a change of 5 degrees, the margin of the cavity begins to become blurred and continues to become progressively blurred until the form of the cavity is completely lost at 40, 45 and 50 degrees.

The form slowly returns, and the margins are sharp again at 87.5 and 90 degrees (this shows that a change of 2.5 degrees does not produce blurring of the margins).

From 45 degrees and up, the rays are passing through the tapering view of the cavity. This fact is noticed from the blurring of the cavity at the base of the wedge, hence it can be said that there is a minimum width of the cavity which will give a clear image on the film.

The above observations will be related to the 'lamina dura' in the Discussion.

The variation in the sizes of the wedges used did not change the results obtained. The above series is for the larger wedge.

Over/...
Fig. 51: Radiograph of the head of the sheep's femur
Fig. 52: Radiograph of the head of the femur from which a wedge of bone was removed. The central ray was directed tangentially to the margins of the wedge.

There is a 'Mackie Line Effect' around the edge of the removed wedge of bone. This effect is clearer in the radiograph. (Note: These radiographs were taken at the same exposure, and the difference in contrast is due to the processing of the print. The "Mackie Line Effect" will be considered later).
Fig. 53: Demonstrating the effect of rotating the lower right canine socket in relation to the film. Top left hand corner - 90, 87.5, 85, 82.5, 80, 77.5 and 70 degrees.
Fig. 54: Demonstrating the effect of rotating the lower right canine in situ in relation to the film. Top left hand corner - 90, 87.5, 85, 82.5, 80 and 75 degrees (77.5 degrees was not used in this series).

The serial radiographs of the socket demonstrates most clearly the effect of changed horizontal angulation on the 'lamina dura'.

The canine was studied, as this tooth is wide labio-lingually, and it was thought that because of this feature the effects of changing the horizontal angulation would be seen more clearly. This line of thought was proved correct. This particular canine was grooved longitudinally on its distal surface; consequently the distal of the socket was elevated to correspond.
In the 90° view the 'lamina dura' of the distal wall of the socket is represented by what may be termed a 'double lamina dura'. It fuses approximately 3/4 of the way down the socket. The mesial of the specimen was rotated to the tube. A change of 2.5° produced what appears to be a thickening of the mesial 'lamina dura' and a spacing of the double portion of the distal 'lamina dura'. The apical region became clearer. This is because the root of the tooth in question is slightly bent to the distal. By rotating the specimen the rays are able to pass tangentially (particularly to the mesial apical region) to this region. There was a slight degree of blurring of the image at this angulation.

The blurred, thickening of the mesial wall continued as well as increased spacing of the 'double lamina dura' of the distal wall at the beginning, with progressive rotation of the specimen. At a rotation of 7.5° the double appearance of the distal wall broke just before the double image gave way to one in the apical region. This break is only slight, but at 10° rotation it is quite definite. Also at 10° rotation the image of the mesial wall is very blurred, and bears no resemblance to that at 0°. This picture becomes progressively worse in the subsequent radiographs.

The critical rotation for a break in the 'lamina dura' to appear, is between a change of 7.5 to 10° in horizontal angulation, and for blurring and other associated changes, 2.5°.
With the tooth in position, the following changes were observed:

At 90° the mesial 'lamina dura' is clearly defined, except apically, where it becomes slightly indistinct but still traceable. The distal 'lamina dura' is still double, but that portion nearest the tooth is very dense. This illusion is produced by the slight elevations of the tooth being projected on the film, that is, the tooth fills the space between the two arms of what was referred to as a 'double lamina dura'.

A rotation of 2.5° slightly increased the thickness of the mesial image, and the apical region became more readily discernable (See Fig. 53). The interesting feature of this view, was the apparent increase in both width and density of the arms of the 'double lamina dura' nearest to the tooth. With a 5° rotation, the distal picture was further accentuated, the apical region was not as clear. Mesially the apparent thickening progresses still further, and the 'lamina dura' appears to merge with the tooth. At rotation 7.5° the mesial image has almost united with the image of the tooth, and the apparent distal thickening continues. This view is clinically useless, and so are the remaining radiographs. The apparent distal thickening of the 'lamina dura' could be mistaken for bone deposition in an orthodontic patient, and this, and other points will be dealt with in the Discussion.

Over/...
Fig. 55: Demonstrating the effect of rotating the lower left second premolar in relation to the film. Top left hand corner - 90, 87.5, 85, 82.5, 80, 77.5 and 75 degrees.
Fig. 56: Demonstrating the effect of rotating the lower left second premolar in situ in relation to the film - Top left hand corner: 90, 87.5, 85, 82.5, 80, 77.5 and 75 degrees

The position and presence of the mental foramen is obvious. Its image becomes distorted with rotation. The 'lamina dura' of this root shows changes with rotation, but less graphically than that shown by the lower canine. This is a function of root shape. Note also that the image of the 'lamina dura' is much more obvious in the radiographs of the socket. The tooth has a masking effect.

The socket series shows that with rotation of 2.5 and 5°, the image is becoming blurred, but is still clearly discernable. At
rotation $7.5^\circ$ the mesial 'lamina dura' is not only more blurred, but has lost its form. This process of blurring and distortion continues, and the remaining radiographs could not be considered diagnostic.

The series with the second premolar in situ shows that at rotation $7.5^\circ$, the mesial lamina dura is distorted beyond recognition, and at $10^\circ$ rotation all resemblance of same has completely disappeared. That is to say, a radiograph taken with a central ray $7.5^\circ$ from the perpendicular to this tooth is of doubtful diagnostic value, and at $10^\circ$ is of no use whatsoever.

Fig. 57: Indicating the canine socket after the distal wall of the lateral socket had been removed, and also some of the 'central trabeculae' which were attached to the mesial wall of the canine socket.
If this figure is very closely studied and compared with Fig. 53, it will be observed that the trabecular pattern as shown in both radiographs is unaltered. There is an area of increased radiolucence in the region of the mesial wall of the canine. This confirms the claims made by Roveda (1964), Ramadan and Mitchell (1962) and Bender and Seltzer (1961a,b) that the trabecular pattern, as shown in a radiograph, is not the function of the 'central trabeculae' but the 'junctional trabeculae'. (Junctional trabeculae are those which are joined to the cortical layer of bone).

The following is a series which shows the canine socket where the mesial wall has been drilled by progressively larger flat fissure burs. They are of the canine socket with the bur in place, of the socket, and of the socket with the tooth in situ.

