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B.D.S., F.D.S.R.C.S.
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Some observations on the subject of roots of teeth, retained in the jaws as a result of incomplete exodontia.
The original work presented in this thesis has been carried out by me as an individual research project.

I acknowledge the assistance and advice I have received in discussions with Dr. N. E. Goldsworthy, Dr. H. R. Sullivan and Mr. G. S. Molyneux of the Institute of Dental Research, and the assistance received from Mr. J. Higgs, pathology technician, and Mr. B. Rumble, clinical photographer of the United Dental Hospital.

I desire to express my sincere thanks for their assistance.
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l.

INTRODUCTION AND REVIEW OF THE LITERATURE.

In the course of a dental career, one hears many conflicting opinions on the subject of retained roots. These opinions vary widely, from those who believe that roots seldom give trouble to those who regard every retained root as a danger to the health of the patient. Dental textbooks, on the whole, ignore the subject completely. The average practitioner thus has had to rely on his own clinical experience and this has led to much diversity of opinion.

This work was undertaken in an attempt to find out what happens when a root is left embedded in the jaws. It is in two parts. Part A consists of a clinical survey and Part B pathological investigation.

The literature on the subject of retained roots is very scanty. Views are expressed with little or no evidence other than clinical observation to support them. Many writers agree with Colyer and Sprawson when they say 'The apices of untreated pulpless teeth are always infected ................. what has been said of pulpless teeth also applies to portions of teeth left embedded in the jaws.'

This approach is common throughout much of the dental literature. The assumption is made that roots left embedded in the jaws must be non-vital, therefore infected, and that these roots must have the same effect as do non-vital teeth. Therefore, they are foci of infection. These statements have been made in passing, with no evidence presented and no references given.

Kronfeld is one writer with a very different viewpoint.
He says 'If the root end was chronically infected, three things are possible (1) The root fragment may be gradually eliminated (2) The tissues may heal over it leaving a sinus to the surface (3) The tissues may heal completely, leaving it in the jaw without clinical symptoms, as so-called residual infection.

'If the root was not infected, the tissues heal completely, the pulp stump remains alive and the fractured surface is covered with cementum. Although favourable conditions are occasionally found around embedded root ends, it must not be inferred that any carelessness in removing fractured root apices is justified.'

These views are based in part on earlier literature but are mostly conclusions drawn from his own work.

While few articles have been published on retained roots, the literature on the subject of focal infection is voluminous. This has been summarised recently by many authors. Walsh\(^3\) says 'While the precise relationship of oral sepsis to general disease has yet to be fully determined, no one doubts that oral sepsis affects general health.' Elsewhere he says 'Oral sepsis should be treated as such, and in its own right, in the belief that the health of the part is essential to the health of the whole.'

Jawett\(^4\) writes 'It must be considered that hypersensitivity associated with oral sepsis occasionally may play a role in the production of iritis, arthritis and other conditions which are known to be associated with hypersensitivity phenomena and which, on some occasions, are helped or even cured by the removal of a tooth abscess ................. Needless to say, the pres-
ence of a well established root abscess or granuloma is, in itself, ample reason for removal or correction without having to invoke the potential harm it might do in causing remote disease processes.'

Articles by these authors indicate there is some doubt that dental infection plays a major role in systemic disease. Other authors are more definite. Hanna\(^5\) says 'It is concluded that dental focal infection has little or no relationship to many systemic diseases once associated with dental focal infection. However, in view of the fact that bacteriemias do follow dental operations and that such a bacteremia is capable of causing subacute bacterial endocarditis in certain patients, oral foci of infection should be removed.'

According to Rushton\(^6\) 'Very few specific diseases are now regarded as the direct result of dental sepsis' and elsewhere he says 'Even a well encapsulated area of infection may become dangerous if it be mechanically disturbed or if the patient's resistance falls.'

The consensus of opinion seems to indicate definite connection between acute dental infection and systemic disease, but little or no connection between so-called residual infection and systemic disease.

I tried to obtain some statistics on the incidence of systemic disease in various age groups in Australia, but apparently no facts have been gathered on this subject. However, the Commonwealth publication Health\(^7\) has this to say on life expectancy: 'A man born in Australia to-day may expect to live to nearly 70 and a woman beyond that figure.'
As to causes of death, Health showed that 26,429 people died of cardiovascular diseases out of a total 81,788 deaths in the year 1951. Thus, in that year some 30% of all deaths were due to cardiovascular disease.

Apart from work done by Kronfeld, very little attention has been directed towards retained roots.

Thomas, in 1922, was the first writer to describe cementum forming over the fractured surface of retained roots. He also noted changes in the remaining pulp '................. is rather well compacted fibrous tissue with a scarcity of cellular elements.' He does not mention any other changes.

Cementum has frequently been seen covering the pulpal surface of the dentine of teeth, for a short distance from the apical foramen. Among the first to describe this were Salter in 1874 and Hopewell-Smith in 1903.

Metaplasia of the pulp of standing teeth has been described. Kronfeld, page 106, says 'In cases of metaplasia, the pulp changes its function and forms cementum or bone instead of dentin; then bone or bone-like cementum is found in the pulp chamber.

'True metaplasia of the pulp is a rare condition, it must not be confused with the observation of cementum in the apical portion of root canals, following chronic pulpitis, root canal treatment or pulp injuries. The deposits of cementum are the result of a proliferation and ingrowth of periodontal connective tissue through the apical foramen into the root canal, and of substitution of pulp tissue by connective tissue.'
Professor Darling\textsuperscript{12} reports a case of a standing tooth with the complete pulp chamber occluded by cementum. He mentions cases which have shown cementum covering the pulpal surfaces of the dentine for a short distance from the apical foramen. He concludes that a complete metaplasia of the dental pulp is possible.

Euler\textsuperscript{13} has described a third molar tooth in which cementum was laid down in the coronal pulp. This was separated from the periodontal membrane by atrophic pulp tissue in the root canals.

Orban\textsuperscript{14} makes some interesting observations regarding secondary dentine formation and regarding pulp changes. He says 'Under normal conditions, formation of dentine continues throughout life........... Some areas of secondary dentine contain few or no tubules. Dentine forming cells are often included in the rapidly produced ground substances, such cells degenerate, leaving spaces.'

Of the pulp, he says 'With advancing age, canals become narrower due to secondary dentine. With advancing age, cellular elements decrease in number and fibrous elements increase.' He does not, however, mention retained roots.

Kronfeld\textsuperscript{15} also did some work on the biology of cementum. He says 'Cementum deposition continues throughout life' and elsewhere he maintains 'Function is not necessarily a stimulating factor in cementum deposition.'

Pritchard\textsuperscript{16} reports a study of one retained root in an article on fractured teeth. He describes a fractured root with the pulp laying down 'Secondary dentine' with no odontoblasts in
association with this new tissue. The italics are mine.