Fig. 58: Indicating the use of No. ½ and No. 1 Flat Fissure Burs.
Fig. 59: Indicating the use of No. 2 and No. 3 Flat Fissure Burs

Fig. 60: Indicating the use of No. 4 and No. 5 flat Fissure Burs.
Fig. 61: Indicating the use of No. 6 Flat Fissure Bur

With the hole produced by No. $\frac{1}{2}$ bur, there is no break in the mesial 'lamina dura' except for the vaguest suggestion in the radiograph of the socket alone. Using a No. 1 bur, there appears to be a slight break in both the radiographs. The break is clearer in the radiograph with the tooth in situ. The break is also fairly clearly seen in both radiographs where the No. 2 bur had been used. With a No. 3 bur, the break begins to become blurred and less definite in both radiographs. This process of blurring, and of the break becoming less definite, continues with the use of No. 4 and No. 5 burs. In fact, the break made by the No. 1 bur is more definite than that made when a No. 5 bur was used. Both breaks appear to be of similar size. Using the No. 6 bur, the break in the 'lamina dura' is not any more evident than that produced with the No. 5 bur.
(Compare this to the radiograph before drilling was started).

It was thought that this interpretation was probably extremely subjective, so to check, a number of examiners were shown the radiographs and the procedure explained. They were asked to point out the breaks in the mesial 'lamina dura'. Their interpretations varied, but not widely; in general, they were of the opinion that no break could be seen at all, but that the area was slightly more radiolucent.

Fig. 62 - See overpage
Fig. 62: This indicates the distal wall of the socket of the lower right first premolar intact (top left hand corner). The series moves from left to right. Top right hand radiograph, gingival hole produced by No. 1 flat fissure bur, and apical by No. 2½ flat fissure bur and continuing until the holes were made in the lower right hand radiograph using No. 7 and No. 6 flat fissure burs respectively.
The radiograph of the distal wall of the lower right first premolar in which holes were made by No. 1 and No. 2 burs do not show as a break in the lamina dura. All other radiographs do show a decrease in density in the 'lamina dura' where the holes were positioned. The important thing to notice is that with increasingly larger holes, that the radiograph does not demonstrate an increasingly clearer picture. The break does increase in size, but not markedly. Also, the break in the 'lamina dura', as produced by burs Nos. 4 and 3, is as evident as the break observed when burs Nos. 7 and 6 were used.

It should be noted that the hole (No. 6) in the apical region was almost as wide as the socket wall in which it was cut.

In all of these breaks there is a white line of uniform density (see last apical break produced by flat fissure No. 6 bur) and it is conjectured that this white line is a product, to some extent, of the 'Eberhard Effect'. (See Discussion).

Figure 36 demonstrates the device for checking the effect of apposition of the tooth to one of the bony walls of its socket. The spring is very heavy, as can be seen, and is delivering a force of one pound. The force is of little importance. All that the spring was intended to do was to hold the distal of the canine hard up against the distal wall of the socket, which it did.

Over/...
Fig. 63: A series of radiographs taken of the preparation, as shown in Fig. 36.

Before considering this series, compare the radiograph at 90° of the lower right canine which has been shown and described previously. It will be seen that the 'double lamina dura' effect is almost completely masked because of the close apposition of the tooth to the socket. The mesial 'lamina dura' is accentuated by the increased width of the periodontal space on the mesial (greater contrast). A rotation of 5° to the mesial increases the thickness of the mesial 'lamina dura' which encroaches upon the periodontal space. It is also blurred.

Distally, because of the shape of the tooth, rotation and
proximity of the tooth to the distal wall, it could be said that bone had been deposited on the distal (if this were seen clinically).

There is one 'lamina dura', one periodontal space, not an old and a new, that could be read into this radiograph. This specimen was rotated distally 5° and the effect was the reverse of the above.

The interesting feature of the radiograph at 10° rotation is the thickening of the mesial 'lamina dura'. It appears to touch the tooth, and this could be mistaken for apparent bone deposition. Distally, the trend that was described at 5° continues. The radiograph is blurred. 15° rotation is just a continuation of 10°, but is very blurred.

**FINDINGS**

**Simulated Resorption:**

1. The areas produced using the No.1/2 round bur in the dried specimen cannot be detected.

2. The areas produced using the No.1 round bur in the dried specimen can be detected.

3. The areas produced using the No.1 round bur in vivo cannot be detected.

4. The position of small resorption areas (cemental) are critical in relation to the projection of their image.

5. The correlation of histological resorption with radiographic resorption (cemental) appears to be non-existent.

Over...
Lamina Dura:

1. It is not an artifact. The lamina dura is the image produced on the film by the rays that pass tangentially through the mesial and distal walls of the socket.

2. The socket wall is cribiform, particularly in the molar region.

3. A change of 2.5° of the horizontal angulation (that is, from 90° to the specimen by the central ray) will produce distortion of the lamina dura.

4. A change of 7.5° of the horizontal angulation (that is, from 90° to the specimen by the central ray) will produce an image of the lamina dura that is not diagnostic.

5. The 'Eberhard Effect' does contribute to the production of the lamina dura.

6. A lack of continuity of the socket wall (in vitro), as produced by No. \( \frac{1}{2} \) and No. 1 flat fissure burs did not cause a detectable break in the lamina dura.

7. A lack of continuity of the socket wall (in vitro), as produced by Nos. 2, 3, 4, 5, 6 and 7 flat fissure burs were detectable, but as the size of the bur increased, the lack of continuity of the lamina dura did not increase progressively, demonstrating that the radiograph underestimates the condition.

Over/...
DISCUSSION

Before considering the various features that have been studied and their application, it is fitting we pause and reconsider the criteria proposed by Massler and Malone (1954) (see pages 19 and 20) and by Carpol (1961) (see page 22).

The features that will receive detailed examination arising from these criteria, are, broadly:

1. Root resorption (loss) as seen radiographically
2. "Lamina Dura" and its relation to root resorption.

1. Root Resorption (Loss) as seen Radiographically:

With the interpretation of any radiograph, certain general questions should be given careful consideration, as applied to the detection of root resorptions. Some of the questions are:

(a) What technique was used to produce the radiograph?
(b) Can this technique be reproduced exactly? (Serial Radiographs)
(c) Are there any previous radiographs produced by the same technique for comparison?
(d) Why were the radiographs taken?
(e) What is the age of the patient?
(f) How important is the anatomy of the tooth and bone to interpretation?
(g) Are there any local or general pathological conditions that may be of importance?

(a) Two techniques are mainly used today, namely, the short cone technique and the long cone technique. The short cone technique is by far the most popular.

Both the long and short cone techniques have advantages and
disadvantages. The short cone technique has the advantage of being simple and easy to use, but it has the disadvantage of producing an image that is usually distorted in length, width, or in both. It is most difficult to produce an image of exact anatomical dimensions. This was experienced in the study on simulated resorption, and accurate dimensions had to be achieved by trial and error (See Method, page 53). The important factors in the production of true length are the vertical angulation (see any standard text) and the vertical placement of the cone of the machine. This will be considered when dealing with the more specific details of interpretation. The long cone technique is cumbersome to use, but this technique does produce an image that will be nearer the true dimensions of the tooth being examined. This is the technique that is advocated for the assessment of root loss. McCormack (1954) has produced a long extension device instead of the long cone, which has simplified the use of this technique.

The two techniques that have been mentioned as the most common methods in the production of intra-oral radiographs cannot be exactly reproduced. It is impossible to replace the tube in exactly the same positions. The position of the patient's head will vary, and so will the position of the film. A method that could be employed to partly overcome these inherent errors, would be the use of a combined orientating device for film, x-ray tube and patient's head. This would not be a practicable proposition. Fanning (1962) must have realised the inherent difficulties involved, and she used lateral cephalometric radiographs for
the assessment of root loss in mandibular deciduous molars in relation to caries, taken at six-monthly intervals. In this way, and only in this way can true serial radiographs be produced. This method could be used for detection of root loss in mandibular premolars and molars, but it could not be used successfully with the incisors. Phillips (1955) tried, but unsuccessfully. This is a pity as it is the incisors which need to be assessed most critically (see Table 2). The difficulties have to be accepted and borne in mind when comparing serial intra-oral radiographs.

Note: Massler and Malone (1954) used radiographs from routine full-mouth examinations taken by the short cone technique. They make the extravagant claim in their criteria to be able to detect a loss in root length of 1-2 mm. With radiographic distortion, which is an inherent fault of the technique they used, no man can consistently make such fine judgments in length.

For the assessment of apical root loss, previous radiographs are essential. This was pointed out by Marshall (1935), and is only common sense, because by looking at one radiograph and observing a smooth, blunted root, the examiner cannot say if the root is resorbed or whether this is the normal form of the root end. There are some additional observations that may be made. The periodontal space may be unduly wide in the apical region. The measurements given by Orban (1957(a)), (quoting the work of Coolidge) are interesting. They are:

At ages 11 to 16 years 0.24 mm;
32 to 50 years 0.19 mm;
51 to 67 years 0.16 mm.

The function of the particular tooth must be known; as the periodontal space increases in width with function.
Worth (1963) makes this point - "...if there is a dark space between the existing apex and the bone, it is probable that infection is present." He does not say that it is probable that the root is resorbed, but does say that there is usually an associated osteitis.

The increased width of the periodontal space periapically was accepted by Massler and Malone (1954) and Darpol (1961) as evidence of resorption. The other observations that the examiner may make are associated with the form of the root end and the appearance of the pulp canal. These features will be dealt with when considering apical root loss.

When comparing one tooth with another in serial radiographs, it is good practice to measure the crown of one tooth and compare this measurement with the crown of the other tooth. This was suggested by McLaughlin (1964). This does not necessarily mean that roots will be of the same length if the measurements of the crown should coincide, but it is reasonable to assume that the difference in length of the roots will be minimal.

All the surveys to date have used radiographs taken as routine full-mouth examinations. Massler and Malone (1954) state: "In every instance, each tooth root was examined in two films and, therefore, from two different views". They do not mention what system of angulations they used. With this in mind, consider the views and the angulations used in making the fullest possible full-mouth radiographic examination.

Twenty periapical and four bitewing radiographs would be used. The areas are usually divided as follows:
(d) | Area                          | Vertical Angulation |
---|-------------------------------|---------------------|
Maxilla:  
Third and Second Molars       | + 20° to + 25°        |
First Molars                   | + 30° to + 35°        |
Premolars                      | + 30° to + 35°        |
Canine                         | + 40° to + 45°        |
Lateral Incisors               | + 40° to + 45°        |
Central Incisors               | + 40° to + 45°        |
Mandible:  
Third and Second Molars       | + 5° to 0°            |
First Molar and Premolars      | - 10°                 |
Canine                         | - 15° to - 20°        |
Lower Incisors                 | - 15° to - 20°        |

It can be seen from studying the above angulations, as proposed by McCall and Wald (1957) that there is a 5° variation within the various groups. Such a variation must produce different lengths of the image. The comparison made by Massler and Malone (1954) of the two different views cannot be very accurate; at least not to the order of accuracy that their criteria would demand, because the vertical angulation would vary, so would the horizontal angulation, the position of the patient's head, etc.

For the study of root resorption, each tooth should be exposed separately, and the length of the crown compared to the length of the crown on the film. The teeth should also be in proper alignment. For example, when exposing the maxillary central and lateral incisors, different vertical angulations should be made as the root of the lateral incisor is often not in the same plane as the central incisor. This will also apply to any
irregular teeth, and it is for this reason that they should be eliminated from a study of root resorption.

The age of the patient must be known. The age changes in the periodontal space have been described. The patient must be of such an age that the teeth that are to be examined for resorption must have fully formed apices. The period of time between radiographic examinations should be known. The serial cephalometric radiographs taken six-monthly, as used by Fanning (1962), were ideal in this regard. In this way, the progress of any condition can be followed, or the appearance of any new condition noted.

It must always be remembered when interpreting an intra-oral radiograph that this is a two dimensional view of a three dimensional object. Therefore, in the roentgenographic assessment of resorption, the study must be limited to single-rooted teeth (an exception may be made for the lower first molar.) Ketcham (1927)(1929), Carpol (1961), and McLaughlin (1964) made this observation, and the last two limited their study to single-rooted teeth.

Massler and Malone (1954) assessed everything except the third molars; Becks, Phillips and others, similarly. This fact alone makes the value of their studies questionable.

The structure of the surrounding bone may, and sometimes does, interfere with interpretation. Massler and Malone (1954) in their criteria have a questionable resorption (which was added into the final result). "Resorption questionable. Root outline intact but there appear to be minute areas of spotty resorption. Lamina dura is interrupted and the periodontal
membrane widened." They do not enlarge on what they mean by "Spotty Resorption". It is thought, and by careful examination of Fig. 1 in their article, that this appearance is produced by the trabeculae of the overlying bone.

Fig. 64: The apex of the upper right canine shows what could be called "spotty resorption". This tooth should be scored as not diagnostic.