While investigating a case of repair following tooth fracture, Gottlieb\textsuperscript{17} reported a study of one retained root. The contents of the canals disclosed a complete lack of odontoblasts and the pulp structure of blood vessels and nerves was torn. The canal walls were covered with cementum. This is the only report of such a case that I could find in the literature.

Some articles have been written with regard to roentgenographic interpretation of retained roots. Zemsky\textsuperscript{18} put forward the view that roentgenographically negative retained roots need not necessarily be removed. Helmore\textsuperscript{19} is more doubtful. He says 'Roots exposed are always infected. Fragments completely in alveolar bone show (1) granulation areas (2) cysts (3) appear normal. In the last case, the roentgenogram gives little or no evidence for the assessment of their damage.' A similar view is expressed by Molt\textsuperscript{20} who writes '.................Root fragments in many of these have no pathology aspect and perhaps never may, but as the roentgenogram cannot be an index of this the only safe procedure is elimination.'

This review of the literature shows that while there is a wide variety of opinion on the subject, the majority of authors are agreed that retained roots are a danger to the patient.
PART A - CLINICAL SURVEY.

The clinical survey was based, during a period of two and a half years, on all patients sent to the Oral Surgery Department for removal of retained roots. In each case I either performed the surgery or saw it performed. These patients were those, amongst an estimated thirty thousand X-rayed, who were found to have retained roots. Some patients had been referred to us by other hospitals or institutions; others had been sent by practitioners because of pain, incomplete exodontia, or for root removal to prepare the mouth for dentures. The great majority, however, were found during routine X-ray examination of patients presenting themselves at the Dental Hospital for treatment. Hospital policy is for the removal of all roots prior to construction of dentures, except where surgical or medical risk contraindicates removal. The number of patients used in the survey was two thousand.

It was necessary, first of all, to define what was a retained root and, further, what was a root. For the purpose of definition I decided to use those cases where extraction of the tooth had been incompletely performed. All teeth which had obviously decayed to the gingival margin were necessarily excluded. From the more recent extractions I excluded those with less than one-third of the coronal portion of the root removed. A few cases in which I was doubtful as to whether there had been previous extraction, I excluded. However, in view of the facility of oral mucosa in healing over undescended teeth which have been
previously exposed, something I have observed many times, some
small error must have been made in this regard.

The recognition of roots radiographically was based
on the presence of periodontal space between the root and the
bone and on some evidence of lamina dura surrounding this. Even
with this as a guide, some supposed roots were recognized at
surgery to be small odontomes and were excluded.

Others were found during surgery to be sclerosis of
bone, which radiographically gave a perfect picture of a
retained root – these were also excluded. It was found later,
histologically, that some which radiographically and clinically
looked perfect roots, were in fact sclerosed bone and odontomata.
This must also have given rise to some small margin of error.

METHOD OF SURVEY:

AGE: The ages of patients are obtained in confidence in
another department and are included in the patients' records. I
used these ages for the survey, except where there appeared to be
an obvious discrepancy. I recorded ages in 10-year periods, i.e.
10–20, 20–30 and so on.

SYMPTOMS AND PATHOLOGY: Patients were questioned by me
as to whether they were in pain, had recently had pain, or if
they had ever had pain or tenderness in the region of the retained
root. Patients were also questioned with regard to any swelling
of the area, indicating infection. Here, distinction had to be
made between pain arising from teeth or periodontal lesions.
Other possible causes of pain were maladjusted dentures or tem-
poro-mandibular joint disturbances in those patients with or
without teeth. Where any doubt arose, symptoms were included in
the survey.

Cysts were diagnosed radiographically and all cysts
were confirmed by pathological section.

Granulation tissue was diagnosed radiographically and,
where sufficient tissue could be obtained, confirmed by patholo-
gical section. Where there was insufficient tissue for section,
clinical observation at surgery was the criterion.

Sclerosis of bone around the retained root was judged
radiographically — all doubtful cases were included.

While a few apparent roentgenographic radiolucent areas
were found at surgery to be coincidental and not pathological, no
granulation areas were found which had not previously been diagnosed
roentgenographically.

DATE OF EXTRACTION: When I commenced the survey I had
hopes of accurately recording the date of the extraction of the
relevant tooth. I soon found, however, that the majority of
patients could not recall when extraction had been performed. If
it had been done during the two years prior to questioning, most
could recall the approximate month. Patients who had had a full
mouth clearance were the most precise. Those — by far the majority
— who had gradually lost their teeth had no idea. Most patients
did not know that retained roots were present.
For this reason, I divided them into three arbitrary groups of:

1. Recent extraction, where extraction had been attempted up to one month previously.
2. Where the extraction had been attempted within, approximately, the previous two years.
3. Where extraction had been attempted more than two years previously.

No accurate record could be, or was kept, but a rough estimation showed the average period since extraction, in the third group, to be over 15 years. Some of the older patients had had full mouth clearances more than fifty years prior to examination.

POSITION IN RELATION TO THE CREST OF THE RIDGE: The roots were divided into four groups with regard to position. The groups were:

1. Those uncovered to the saliva.
2. Those through the bone but not the mucosa, that is, with the coronal portion just through the bone on the crest of the ridge.
3. Those below the crest of the ridge with the coronal portion just covered by bone.

The position of the roots was judged radiographically and confirmed clinically.
Classification within the last three groups was not difficult. The first group, however, presented problems. Included in this group were roots with sufficient of the coronal portion of the root through the bone at the crest of the ridge to have been bared to oral secretions, providing they had a sinus communicating with the mouth. Those found at surgery to have the portion of the root through the bone blackened, suggesting past exposure, were included in the second group if the tissues were intact.

**CONDITION OF THE RIDGE:** This was judged in relation to the period since extraction. Arbitrary division was made of patients with good ridges, those with average resorption, and those with gross resorption. Note was made, therefore, of those patients whose ridges had not resorbed to more than a minor degree and those where resorption was very great.

**SYSTEMIC DISEASE:** Prior to obtaining treatment in the hospital, all patients fill in a health questionnaire, which is designed to indicate any local or systemic condition from which they are suffering. In addition to this they are questioned by nursing sisters and myself. A complete medical examination could not be made. Thus, only those conditions which had been previously diagnosed and of which the patients were aware could be recorded.

**PERIODONTAL CONDITION:** In those patients with teeth a note was made of periodontal conditions which had progressed
sufficiently to show bone changes radiographically.

**ROOT FILLING:** Only those which had radio-opaque root fillings could be recorded. This would not include those incompletely filled where fracture had occurred at extraction above the highest point of filling.
NUMERICAL RESULTS.

<table>
<thead>
<tr>
<th>AGE GROUPS</th>
<th>Under 20</th>
<th>20-30</th>
<th>30-40</th>
<th>40-50</th>
<th>50-60</th>
<th>60-70</th>
<th>Over 70</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients in group</td>
<td>29</td>
<td>77</td>
<td>160</td>
<td>210</td>
<td>372</td>
<td>829</td>
<td>323</td>
</tr>
<tr>
<td>Percentage of total</td>
<td>1.45</td>
<td>3.85</td>
<td>8</td>
<td>10.5</td>
<td>18.6</td>
<td>41.45</td>
<td>16.15</td>
</tr>
</tbody>
</table>

SEX.