It was demonstrated in the study of the interruption of the "lamina dura" that the trabecular pattern, as seen in a radiograph, is due to the 'junctional trabeculae' - that is, those trabeculae of the spongiosa adjoining the cortical bone. Depressions in the cortical bone produced radiolucent areas which may be associated with the root of a tooth. This is not common, but it is sometimes seen in the radiograph of the maxillary canine.
Fig. 65: showing such a radiolucent area associated with the apex of the canine. Also, the 'lamina dura' cannot be seen (Worth).

This may be confused with infection. The canine may have such a small girth apically that the 'lamina dura' is not formed. This will be discussed later. Such a radiograph is not diagnostic.

There are other normal anatomical structures that must be given careful consideration in the interpretation of all radiographs, and these features are thoroughly dealt with in the various radiographic texts.

(g) All teeth that have associated pathology, for example, cysts, infections, gross caries and root filled teeth, etc., should not
(g) be scored in any survey of root resorption. Patients having any diseases that may have any bearing on root resorption, for example, thyroidal dysfunction, Paget's disease, Acromegaly, etc., should not be used in any survey.

Having dealt with the general considerations, and before dealing with the more specific applications of the results, it is fitting to spend a short time considering the production of the image of the tooth on the radiograph. It has been mentioned previously that we are taking a two dimensional picture of a three dimensional object. This cannot be stressed too much. The angulations, both vertical and horizontal, and the positioning of the tube, are critical for the production of an image of true dimensions. All radiographic texts make much of the vertical angulation, but little is said of the horizontal angulation except to say that the central ray should strike the transverse axis of the tooth or the segmental area at right angles.

Blackman and Poyton (1963) make this point - "To overcome distortion it is important to check that the x-ray beam strikes the transverse axis of the tooth or segmental area at right angles (Fig. 67). This will minimise the widening or narrowing of the tooth shadow and prevent overlapping of the shadows of the crowns and roots of adjoining teeth." This is true, but the horizontal angulation is much more critical and more important than just to prevent overlapping of the roots or of the crowns. Such a radiograph is useless. The appearance of the "lamina dura" is a better guide than the overlapping of the crowns or roots.
(g) It was shown earlier that a change of $2.5^\circ$ is enough to produce distortion of the "lamina dura" and a change of $10^\circ$ enough to render its appearance quite useless. It is to the "lamina dura" that we should look to assess the horizontal angulation. If the "lamina dura" is clearly shown, then it can be conjectured that the width of the tooth is probably properly projected onto the film. This picture would only be produced with an x-ray beam directed tangentially to the socket wall.

Specific Detection of Resorption:

In this section, it is intended to apply the results of the simulated resorption tests to the appearance of resorption as it would be seen clinically. A tooth may resorb in any one, or more of up to five positions, namely - apically (this position often involves all five surfaces at one time); mesially; distally; buccally or labially, and lingually. The discussion of the detection will deal with:

1. Apical loss
2. Mesial and distal loss
3. Labial or buccal and lingual loss.

i. Apical Loss:

It is important to observe two features of the tooth being examined:

(a) **The shape of the apex:**

A normal apex of a tooth is convex, but there is nothing to stop the apex of a tooth being any shape it chooses. Often with resorption the root is blunted, as has been referred to by all the authors, and is shown in Fig.2. It may be
i. (a) **Apical Loss**: (Contd.)

conca ve, shelved, eroded circumferentially or even scalloped. These last two appearances are shown in Fig. 1. Usually the more irregular its shape, the more rapid is the process of resorption. The amount of apex missing may vary from substantial loss to only very slight loss. It is the very slight loss that is difficult to detect, and its appearance in the radiograph will depend entirely on its position in relation to the tangentially passing rays, or in relation to the amount of apex remaining if its position be such that it is not outlined by the tangential rays. It must also be remembered that the No.1 round bur hole which was placed tangentially to the central ray was not detectable in the repositioned lower first premolars, but it was in the distal root of the lower first molar.

(b) **The Root Canal**:

Worth (1963) has said that it is rare to see the end of the root canal (apical foramen) in the radiographs of teeth with completed roots. In resorption the canal and the actual foramen can be seen clearly. Also observe if the walls of the canal diverge or converge to the apex. If they diverge, then the root is not fully formed; if they converge it is fully formed.

Becks (1936) stated - "Since it is difficult in many instances to determine roentgenographically whether the peculiar appearance of a root end is the result of a resorptive activity or of a development deficiency..." This difficulty is overcome to a large degree by making the above
(b) The Root Canal (Contd.)

observations.

With these criteria, it is possible to distinguish between
(1) teeth which normally have short blunted roots;
(2) teeth which have resorbed and have blunted roots;
(3) teeth that have not fully formed, or whose development
    has been interrupted
(4) teeth which have just been foreshortened by the
    angulation.

In general, it may be said that the apex of a resorbed
tooth is blunted, but the root canal diverges to the apical
foramen. This is clearly seen. Note the width of the
periodontal space; nor is the interruption of the 'lamina
dura' diagnostic of apical loss, but the appearance of the
apex of the root is.

If the apical condition should be doubtful, and if all
the examiner is trying to determine is whether the apex
is resorbed or not, then elongate the image intentionally
and this will accentuate the condition.

ii. Mesial and Distal Loss:

From the results, it has been demonstrated that the appearance
of either mesial or distal resorption is dependant on:
(1) The position of loss
(2) The cross-sectional shape of the root
(3) The amount of loss
(4) The rotation of the socket
(5) The angulation of the central ray, particularly the
    horizontal angulation.
ii. **Mesial and Distal Loss** (Contd.)

All these factors are related. The appearance of an area of resorption in the image is the result of the interplay between these factors. The factors will be discussed separately, but they cannot be divorced from each other.

(1) The Position of Loss:

It is believed, as stated previously, that the outline of the image of the tooth is produced by the rays that pass tangentially to the tooth. This is the critical area in which an area of resorption must be if it is to be clearly projected on to the film. This critical area could generally be said to be the area of greatest convexity of the root. These points are substantiated by the results.

The radiograph of the lower right central shows that because of the position of the mesial area which was not in the area of greatest convexity (tangential area), and because it was protected, as it were, by a very slight amount of tooth structure, then this area showed as a small radiolucent area in the tooth (See Fig. 38). This is a No. ½ round bur hole.

The tangential effect is demonstrated yet again in the radiograph of the lower left central (round No. 1 bur) in situ, when considering the appearance of the mesio-central area. This area also appears to be incorporated in the tooth. The same reasoning applies as for the preceding example.