731 patients, or 36.55% were male.
1,269 patients, or 63.45% were female.

SYMPTOMS AND PATHOLOGY.

<table>
<thead>
<tr>
<th></th>
<th>Acute Pain</th>
<th>Acute Infection</th>
<th>Cyst</th>
<th>Granulation Tissue</th>
<th>Sclerosis Around Root</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of patients</td>
<td>82</td>
<td>21</td>
<td>38</td>
<td>236</td>
<td>113</td>
</tr>
<tr>
<td>Percentage of total</td>
<td>4.1</td>
<td>1.05</td>
<td>1.9</td>
<td>11.8</td>
<td>5.65</td>
</tr>
</tbody>
</table>

MAXILLARY OR MANDIBULAR.

Upper Roots = 1,351 patients, or 67.55%
Lower Roots = 649 patients, or 32.45%

EXTRACTION DATE.

<table>
<thead>
<tr>
<th></th>
<th>Performed Recently</th>
<th>Within previous two years</th>
<th>Extracted Many years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients</td>
<td>79</td>
<td>137</td>
<td>1,784</td>
</tr>
<tr>
<td>Percentage of total</td>
<td>3.95</td>
<td>6.85</td>
<td>89.2</td>
</tr>
</tbody>
</table>
OWN TEETH OR DENTURES.

472 - 23.6% of patients had some standing teeth in the same jaw as the retained root.

1,528 were edentulous, and only a small number had not worn dentures.

POSITION IN RELATION TO THE CREST OF THE RIDGE.

<table>
<thead>
<tr>
<th>Roots Uncovered to Saliva</th>
<th>On Crest of Ridge</th>
<th>Just Below Crest</th>
<th>Deep Roots</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>334</td>
<td>877</td>
<td>591</td>
</tr>
<tr>
<td>Percentage of total</td>
<td>16.7</td>
<td>43.85</td>
<td>29.55</td>
</tr>
</tbody>
</table>

CONDITION OF THE RIDGE.

<table>
<thead>
<tr>
<th>Good</th>
<th>Average Resorption</th>
<th>Very Resorbed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>224</td>
<td>1,408</td>
</tr>
<tr>
<td>Percentage of total</td>
<td>11.2</td>
<td>70.4</td>
</tr>
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</table>

SYSTEMIC CONDITIONS. (Total Number 514 - 25.7%)

<table>
<thead>
<tr>
<th>Cardio-Vascular Disease</th>
<th>Hyper-tension</th>
<th>Ulcers (Gastric and Duodenal)</th>
<th>Tuberculosis</th>
<th>Various Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>245</td>
<td>92</td>
<td>58</td>
<td>25</td>
</tr>
<tr>
<td>Percentage of total</td>
<td>12.25</td>
<td>4.6</td>
<td>2.9</td>
<td>1.25</td>
</tr>
</tbody>
</table>

OTHER CONDITIONS. (Each less than 1% of Total Survey.)

<table>
<thead>
<tr>
<th>Asthma</th>
<th>Arthritis</th>
<th>Anaemia</th>
<th>Thyroid</th>
<th>Parkinsons</th>
<th>Pagets</th>
<th>Syphilis</th>
<th>Sclerosis of Liver</th>
<th>Diabetics</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>15</td>
<td>15</td>
<td>6</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>6</td>
</tr>
</tbody>
</table>

1 each of Hodgkinson's Disease, Spondylitis, Thrombosis, Bronchiectasis, and various others totalling 23.
15.

**RADIOGRAPHIC PERIODONTAL CONDITIONS** - totalled 176 patients, or 37.3% of those patients with some standing teeth in the same jaw as the retained root.

**ROOT FILLINGS.**

Only 12 retained roots with root filling material present were seen. None of these had any associated pathology.

**ANALYSIS OF RESULTS.**

**AGE:** As is seen, nearly half the patients were in the 60–70 age group, and 76% were over 50. This is due partly to the fact that the majority of patients treated in the hospital are age, invalid and widow pensioners. However, a significant proportion is due to general improved standards of dentistry, in that fewer roots have been left in the younger age groups.

**SEX:** Of patients seeking treatment there is a slight preponderance of female over male, but not to the extent indicated by these figures. While no definite conclusions can be drawn, it is obvious that far more roots are left in females than males.

**MAXILLARY OR MANDIBULAR:** An overwhelming majority of upper roots were premolar and molar roots in close proximity to the maxillary sinus. Similarly, the vast majority of lower roots were premolar roots close to the mental foramen or roots of third molars. It would seem that ease of removal plays a large part in the decision of the dentist to remove a fractured root. Therefore, no conclusion can be drawn from these figures as to liability of fracture.
SYMPTOMS AND PATHOLOGY: The overall number of patients, excluding figures duplicated by patients having more than one associated condition, was 442, or 22.1%. This includes those with sclerosis of bone.

(1) **PAIN**: 82 patients complained of pain in the area of retained roots. 75 of these roots were exposed to the mouth. Two were recent extractions. Two were deep-seated roots of long standing with no recognisable pathology, where the pain was suspected of being due to other causes. Three were due to acute infections of deep roots of long standing showing radiographic areas of granulation tissue.

(2) **ACUTE INFECTION**: Was seen in sixteen patients, fifteen of whom had roots with granulation tissue, twelve of which were roots exposed to the mouth. One cyst was acutely infected, and the root was present in the mouth.

(3) **SCLEROSIS**: Was evident radiographically in 118 cases, ranging from slight thickening of the lamina dura to well marked areas around the root, not necessarily at the apex. In one case it was associated with both pain and granuloma, and in eight other cases with granuloma. The position of the root in relation to the crest of the alveolar ridge did not seem to affect it. Distribution between males and females was similar to the over-all proportion. It was seen associated with 49 maxillary roots and 69 mandibular roots, indicating a much greater tendency towards sclerosis in the mandible. 38 patients had very good alveolar ridges, 69 patients
average resorption and 11 were very resorbed, indicating much less resorption in patients with a tendency towards sclerotic bone formation, as would be expected.

Systemic conditions recorded in this group were 11 cardio-vascular cases, 3 hypertensions, 5 ulcers, 2 asthmas, 2 arthritics, 1 diabetic, 1 Paget's, 1 Parkinson's and 1 sclerosis of the liver. These figures give a similar percentage to the over-all percentages for the survey.

4. **Cysts**: Of the 38 cysts found, in relation to retained roots -

(a) 20 were roots uncovered to the mouth with the cyst at the apex. Of these, 9 had had exodontia attempted in the previous two years.

(b) 11 had the roots contained inside the cystic cavity. Only one of these was not of many years' standing. 7 of this group were covered with tissue only, that is, bony resorption of the ridge was complete.