(2) The Cross-Sectional Shape of the Root:

It follows from the preceding discussion of the position of loss that the shape is important. If the central incisors considered had not tapered in a labio-lingual direction (from
(2) The Cross-Sectional Shape of the Root (Contd.)

the labial), and had parallel mesial and distal surfaces, then the areas of resorption would have appeared in the outline of the image. The shapes of the roots of teeth vary from patient to patient and from tooth to tooth within the same patient. It may be said that teeth do exhibit a characteristic shape, for example, the mesial root of the lower first molar is often dumb-bell shaped, the upper lateral incisor is roughly conical, but the apex is often hooked to the distal; the lower cuspid is often grooved distally, and the mesial and distal surfaces are flat, tapering slightly to the lingual, and so on. Now if a resorbed area is in the groove of the dumb-bell shaped lower first molar, for example, and if it should be small enough not to affect the radiolucence of the root, then it will not be visible in a radiograph of that tooth. The examples are innumerable.

(3) The Amount of Loss:

All the mesial and distal areas of simulated resorption were visible in the radiographs of the teeth, but the radiographs of the teeth in situ showed only the areas produced by the No.1 round bur. This is due to the attenuation of the rays by the bone.

In vivo, the attenuation of the rays appears to be more pronounced. The radiographs of the lower first premolars in which areas had been produced using a No.1 round bur, which were placed in the most advantageous position for detection, in the subsequent radiographs were not visible. The round bur hole which was placed in the distal root of the lower first
(3) The Amount of Loss: (Contd.)

Molar was visible. This hole was larger than those in the premolars, and was made by holding the bur at right angles to the surface. It can be reasoned, then, that there is a critical amount of loss before it is discernible in the radiograph. The critical amount of loss for the dried specimens in the lower incisors, is somewhere between the loss produced by the No.½ round bur and No.1 round bur. The critical loss for the in vivo tests cannot be stated because of the small number of tests performed.

Henry and Weinmann (1951) and Becks and Grimm (1945) both found that there was high degree of correlation between histological and roentgenographical examination of autopsy material. Their roentgenograms were taken of the specimens with the teeth in situ before histological preparation.

Becks and Grimm (1945) notched the lower borders of the mandibles opposite where the sections were to be taken. In this way they claim that they were able to orientate the radiograph with the histological section. Their sections were cut bucco-lingually or labio-lingually, and were from 8 to 10 microns thick. They do not say if the sectioning was serial. It would be an almost impossible task to re-orientate such a thin section with a particular position on the notch. From the simulated resorption tests of the lower centrals, it would appear that histological and roentgenographical comparisons could not be made. The No.½ round bur holes were not visible radiographically. It was because of this that histological and roentgenographical comparisons were not made in this study.
(4) **The Rotation of the Socket:**

This is clearly demonstrated by the radiograph of the lower left premolar. In this radiograph only the mesio-gingival area is visible, and this not very clearly. This socket is rotated, the buccal being rotated mesially. It was attempted to increase the areas of simulated resorption using acid, but this could not be done precisely. It was shown, however, that with increased loss, that the areas did become apparent on the radiograph even though the tooth was rotated. This tooth, and the lower right premolar, are most interesting, because these teeth were in the alignment of the arch, yet the sockets were rotated. There was torsion of the crowns of these teeth on their roots. This can be seen quite noticeably by observing the "lamina dura" of these teeth.

(5) **The Angulation of the Central Ray:**

The effect of changing the horizontal angulation has been noted previously. It is enough to say here that such a change may blur, or completely mask the appearance of an area of mesial and/or distal resorption.

On the other hand, a changed horizontal angulation may detect an area of resorption that may have not been detectable with the correct angulation. This image will be distorted. It is not recommended that such a change be made for this purpose. If the tooth be distorted by the use of incorrect vertical angulation, then an area of mesial and/or distal resorption is likewise distorted.

Over/...
iii. **Labial or Buccal and Lingual Loss:**

The lingual simulated resorption produced by the No. ½ and No. 1 round burs were both visible in the radiographs of the teeth, but they were not visible in the radiographs of the teeth in situ. The lingual areas were not visible on the lower right premolar.

The appearance of resorption in these areas on the radiograph is simply a function of the amount of loss and its position vertically on the root. A loss of a small amount may be visible apically - a similar loss gingivally would not be visible.

Often at the time of apicectomy (that is on exposure of the apex) it is noted that the labial surface of the apex is resorbed, but this resorption is not visible in the radiographs.

11. **Lamina Dura and its Relation to Resorption:**

Lamina Dura literally means 'hard layer'. The term is radiographical. It refers to the white line that surrounds a tooth in a radiograph. The lamina dura is the radiographical image of the mesial and distal walls of the socket of the tooth, as projected on the film. It is regarded as of great clinical importance. Almost all roentgenographical texts would agree that if the continuity of such should be interrupted, then the tooth concerned is in some way pathologically involved.
Worth (1963) has stated - "The essential feature in radiographic interpretation is that the shadow of the lamina dura shall be continuous throughout its extent; any deviation from this - any slight deficiency or discontinuity - is highly suggestive, if not quite indicative, of an abnormal condition."

It was precisely because of similar thinking that the interruption of the lamina dura was questioned as a requirement of root resorption, as proposed by Massler and Malone (1954).

It was stated in the previous paragraph that the lamina dura is the radiographic image of the mesial and distal walls of the socket. There is quite a deal of variation of thought concerning the actual nature of the walls of the bony socket. Scott and Symons (1961), Blackman (1959), Worth (1963), Miller (1957) and others, described the socket wall as consisting of a thin layer of dense cortical bone.

Goldman, Millsap and Brenmar (1957) state that the white line reflects a layer of compact bone (alveolar bone proper) which lines the socket. On the other hand, Weinmann and Sicher (1955) and Orban (1957(b)) are of the opinion that the wall of the dental socket is lined by "bundle bone" which contains few collagenous fibrils and therefore a larger amount of mineralised matrix per unit volume than the neighbouring bone. Hence they say that the line of increased radio-opacity which delineates the socket margins on the radiograph is the result of this "bundle bone".

Massler (1945) states - "Correlation of the roentgenographic and the histologic picture shows that the lamina dura is very wide and radiopaque when the bone is newly deposited and of a
fibrous character and that when the fibrous bone is transformed into lamellar bone, as seen in the histologic section, the lamina dura in the roentgenogram becomes thinner and less radiopaque."

"Although the newly formed and calcified layer of the alveolar bone proper is radiopaque, historically* this layer appears to be no more dense than the adjacent bone. On this basis the term 'hard layer' (lamina dura) does not seem to be justified. It would be more accurate to call it the alveolar bone proper and to regard it as the site of the newly calcified layer of bone in the roentgenogram or the newly formed layer of bone in histologic sections (the alveolar bone proper, cribiform plate or inner compacta)."

On this basis, he makes a rather startling claim - 
"...its accentuation in the young and its disappearance in the older individuals is constant."

This, I am sure, he does not mean. The lamina dura never disappears unless there is disease.

Manson's (1963) work is very important, and a section of it will be quoted here:

"During a microradiographic investigation of age changes in the mandible a number of specimens of mandible with teeth in situ were collected, thus providing the opportunity for a microradiographic study of the socket wall and specifically for determining whether the view of Weinmann and Sicher could be substantiated....."

Over/...

*Historically is as quoted - should read histologically
"Findings -

In bucco-lingual sections the normal pattern of the Haversian bone with osteones of varying mineral density was found throughout the width of the mandible from the buccal or lingual surface to the socket wall in all specimens. In the marginal bone, for a varying distance apically, few marrow spaces were present (Fig.1). In some places the socket wall was lined by circumferential lamellae, but in many areas osteones were involved in the socket wall and no circumferential lamellation were present (Fig.2). Both deposition and resorption could be identified in places, deposition being indicated by low-density lamellation and resorption by a sharp crenated line cutting across the lamellar pattern (Fig.2). In none of the microradiographs was there evidence of a high-density band which would correspond to the lamina dura: indeed, there was no evidence of any high mineralised tissue which might correspond to Weinmann and Sicher's description of "bundle bone" - Fig. 1 and Fig. 2.

More apically, where the mandible was broader, there was some cancellous tissue between the buccal or lingual cortical bone and the socket wall was formed by a plate of bone of uneven thickness perforated on many places, forming the cribriform plate. It may be misleading to describe this plate as cortical or even compact bone, as it is little, thicker than a trabeculum of cancellous bone (Fig.1). Again there is no evidence of more highly mineralised tissue lining the socket wall."
It should be noted that Manson found that deposition was represented by low-density lamellation. This is contradictory to the hypothesis as proposed by Massler. His findings are in agreement with those of Massler, in that he found the socket wall to be cribiform, particularly in the apical region. Massler uses conflicting terminology (the alveolar bone proper, cribiform plate or inner compacta).

From observation of dried specimens, it was found that the socket wall varies in texture. In general, it was found that the walls of the mandibular premolars were perforated, but more finely so than that of the mandibular molars. The socket walls are shown to be cribiform.

Fig. 66: Distal wall of the lower right first premolar demonstrating its cribiform appearance.
Fig. 67: Showing the socket of the lower left first molar.
Note: This shows the socket to be more cribiform apically.

Worth (1963) makes the point that the socket is perforated by vessels, and that these perforations do not interfere with the appearance of the lamina dura.

Sicher (1962) stated that there is an arterio-venous anastomosis in the periodontal space, and this was in agreement with the observations of Parfitt (1961). It is not inconceivable that the vessels for such an anastomosis gain access to the periodontal space by piercing the socket wall. The
integrity of the socket wall as applied in relation to the lamina dura will be discussed later.

The appearance of the lamina dura is not an artifact. Its appearance is dependant on the following inter-related factors:

i. The position of the mesial and distal walls of the socket in relation to the central ray.

ii. The shape of the socket

iii. The width of the mesial and distal walls bucco-lingually

iv. The integrity of the walls

v. The Eberhard Effect

vi. The exposure used to produce the film.

vii. Film placement

viii. The relation of the lamina dura to orthodontic movement.

i. The Position:

It has been demonstrated that for a clear and concise image of the mesial and distal walls (lamina dura) that the rays must pass tangentially through these walls. This is in agreement with Worth (1963), Manson (1963), Goldman, Millsap and Brenman (1957), and others, but not with Massler (1945) who has made the following statement:

"It has been suggested that the appearance of the lamina dura in the roentgenogram might be the result of an artifact produced by the superposition of the peripheral layers of the bony crypt. This hypothesis is not valid on the basis that its accentuation in the young and its disappearance in the older individuals is constant. In addition, the lamina dura is quite apparent in films which are variously angulated to eliminate the effects of superimposition."
This quotation will be referred to in the subsequent discussion.

The tangential effect of the rays are influenced by (a) the rotation of the socket (which may or may not be evident from an observation of the alignment crown of the tooth being considered), or (b) the horizontal angulation of the central ray, or both.

The effect of the rotation of the socket is well demonstrated by observing the radiographs of the premolars in the simulated resorption tests (Figs. 40 and 41). In both these rays the lamina dura is blurred and most indistinct. In the positioning device the effect of rotation of the socket or changing the horizontal angulation is clearly shown. The radiographs of the plaster-sawdust mould demonstrate that with a change of $5^\circ$ that the tangential nature of the rays are disturbed and the margins of the wedge-shaped cavity are beginning to blur (See Fig. 50).

Results of rotation on the lower canine and premolar indicate that with a rotation of $2.5^\circ$, that the lamina dura is becoming less dense, and wider. This is more noticeable in the canine because of the shape of the socket. It is important to note that with a change of 7.5 degrees that the lamina dura has broken down entirely. It is no longer diagnostic.

These results show quite conclusively that for a clear, concise and dense image of the lamina dura, that the rays must pass tangentially through the mesial and distal walls of the tooth socket. They also show that a change of $7.5^\circ$ either of the horizontal angulation or of the socket to the central ray
will produce a radiographic image that is not diagnostic. Greater care and attention must be given to the shape of the socket.

ii. The **Shape of the Socket** is dictated by the shape of the root of the tooth. It has been mentioned previously that the shapes of the roots are many and varied. If the rays must pass tangentially to produce a clear, well defined image of the lamina dura, then the following figure, as taken from Worth, will give some indication of the varieties of form that the lamina dura may take.