(c) 2 were on the crest of the ridge with the cyst at the apex of the root. Extraction attempted many years previously.

(d) 5 cysts were associated with deeply buried roots. 2 in this group showed the roots to one side, suggesting that the presence of the cyst and the root was coincidental. Extraction had been attempted many years previously.
28 of these cysts were in males, 10 in females. As the total percentage of males in the survey was only 36.55%, this indicates a much greater tendency towards cyst formation in males than females with retained roots.

The cysts were spread over all age groups in proportions similar to the percentages of each age group.

Only one patient complained of pain, and this cyst showed clinical acute inflammation. The root was exposed to the mouth.

13 patients had their own teeth and 5 of these had periodontal lesions.

All showed average resorption of the ridges.

28 were maxillary lesions, 11 mandibular, which are similar proportions to the over-all percentage.

Of systemic symptoms, there were 5 cardio-vascular cases, 3 hypertensions, 1 ulcer, 1 diabetic, 1 thrombosis and 1 tuberculosis – a total of 12 cases, representing 31.6% of the total cysts.

(5) **GRANULATION TISSUE:** Of the 236 roots which had associated granulation areas, only 133 had apical areas. The remainder were to one side of roots exposed to the mouth.

16 were recent extractions, 69 in the previous two years, and 151 of many years' standing.

179 were exposed to the mouth, 22 through the bone but not the soft tissue, and some of these had obviously been previously exposed. 35 were wholly in bone. Of the 35 wholly in bone, only 12 were of many years' duration.
22 patients with granulomatous areas experienced pain. All but three in this group were roots exposed to the mouth, and these three were deep roots showing clinical signs of acute inflammation. In fact, 15 of the 22 with pain had acute infection and of the seven not infected five were recent extractions and the other two exposed to the mouth.

Proportions of male and female, maxillary or mandibular roots were similar to the overall proportions.

Systemic records showed 31 cardiovascular cases, 7 hypertensions, 4 diabetes, 4 ulcers, 2 asthmases, 1 thyroid, 1 sclerosis of liver and 1 Paget's - a total of 51 cases, representing 21.6% of those patients with granulation areas. No eye disease was recorded.

POSITION IN RELATION TO THE CREST OF THE RIDGE: 16.7%, or 334 roots, were exposed to the saliva. Of this group, 199 were associated with cysts or granulation tissue, the total cases of which numbered 274. Thus, this group was associated with 72% of the total pathological states.

CONDITION OF THE RIDGE: Those patients with good alveolar ridges in the region of the root represented only 11.2% of the total, while 23% of all patients had some standing teeth. The greatest proportion of these were recent extractions, but quite a few good ridges were seen where dentures had been worn for many years. There is no doubt that there is great variation in the rate of, and liability to, resorption of alveolar ridges.
As will be seen from the figures of position of roots in relation to the alveolar crest, deeply buried roots represented only 9.9% of the total, showing that resorptive processes will eventually bring roots to the crest of the ridge and possibly expose them to the mouth, providing the patient lives long enough.

**RADIOGRAPHIC PERIODONTAL CONDITION:** I kept a record of periodontal destruction of bone around standing teeth—indicating poor oral hygiene—to see if there was any relation to the amount of resorption of the ridge in the area of the retained root. I could not find any connection.

**SYSTEMIC CONDITIONS:** The figure for cardio-vascular disease includes seven patients with a history of rheumatic fever. It can be seen that cardio-vascular diseases comprised 47.7% of the total systemic conditions. Hypertension was the next largest group, with 17.9%. Particularly worthy of note is the fact that only 15 patients with arthritis were seen, and no case of eye disease was recorded in the group.

**COMMENT.**

Pain and acute infection is experienced only rarely in connection with retained roots and then mostly with roots exposed to the mouth. Only three definite cases of pain involving deeply buried roots were seen, and these were acutely infected.

Sclerosis of bone was only associated with definite pathology in nine patients. My impression was that very few of the sclerotic areas seen were a pathological response, and that the
majority were part of the architecture of the bone. By this, I mean a strengthening of the area, which was weakened by the physical presence of the root, had taken place, particularly in attenuated mandibles.

The most striking result of the survey is that such a small percentage (22.1%) of retained roots have caused symptoms or any demonstrable pathological change. It is doubtful whether sclerosis of bone in the region of the root is, in fact, pathological. If sclerosis of bone were excluded the figure for this group would be 324 or 16.2%. If this figure is compared with the figure of roots exposed to the saliva (334 or 16.7%), it can be seen that the eventual resorption of the alveolar process, bringing roots to the surface, is by far the greatest factor in the pathology of retained roots.

Of all roots not exposed to the mouth, only a total of 75 had an associated pathological condition, if we again exclude sclerosis of bone. This represents 4.5% of unexposed roots. This figure includes some roots which could have been previously exposed.

Breaking this down further, only 40 roots wholly in bone showed any pathology, and of this group only 12 with granulation areas, and 5 definite cases with cysts were of more than two years' duration.

From this it may be seen that the danger period with retained roots is either soon after extraction is attempted or many years later when resorbtive processes have brought the root
to the surface. The exceptions to this are very few. The figures tend to indicate that roots which are eventually exposed cause by far the most trouble. This is not necessarily so, as the survey could not include the number of roots in the older patients which became troublesome soon after attempted extraction and were then removed.

After adjusting the figures to exclude duplication in the symptoms and pathology group, it is seen that 1,676 patients had retained roots present in their jaws for periods ranging in some cases to over fifty years without symptoms or recognizable pathology.

One patient in four had an associated systemic medical condition. This figure seems very high until one considers the age groups of the patients concerned, i.e. 76% more than 50 years of age, and sees that 65.6% of the total conditions were cardiovascular diseases and hypertension. Thus, the figures show what would be expected in any collection of persons in similar age groups.

Of particular significance is the proportion of systemic disease associated with definite local pathology or sepsis of the retained root. The group with granulation areas showed 21.6% with systemic disease, while the figure for the whole survey was 25.7% with systemic disease. The only group which showed a slightly higher proportion of systemic disease was that of cysts. With so few cases, no conclusions can be drawn.
Thus, the survey does not indicate any connection between the presence of retained roots and systemic disease.

CONCLUSIONS FROM CLINICAL SURVEY.

1. Roentgenographic identification of an object as a retained root is not positive in every case, and errors can be made.

2. Roentgenographic identification of a granulation area or cyst, associated with a retained root, is comparatively easy.

3. Sclerosis of bone in the vicinity of retained roots occurs more in the mandible than the maxilla.

4. There is less tendency towards resorption of alveolar ridges in those patients with sclerotic areas of bone.

5. Pain, infection and pathological change are common in retained roots exposed to the mouth. This observation is equally true for the initial exposure when extraction is attempted or for later exposure by resorptive processes.

6. Pain, infection or pathological change is rare in roots wholly in bone.

7. Eventually most roots will reach the surface of the bone.

8. Eventually some roots will become exposed in the mouth. This depends on the size of the root and the rate of resorption of the bone.

9. The buried root without radiographic evidence of pathological change will remain so, unless resorptive processes expose it to the mouth.

10. No evidence of a connection between retained roots and systemic disease was found.
PART B  -  PATHOLOGICAL INVESTIGATION.

METHOD.

During the period of the clinical survey, sixty roots were retained for pathological section. The roots were taken consecutively, with no attempt made at selection, other than the fact that they were roots wholly in bone. Only in one patient was there seen any roentgenographic pathological change, which was a small granulation area at the root apex. All patients were symptom-free. Whenever surgical principles would permit, a block of bone enclosing the root was removed in toto with the aid of a surgical bur rather than simple root removal.

Later, a further twenty roots were deliberately and carefully selected, each root fulfilling certain specific conditions, to investigate problems arising from the previous study.

Immediately upon removal each root was placed in a solution of neutral buffered formaldehyde, formula:-

\[
\begin{align*}
40\% \text{ Formaldehyde} & \quad 100 \\
\text{Water} & \quad 900 \\
\text{Sodium dihydrogen phosphate} & \quad 4 \text{ gms.} \\
\text{Disodium hydrogen phosphate} & \quad 6.5 \text{ gms.}
\end{align*}
\]

in which it was fixed for two to three days or longer. It was then decalcified in 5\% nitric acid in distilled water for one to three days and a roentgenogram taken to determine that decalcification was complete.

The root was washed and placed in 70\% alcohol for twenty-four hours, then in 95\% alcohol for six hours, absolute alcohol for three hours and then cleared in chloroform for fifteen hours. After clearing it was put in a paraffin embedding oven for one hour and embedded in a paraffin block. Some roots were embedded
vertically and some horizontally. The block was mounted on a microtome and sections cut at 7μm thickness, using ice constantly on the face of the block. Serial sections were taken at previously determined levels and selected to show the pulp canal. The sections were fixed carefully on a slide over a very small flame. Up to ten serial sections of each root were taken and one at the beginning and end of each series, that is, two slides of each root, were selected for initial staining with haematoxylin and eosin. The standard acid haematoxylin and eosin stain was used. The patients whose roots were sectioned comprised thirty-six females and twenty-four males. Forty-five of the roots were from the maxilla and fifteen from the mandible. Nine of the roots had been present for less than ten years, fifteen between ten and twenty years, twenty-one between twenty and thirty years, ten between thirty and forty years and five roots had been retained for over forty years.

RESULTS.

In spite of the fact that only objects showing roentgenographic evidence of periodontal space and lamina dura were diagnosed as roots, pathological investigation showed that five specimens in the series were actually sclerosed bone. The apparent roentgenographic periodontal space and lamina dura must have been superimposition of the trabecula of cancellous bone. Eight of the smaller roots were found to be fragments of cementum only or cementum with a little dentine, indicating fracture either above the apical opening of the root canal or to one side of it. The cementum of these roots was in similar condition to those of the
following series and will be described with them.

Of the remaining forty-seven roots, forty-six had certain features in common. The other one was entirely different and will be described later.

The first outstanding feature of these forty-six roots was that they each contained a vital pulp. While this was recognizable as a dental pulp, it was very different from the pulp of standing teeth.

The average pulp contained a nerve bundle, an artericle and two veins, although in some sections up to four vessels were seen. These are features common to dental pulps, but here the similarity ended. They serve, however, to identify the tissue as pulp.

Firstly, not one section contained an odontoblast layer lining the dentinal surface, nor were any cells seen resembling odontoblasts.

Secondly, not one section contained star-shaped pulp cells, which usually serve to distinguish pulp from connective tissue.

The pulp in each case was, with the exception of its nerve and vessels, indistinguishable from connective tissue. Its cells were fibroblasts and fibrocytes arranged with their nuclei roughly parallel to the pulpal walls. These nuclei averaged from about six to fifteen to a 950X field. In other words, the pulps were relatively acellular. These fibrous cells were scattered in interlacing fibrous bundles, which also were arranged roughly
parallel to the pulpal wall.

The second outstanding feature was that in forty-two of the forty-six roots there was marked narrowing of the pulp canal. The four exceptions I shall deal with later.

Separating the pulp from the dentine, in each case, was a band of calcified substance of varying width. This decreased the volume of the pulp canal by about a quarter in some cases to more than ten times in others. (See plates 1, 2, 3 and 4.)

A description of a typical transverse section across the root in the region of the pulp canal is given below. This is stained with haematoxylin and eosin. Extraction of the root in question had been attempted twenty years previously.

The pulp canal is only one-third of its previous width. A wide band of calcified material separates the pulp from the dentinal tubules. This band is much lighter in staining than the dentine. The dentinal tubules finish abruptly with a fine thin line of blue (Haematoxylin) staining material separating them from the new calcified tissue. This averages 1mu in width but widens to an amorphous band, 7mu in width in a few places.

The new calcified tissue stains pink and looks irregular. It has empty lacunae with the edges lightly blue stained, as well as small irregular cracks, also with edges stained blue. These are mostly arranged at right angles to the tubules of the dentine. The pink stain of this material varies in places, some cell sized areas staining a deeper pink. There are no tubules to be seen.
Various artifacts of film.

Outline of original pulpal wall

Dentinal tubules

Dentine torn during cutting

New calcified tissue which has narrowed the canal

Pulp canal containing a nerve, blood vessel and fibrous tissue

Transverse root section, magnified 100X.
- PLATE 1 -
A higher magnification of section seen in Plate 1—magnified 450X.

- PLATE 2 -
A nearly transverse section of another root, magnified 100X.

- PLATE 3 -
Section seen in Plate 3, magnified 450X.

- PLATE 4 -
The inner edge of this material is stained intensely blue with haematoxylin for about one-twentieth of its thickness. This band stains more intensely towards the pulp so that the pulpal border is a thick, very dark blue band. This band has peninsulas projecting into the pulp, averaging about 7μm in length. In some areas there is a much lighter stained calcified material, averaging about 5μm in width between this very dark band and the pulp. This lighter stained material is between the projections into the pulp but is not seen on the projections.

From the end of these projections, collagen fibres proceed into the pulp, joining up with branching fibres of the pulp. Some collagen fibres do not arise from the projections, but from the lighter stained material between the projections, and appear to become continuous with it. (See Plate 5.)

The pulp has fifteen fibrous cell nuclei per 900X field with branching and interlacing collagen fibres between. The fibres are in bundles, parallel to the pulpal wall. There are two thin-walled blood vessels, with red blood cells in them and a nerve bundle, about 90μm in diameter, showing healthy nervous tissue. The general picture is that of healthy connective tissue. The cells are normal in shape and size and there is no sign of degeneration. There are no odontoblasts and no stellate pulp cells.

The pulpal tissue described is seen in every one of the forty-six roots. There are variations in the number and density
Pulpal wall, magnified 450X.