![Diagram of socket shapes](image)

**Fig. 68:** These diagrams demonstrate the reason underlying the variation of the appearance of the lamina dura. (The tangential behaviour of the rays is basic.)
The appearance of the lamina dura depends on the shape of the socket, as emphasised by this study. In fact, the same conclusions had been reached before the diagrams, as shown in Fig. 68, were seen. Conclusions stemmed from the appearance of the "double lamina dura" of the distal wall of the canine socket. This can be seen most clearly. It is due to the elevation on the distal wall. The shape and dimensions of the lower canine make this tooth susceptible to changes in angulation, and further emphasise the importance of shape. This is why this tooth was chosen for study originally.

iii. The Width of the Walls Bucco-Lingually:

The amount of bone that the rays must pass through has a direct bearing on the appearance of the image. The greater the thickness in a bucco-lingual direction, the greater the attenuation of the rays. This is simply explained by studying the previous section on shape, and can be seen in the rays produced. The lamina dura becomes less dense as the apex is approached. This is because the thickness of bone (or width of bony socket) is decreasing towards the apex. The image of the lamina dura, as shown in Fig. 65, is absent in the apical region. This is because the root in the apical region is very fine and there is not enough bone to attenuate the rays, also, because of the width, the lamina dura of the lower canine is of greater density than that shown by lower premolars. The premolars are roughly conical, whereas the lower canine has flat mesial and distal surfaces. The importance of width was also indicated in the radiographs of the plaster-sawdust moulds. When the attenuation was caused by 1/4" of
material, the full wedge shape can be seen, but when turned through $90^\circ$ so that the rays were now passing through the tapering section of the wedge, the full length of the cavity cannot be seen; the image fades away to nothing. This principle is the same for the lamina dura of a finely rooted tooth. The upper canine may be an example of such behaviour (See Fig. 65).

iv. The Integrity of the Walls:

It has been shown previously that the socket wall can be considered as "cribriform", particularly in the molar region, and that this cribriform character of the socket does vary from socket to socket and from patient to patient. Worth (1963) makes the following point, that the socket is perforated by vessels, and that these perforations do not interfere with the appearance of the lamina dura.

In Fig. 67, which is of the socket of a lower first molar (showing the perforated walls), it is to be noted that some of these holes are as large as those produced by the No. $\frac{1}{2}$ and No. 1 flat fissure burs. The results substantiate the above observation.

In the dried specimens, the holes produced by the No. 2 flat fissure burs could be detected in the radiographs. The remainder of the series exhibit a broken lamina dura corresponding to the position of the holes in the socket walls. It is important to note that the break in the lamina dura does not become progressively clearer in the radiograph as could be expected with progressively larger holes. This observation may be the result of decreasing contrast as the
ends of the break move apart. The contrast in the region of
the break is also confused by the appearance of a white line
between the ends of the break. This was thought to be
produced by the remaining wall of the socket on either side
of the hole. This is part of the explanation for the exist-
ence of this white line.

It is believed that the 'Eberhard Effect' must account for
this appearance in some measure. The reason for making this
statement is that the hole produced by a No.6 flat fissure
bur in the apical region of the lower first premolar, is
almost as wide as the socket wall itself, yet the white line
is still present (See Discussion of the 'Eberhard Effect').
This line appears to be of uniform density which is a feature
of the 'Mackie Line' (See Fig. 49 - radiograph of the cavity
in the block of wood).

These tests were made in dried specimens. This is most
significant. Clinically, it may be conjectured that deficien-
cies in the socket wall would be even less noticeable in the
radiographs (attenuation of rays), and that if a break in the
lamina dura was observed, then the deficiency responsible for
such a break must be of reasonable magnitude.

These observations confirm the belief that the image, as
shown in the radiograph, underestimates the condition.
This statement is applicable to the dried specimen, but even
more so to clinical assessment.

It is on the above basis that interruption of the lamina dura
cannot be accepted as a requirement for root resorption.

Over/..
v. The Eberhard Effect:

This is an effect produced during the development of the film. It was first described by Eberhard in plates which had been left in the developer without agitation. Today, it is known as the 'adjacency' or 'edge' effect. It occurs at the junction of light and dark objects. This is well shown in the following figure:

Fig. 69: This halo along the edge of the centre tree clearly shows the 'Eberhard Effect'.

This ghostly halo around the edges of dark objects is caused by the 'Eberhard Effect'. The halo and its adjacent border of low negative density are called 'Mackie' lines.
The Eberhard Effect is brought about in the following manner. At the boundary of high and low density, the waste product (potassium bromide) diffuses from the low density (periodontal space) to high density (bone), and there restrains development in the area adjacent to the low density. On the other hand, the fresh developer from the high density region diffuses into the low density region, and hence the edge of the low density is blacker than the rest of the low density area.

The increased blackening is known as the 'border effect', and the halo, as produced outside the dark image, is known as the 'Fringe Effect' - together these effects produce the 'Mackie' line. Mackie(1917)(1961(b)).

Fig. 70: This diagram shows the Eberhard or 'Adjacency" effect in a magnified form, and explains the preceding paragraph.

("Practical Photography" July, 1965)
The development is the important factor in reducing this effect. It can be accentuated by developing the film in an unagitated horizontal position. The horizontal position is no problem in the development of radiographs, but it should be noted that it is good practice to agitate the film during development. The radiographic film has a double emulsion which increases the contrast range and the sensitivity of the film, but it also makes it susceptible to the Eberhard effect. Manson (1961) stated: "Also, it is my constant experience in the examination of microradiographs that a fine white line appears at the interface of two media that differ considerably in radiographic density." He suggested that a hole in a block of wood or plaster may be radiographed (See Fig. 49). It was found that by using a mixture of plaster-sawdust that greater contrast was gained than with plaster (See Fig. 50). These lines are of even intensity, whereas the lamina dura is of uneven intensity. Also, by removing a wedge of bone from the head of a sheep's femur and radiographing, the Eberhard effect can be produced (See Fig. 52).

It is believed that the white lines seen in the wood, plaster-sawdust, and bone, are 'Mackie' lines. It is also believed that this effect must contribute to the production of the white line that is known as the lamina dura.

vi. The Exposure used to Produce the Film:

It is a well accepted radiographic fact that there is an optimum exposure (Degering, 1962) to produce a radiograph of optimal density. In such a radiograph the outline form of the structure is correctly shown. There is good definition and
detail with adequate contrast depicting a correct image of the mineralisation of the structure.

Degering (1964) has shown that an under-exposed radiograph shows an acceptable outline form, but has a measurable lack of detail and definition of component parts, and gives an incorrect diagnostic impression of mineralisation. In an over-exposed radiograph of the same structure, Degering (1964) was of the opinion that there was a measurable diminution of outline form and internal structures, and an incorrect diagnostic impression of mineralisation but there was adequate contrast. He also found that if the radiograph was over-exposed, then the alveolar crest was burned out, and this gave the impression of resorption. These observations apply particularly to the lamina dura. It is important to note that in serial radiographs that the same exposure be used if a critical assessment is to be made of changes in mineralisation etc. In the radiographs taken in the various series, a point was made of using the same exposure and this has been referred to previously.

vii. Placement of the Film:
The film should not be distorted, as this will produce distortion of the subsequent image. It is suggested that in a radiographic survey for resorption, or for any critical radiographic assessment, that a film holder be used. A film holder was constructed and used in all radiographs taken in this study.