- PLATE 5 -
of the fibrous cells present and in the number of blood vessels, but in every case healthy tissue resembling connective tissue is to be seen.

There is some variation in the more recently calcified tissue which narrows the pulp canal. The four roots mentioned earlier are different in that this wide calcified band is absent, that is, there has been no decrease in size of the canal. These roots were sectioned transversely. In these four roots the dentinal tubules are separated from the pulp by a blue, stained band of calcified material varying in width from 1μm to 7μm with a thin band of pink staining material on its pulpal surface. Once again, there are projections into the pulp, to which collagen fibres are attached.

In the roots which were sectioned longitudinally some further variations are seen in this calcified band. Firstly, near the point of fracture, in two of the larger roots, a narrow band of secondary dentine is seen proceeding towards the apex for a short distance. This secondary dentine is separated from the dentinal tubules by only a fine line of deeply staining material. The secondary dentine contains fewer tubules than does the dentine. They lie at an angle to the direction of the dentinal tubules. Now these two root canals have been narrowed by the same band of calcified material, which is seen as a wide band on either side of the pulp canal. Where the secondary dentine is present it is covered in exactly the same manner as the primary dentine, which results in a further narrowing of the canal. The band is thus
continuous along the pulpal wall.

Secondly, in a few of the roots there is more than one band of this calcified material. In one root three distinct layers are seen and the others show two layers. In each case, the innermost band is the more heavily stained. The bands are separated by a line of fairly deeply stained blue material.

In these longitudinal sections, the band next to the dentinal tubules has a finely striated appearance, with the striations at right angles to the dentinal tubules. Some empty lacunae are seen arranged irregularly throughout the material. This band is quite wide and is fairly regular in width down the length of the canal. On its pulpal side it becomes heavily stained with haematoxylin, with the peninsulas projecting once again towards the pulp. (See Plate 6.)

The second and innermost band is not continuous. It is quite wide in some places, narrow in others. At the ends of each section it becomes continuous with the haematoxylin stained inner boundary of the outermost band. It, too, has a finely striated appearance, but the lines are roughly at right angles to the striations of the outer band. The pattern, however, is not as regular. It does not contain empty lacunae.

Thirdly, in a few of the roots sectioned longitudinally I succeeded in obtaining the apical foramen as well as the length of the pulp canal. The cementum layer of the outer surface of the root can be seen entering the pulp canal in a continuous band, as is described in the literature. But in these sections this band
Longitudinal section of a root, magnified 100X.
is continuous with the band lining the dentinal surface of the pulp, that is, the calcified tissue which narrows the pulp canal. While this band is continuous with the cementum of the outside of the root, its appearance gradually changes a short distance from the apical foramen. The empty lacunae of the cementum gradually become very sparse or disappear. The lamellae of the cementum become much finer and shorter until the finely striated appearance shown in Plate 6 is seen. This change in morphology is not accompanied by a change in staining reaction. This band takes up eosin stain similarly to cementum.

Fourthly, the roots sectioned longitudinally show the fractured surface of the root to be covered by one or more layers of cementum, which has been described in the past. This cementum bridges across the pulp canal.

In some roots where I have obtained longitudinal sections through the pulp canal towards the fractured surface, this cementum is seen to be entering and filling the pulp canal for a considerable distance until the pulp is reached, where once again it becomes continuous with the band of calcified tissue narrowing the canal. It is similar to the cementum entering the apical foramen in that, as it proceeds down the canal, its morphology gradually changes. Towards the fractured surface, many lacunae are seen. The lamellae are fairly thick or arranged irregularly. As it nears the pulp, the lacunae gradually disappear and the lamellae become finer and arranged in a longitudinal direction. (See Plate 7, Plate 7a and Plate 7b.)
This shows the pulp canal of a retained root, near the fractured end. It has been completely filled with calcified material. The dentinal tubules are seen on either side.

This is one of a series of three photomicrographs of the same longitudinal section. The prints join each other at the levels indicated.
Towards pulp.

Level at which Plate 7 joins.

Level at which Plate 7b joins.

Note the gradual change in appearance of this calcified tissue.

The second of the series. They are magnified 100X.

- PLATE 7a -
A distinct layer of secondary dentine

Level at which Plate 7a joins

The appearance of this calcified tissue as seen in most transverse sections.

The third of the series.

- PLATE 7b -
What then is this new calcified tissue, which is laid down in retained roots? It takes up haematoxylin and eosin stain to the same degree as does cementum. It stains differently from dentine and secondary dentine, but this difference is not great. In longitudinal sections it is continuous with the cementum entering both the apical canal and the pulp canal at the fractured surface. In some areas it has exactly the same morphology as cementum. It has a fine lamellar structure similar to acellular cementum.

Proceeding from it into the pulp are bands of collagen fibres. In some sections there are cells with large oval nuclei lying between the bands. (See Plate 8.) These cells have an appearance similar to the cementoblasts lying along the cemental surface of the periodontal membrane, which also lie between fibre bundles. (See Plate 9 and Plate 13.)

I think, therefore, I am justified in calling this calcified tissue cementum.

This cementum was laid down in forty-two of the forty-seven roots examined. Four of the others had similar pulps but cementum had not been laid down except for a thin band sealing the dentinal tubules. A perusal of the records provided the answer to this. They were the four roots which had been present in the jaw for the least time. One had had extraction attempted eighteen months previously, one two years previously and two three years previously. (See Plates 10 and 11.) Thus, it is seen that this cementum deposition is a very slow, gradual process. The
Collagen fibres

Cells resembling cemento-blasts

Pulpal wall

Fibres arranged in circular pattern

Nerve bundle

Transverse root section, showing pulp magnified 450X.

- PLATE 8 -
Note the cementoblasts lying between fibre bundles.

Transverse section, showing the periodontal membrane attachment to a retained root, magnified 1000X.

- PLATE 9 -
A nearly longitudinal section, showing a pulp canal before cementum has been laid down. Magnification 450X.

- PLATE 10 -
A transverse section, showing a pulp canal with early cemental deposition. Magnified 450X.
deposition was seen to be very great in the roots where extraction had been attempted over forty years previously. However, the greatest narrowing of the canal was seen in two roots in the twenty-year group, indicating variation in cementum deposition between different patients.

As has been recorded above, the cementum may be laid down in the pulp canal in two or three different layers, similar to deposition on the root surface. Also this deposition apparently continues for many years. It has been stated that cementum deposition continues throughout life on the root surface and that function is not necessarily a stimulating factor. The same appears to be true of cementum in the pulp canal of a retained root.

The pulp itself apparently undergoes rapid modification after fracture. At first I thought that the pulp had been avulsed and connective tissue had grown into the root. It was obvious, from the presence of nerve bundles and the requisite numbers of arteries and veins in every root canal, that the pulp was still present although in a modified form. Cases have been recorded of metaplasia of the pulp of standing teeth with cementum deposition. Metaplasia of the pulp after fracture appears to happen very quickly. The odontoblasts disappear completely, the pulp cells either become fibrous cells or are replaced by fibrous cells and there must be further modification of some of these cells to cementoblasts. In every section that I studied this change appeared to have been completed.
When I first started sectioning these roots I was fairly certain, from its appearance, that the calcified tissue which had been laid down was cementum. At that time I did not have the evidence presented above. It was relatively easy, by various staining reactions, to establish that the fibres proceeding from the cementum into the pulp were collagen fibres. (See Plate 12.)

In the literature I found an article by Levey in which he claimed it was possible to differentially stain cementum. I attempted for some months to stain roots by this method without success. I could not succeed in obtaining a uniform stain in the cementum of the root surface. I then started staining tooth sections, on which the original work had been done. By modifying the stain I eventually succeeded in differentially staining cementum by this method but the stain is only taken up by acellular cementum. Levey states that cementum will stain red and dentine green. This result I found is only possible where the dentine is covered by a thin layer of acellular cementum. Cellular cementum stains green, and tooth sections towards the apex, where there may be layers of cementum, may stain green or red or pink. There may be variations in staining in the same layer of cementum.

With this modified method I succeeded in differentially staining the cementum laid down in the pulp canal of a few roots, but the results showed such great variation as to be inconclusive. Levey's stain, as modified by me, I record below, as it may be of benefit to someone else.
A section of the pulpal wall of a root, stained by Van Gieson's method, to show collagen fibres. Magnified 450X.

- PLATE 12 -
1. Sections are removed from 50% alcohol and placed ten to twelve minutes in Weigert's acid iron chloride haematoxylin. (This is stored as two stock solutions, A and B. Solution A consists of 100 ml. of fresh 1% haematoxylin in 95% alcohol. Solution B consists of 95 ml. of distilled water, 1 ml. of concentrated hydrochloric acid, and 4 ml. of U.S.P. solution of iron chloride (37.2 Gm. of ferric chloride in 100 ml. of distilled water.) Equal parts of stock solution A and B should be freshly mixed together before use. (Stock solutions last two to three weeks).

2. Wash in distilled water.

3. Sensitize ten seconds in a fresh mordant solution by adding 200 ml. of distilled water to 1.5 ml. of concentrated nitric acid with 1 ml. of formaldehyde and 1.5 ml. of U.S.P. iron chloride added in the order given.

4. Rinse in distilled water.

5. Stain ten minutes in a fresh dilution of 3 ml. carbol fuschin in 50 ml. of 0.2% acetic acid.

6. Rinse in distilled water.

7. Differentiate by returning to mordant for up to one minute (depending on section).

8. Rinse in distilled water.

9. Stain five to ten seconds in 0.01% aniline blue in saturated picric acid solution.

10. Rinse in distilled water.

11. Rinse fifteen seconds in absolute alcohol.

12. Clear with xylol and mount in balsam.
In forty-six of the forty-seven roots examined the dentine appeared normal. Compared with sections of normal teeth it gave an identical appearance and the same staining reactions. The dentine may be vital, alternatively, it may be non-vital but with the appearance of vital dentine in pathological section. With the loss of the odontoblasts, the sealing of the pulpal wall with cementum may have preserved the status quo. Certainly in sections cut along the tubules they appear to be filled with air, and in sections cut across the tubules Tomes' fibres can be seen. As this is the microscopic appearance of normal dentine, all that can be said is that the dentine appears normal. (See Plates 10. and 11.)

The cementum of the root surface in some roots is very thick and in many layers. This thickness generally occurs at the apical end, but in some roots extends for a considerable distance up the root. The cementum may be in as many as five distinct layers, some of which are cellular, others acellular cementum. There is no regularity in this, all possible combinations of pattern having been observed. The only constant factor seen in these roots is that the outermost layer tends to be cellular cementum, but cellular cementum that is relatively acellular. Only two lacunae may be seen in a 500X field. These lacunae contain vital cells. This outer layer tends to be regular and intact, but in a few roots there are small areas where there has been some resorption of the outer layer. This appears as a small saucer-shaped depression lined by cells with large, pale nuclei, giving
the same appearance as is seen with osteoclasts resorbing bone.

The fractured surface of the root is covered by cementum as has been described in the past. This cementum may be in two or three layers, and in some roots is quite thick. Where there are depressions in the fractured surface of the cementum or dentine, they have been filled with cementum. Similarly, the opening of the root canal is filled. The inner edge of this cemental layer is, therefore, quite irregular. The outer surface tends to be smooth and unbroken, giving in many cases a smooth continuity with the root surface.

Some roots were removed encased in a block of bone and sectioned intact. In these the collagen fibres of the periodontal membrane are seen to be attached to the outer layer of cementum of the root surface. Between those fibres cementoblasts are seen in a single line along the root surface. (See Plates 9 and 13.)

The periodontal membrane is identical in structure with that of standing teeth. It contains fibrous cells, cementoblasts, fibre bundles and blood vessels. No section showed fat spaces or any signs of degeneration. In cross section the fibres are seen to be arranged in a circular pattern around the root. In longitudinal section fibres at the apex join with fibre bundles entering the apical foramen. Of particular interest is the fact that the periodontal membrane is continuous around the whole root, even across the fractured
Fibres of periodontal membrane

Cemental surface of root

Surrounding bone

Blood vessel

Cementoblasts lying along root surface

A section through root, periodontal membrane and surrounding bone. Magnified 450X.

- PLATE 13 -
surface. Following fracture, the periodontal membrane must
grow across this surface and unite and thus can be seen the
mechanism by which cementum is laid down on this surface.
With the smaller roots mentioned earlier, which were only
fragments of cementum, the periodontal membrane was seen to
be continuous around them.

In all sections the periodontal space is narrow
and the tissue is compact. This agrees with the observations
made on standing teeth, that the width of the periodontal
space varies with the amount of function, the space decreas-
ing with loss of function and increasing with increased function.

Usually, teeth are extracted because of pain or
periodontal lesions. In the case of periodontal disease the
majority of teeth extracted are vital. The usual cause of
pain is carious involvement of the pulp. Kronfeld\textsuperscript{23} and other
workers have shown that acute partial pulpitis affects portion
of the pulp in the pulp chamber of a tooth. The pulp tissue
in the root canals remains normal. In acute total pulpitis
the tissue in the root canal is the last affected. Chronic
pulpitis affects the pulp chamber at first. The tissue in the
root canal may remain vital for a considerable time, even though
there is complete loss of pulp in the pulp chamber. In these
cases, attempted extraction with fracture would tend to remove
the infected portion of the pulp, leaving vital pulp tissue in
the remaining root. It is easy to see why so many retained
roots are vital.
In this series of forty-seven roots, forty-six have been described above. The remaining root was completely different. Firstly, the pulp was absent and the pulp canal contained cell debris and fibrin. Secondly, there had been no narrowing of the pulp canal. No cementum had been laid down. The pulpal wall was dentine. (See Plate 14.) The tubules of this dentine stained heavily and contained many large black blobs, usually considered to be bacterial colonies, although this has not been proved. These possible bacterial colonies were very thick at the pulpal wall and apparently penetrated into the dentino for about one-third of its thickness. The section shows them getting fewer in number as the tubules proceed out from the pulp until about one-third of the thickness of the dentine has been covered, when normal-appearing dentine is seen. (See Plate 15.)