Over/..
viii. The Relation of the Lamina Dura to Orthodontic Movement:

From the results, it has been shown that when the spring is holding the tooth hard up against the distal wall, that the appearance of the mesial lamina dura is accentuated because of the increased width of the periodontal space which is black. This has the effect of increasing the contrast. On the distal, however, the appearance of the lamina dura is marked by the apposition of the tooth to the bone (compare the radiographs of the canine at 90° with and without spring). Oppenheim (1944) found histologically that the width of the periodontal space on the traction side was ten times greater than on the pressure side (see Review).

Muhlemann (1954) found that a tipping force of 100 grams produced 8.5% decrease in width of the periodontal space on the pressure side, and a 12.2% increase in width on the tension side. With a force of 300 grams, the tension side remained the same, but the pressure side decreased further to 24.6%. He also found that there was a distortion of the alveolar bone with a force of 300 grams in young monkeys. That is, he found that the root very closely approximates the bone at the sites of pressure. He does not go as far as Gottlieb (1942), who describes an actual contact between the root and the bone on the pressure side if the force is great enough.

In view of the work of Reitan et. al. (Hyalinisation, etc.) the above observation of Gottlieb's cannot be considered to be strictly accurate, but the trend in decrease in width of the periodontal space on the pressure side can be.
Storey (1953) found from radiographs that in the tipping of a tooth, that the width of the periodontal space on the pressure side was maintained by bone resorption, but was increased on the tension side. Massler (1945) has considered the effects of orthodontic movement on the lamina dura, but does not mention the increase or decrease in the periodontal space per se. Both Massler (1945) and Storey (1953) say that bone is deposited on the tension side and resorbed on the pressure side, and that these processes are evident from the radiographs. On the tension side they say that the lamina dura is much thicker. The reasons they give are different. Storey says that it is because the resorption of the old lamina dura lags behind the deposition (lagging is substantiated by a ghost lamina dura) of the new, and Massler because of the newly formed fibrous bone that has been laid down and not had time to mature (see previous Discussion). The observations of both Massler and Storey that the lamina dura is accentuated on the tension side is agreed with. It is felt, however, that the horizontal angulation of the central ray must be considered, as well as the increased contrast on the tension side.

Storey states that the radiograph must be taken at right angles to the direction of movement (it is a pity that the reproductions of the radiographs used in Storey's article are most indistinct). Massler (1945) makes no mention of the horizontal angulation.
It is clearly shown that with a rotation of 5° of the canine, that the mesial lamina dura is thickened (but less dense), and the periodontal space widened. The explanation for this behaviour is to be seen in Fig. 68. At 10° rotation the lamina dura is thickened even further, and this could easily be misconstrued as apparent bone deposition.

Because of the shape of the distal wall, at 90° a double lamina dura was seen. This demonstrates how confusing it may be in making predictions of resorption from radiographs of orthodontic patients.

Because of the shape of the socket and apposition of the root to the distal wall with a rotation of 5°, it could be erroneously said that new bone had been deposited on the distal because of the position of what could be called the new and old lamina dura. Such a radiograph could be even more confusing clinically with greater attenuation of the rays.

The proximity of the root to the lamina dura must be considered, and the effects of horizontal angulation.
CONCLUSIONS

The main conclusion is that a properly planned serial radiographic study of root resorption is yet to be done.

In all the studies quoted (with the exception of McLaughlin (1964)), there has been little stress placed on radiographic technique. The investigators have used radiographs taken for routine full-mouth examinations using the short cone technique, the disadvantages of which have been mentioned in the discussion.

It is believed that for a thorough study of root resorption, the radiographs should be taken specifically for that purpose, using the long cone technique. The radiographs should be taken under as near to identical conditions as possible, that is, using identical kilovolts, milliamperes, exposure, etc. The films should be taken by the same operator. A magnifying lens should be used to view the films with the aid of the same source of illumination.

The radiographs must be taken serially. A period of twelve months between each series would be suitable. One series of radiographs can then be compared with the succeeding series. It is imperative for the detection of root loss that such comparisons are able to be made of the same tooth. Each view should be taken twice, at the same angulation.

The subjects should be healthy young adults who have not had orthodontic treatment. Equal numbers of both sexes, and equal numbers of maxillary and mandibular teeth should be examined. The numbers used in the study should be statistically orientated. The teeth examined must be single rooted teeth in good alignment and in normal function. Teeth not in normal function should be excluded.
from the study. Models should be taken, and the occlusion checked prior to the radiographs being taken.

Radiographically the following points should be noted very carefully:

1. The lamina dura must be continuous. It has been shown that if the lamina dura should be interrupted, then the lack of continuity must be considerable. This lack of continuity can be due only to disease, except apically in very fine-rooted teeth.

2. The comparison of the length of the crowns of the teeth does indicate, to some degree, whether the shadow of the tooth be foreshortened or lengthened. This comparison would be helpful.

3. The apical foramen must not be visible on the radiograph. If it is, and if the walls of the root canal converge towards the root apex, then the root of the tooth was once fully formed but is now resorbed. On the other hand, if the walls of the root canal diverge, then the root is either not fully formed, or has failed to develop.

4. The root end is usually smoothly convex (this does not mean "blunted"). Should there be any variation of this form, then carefully observe the root canal and the apical foramen.

5. If the trabecular pattern of alveolar bone should be such as to obscure a clear outline of the root, then this radiograph must be considered not diagnostic.

6. As Worth (1963) has said, if the periodontal space is unduly wide, then this may be indicative of an inflammatory change. Such a condition is usually associated with an osteitis of the adjacent bone. If the apical foramen cannot be seen and the
6 (contd.)

walls of the canal diverge, then this tooth cannot be considered as being resorbed.

7. Restored teeth can be included in the study. Teeth showing evidence of any other pathology must be excluded from the study.

Criteria for a Proposed Method of Scoring Root Resorption


1. Lamina dura continuous, apical foramen visible. Root canal convergent; root end blunted showing a loss of up to 5 mm. Remainder of root outline clearly seen and intact.

2. Lamina dura continuous, apical foramen visible. Root canal convergent. Root end severely blunted showing a loss from 5 mm. to half the root. Remainder of root outline clearly seen and intact.

3. Root obscured by trabecular pattern (not diagnostic).

4. Teeth with associated pathology (root canal therapy, periapical infection, cysts, etc.) These teeth are discarded from the study.
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ADDENDUM


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