My records show that with this root extraction had been attempted twelve years previously. It is an upper bicuspid root. The patient had been symptom-free since extraction. The root was high in the alveolus. It seems to me to be of great significance that this root is the one root in the series which had an associated area of granulation tissue.

It was obvious from the work above that the average root remains vital and that cemental deposition on the pulpal wall occurs. Here I had a non-vital root and no cemental
Pulp canal contains cell debris and fibrin

Note that there is no cemental deposition, or narrowing of the pulp canal. The pulpal wall is dentine.

A transverse section of a non-vital root, magnified 100 X.

- PLATE 14 -
Note what may be bacterial colonies in the dentinal tubules, which are most dense towards the pulpal wall.

A higher magnification of the section shown in Plate 14, showing the dentine of the pulpal wall. Magnified 450X.

- PLATE 15 -
deposition. The answer most likely was that the root had been non-vital since extraction. If pulp had been present and later had become infected, surely there would have been some cemental deposition? This raised so many questions in my mind that some further work became essential.

Accordingly, I collected a further series of roots. As may be seen from the clinical survey, deeply buried roots showing areas of granulation tissue are by no means common, and it took me some months to collect eight of them.

These roots had been present, symptom-free, in the alveolus for periods ranging from six months to fifteen years. Each one showed roentgenographic granulation areas and each one was found to be associated with granulation tissue at surgery.

Each root was sectioned and found to be identical with the root described above. (See Plate 14.) No pulp was present, no cemental deposition had occurred. There was no decrease in the size of the pulp canal.

Concurrently, to complete the picture, I collected twelve roots which had become exposed to the mouth, through resorption. The period since extraction had been attempted for these roots varied between ten and forty years. Five of these patients had clinical symptoms of acute infection. Eleven of these roots were associated with granulation tissue.

The root without granulation tissue showed a
healthy and vital pulp, as previously described, with cemental deposition on the pulpal wall. Three of the roots showing clinical infection were seen to be blackened and eroded and microscopically were so altered as to be useless.

The remaining eight roots, in varying degrees, showed characteristics different from the two types already described. In each case no pulp was present. The pulp canals contained cell debris, fibrin and some inflammatory cells, but no tissue. Every one contained evidence of cemental deposition on the pulpal wall. In most of them this had been resorbed to some degree, as seen in plate 16.

It was obvious then what had happened to these roots. Cementum had been laid down and laid down in great thickness. The pulps had obviously been vital until resorptive processes had exposed them to the mouth, when infection supervened.

CONCLUSIONS.

From the work above a complete sequence of events can be put forward.

1. Some roots are non-vital when extraction is attempted or become so as a result of the trauma of fracture when the pulp is lost or dies. Some of these roots become immediately infected and are removed a few days later. Others are loose in the socket and are gradually exfoliated. The small number of non-vital roots which remain in the jaw are
A transverse section of a root pulp canal, originally vital, which has become non-vital on exposure to the mouth. Magnified 100X.

- PLATE 16 -
surrounded by granulation tissue when the tissues heal over them. The granulation tissue may be a residue from that which is produced by the body as a first stage of repair of the socket. Alternatively, the root end may be infected while the socket is still open and granulation tissue produced. This infected area is then walled off by the normal defensive mechanisms. This area of root and granulation tissue may remain quiescent indefinitely. On the other hand, it provides an ideal site for bacterial growth. Clinical evidence shows that acute infection may supervene at any time, probably as a function of the resistance of the patient. Another possibility is that cyst formation may occur.

2. The vast majority of roots that are retained are vital when fractured and remain vital. The tissues heal over them. The periodontal membrane extends across the fractured surface until it meets. Cementum is then laid down on the fractured surface. The pulp undergoes metaplasia and cementum is laid down on the pulpal walls, sealing off the dentine. Thus, the condition of the root has been returned to normal. It is sealed off from the mouth. The dentine is covered. Cementum deposition continues both externally and internally. In other words, conditions are the same as if it were still attached to a healthy tooth, except for the stresses of function. On rare occasions, bacteria may reach and infect the pulp of an intact vital tooth, in patients with an overwhelming septicaemia, as reported by Lieck. Apart
from this, the pulp of a vital tooth does not become infected unless bacteria reach it from an external source, as a result of caries or trauma. Similarly, the pulp of a vital retained root does not become infected unless it is again exposed to the mouth.

3. If the root is exposed to the mouth, it may remain vital for a period. Bacteria may reach the pulp and it then dies. Acute infection may follow. Or the tissues may heal again, leaving it just below the surface with an area of granulation tissue surrounding it. Clinically these roots are sometimes found to be blackened when removed and may be eroded. Microscopically the pulp is absent and the cemental lining of the pulpal wall eroded. Those that have been exposed many times, or have been enclosed in pus, may be eroded away to a mere shell.

With the loss of teeth, resorption commences in the alveolar process. The rate of resorption varies from patient to patient. The length of the roots of teeth differs considerably. The amount of root remaining after fracture varies greatly. I have no doubt that if the patients lived long enough, most root ends, which are more than just a tip, would eventually reach the surface. Yet in some patients of over 90 years of age, I have seen retained roots with a quarter of an inch of bone over them. So, all that can be said is that some vital roots will eventually reach the surface and become infected.
CLINICAL CONSIDERATIONS.

It is obvious that, at time of extraction, there is no method of determining whether a root left will remain vital. Initially there may be pain or infection. If the root is non-vital, acute infection or cyst formation may occur. The acute infection may not occur until many years later. There is nothing shown in this work to justify anyone indiscriminately leaving portions of root fractured at extraction.

When a retained root is discovered during roentgenographic examination it can now be treated on its merits. As stated earlier, granulation tissue in association with a retained root can always be identified roentgenographically, and this has been my experience. It is, of course, possible to identify incorrectly some cancellous structures of the bone as granulation areas. But if the granulation area is there it can be seen roentgenographically. It is then an indication of a non-vital root, which is a danger to the patient and should be removed. Cyst formation could occur or this root could become acutely infected at any time. It is possible, as residual infection, that it may affect the health of other parts of the body. It is with this root that the theory of focal infection may be concerned.

The root which is seen roentgenographically to be in bone, with a periodontal space and lamina dura surrounding it, is in a different category. If small, it may not be a root at all, or it may be a fragment of cementum only. If it is big
enough to have a pulp canal, it is a vital root so long as it is covered. It is of no danger to the health of the part or the whole. Each root must then be judged individually. If its position is such that resorbtive processes will expose it, taking into account the age of the patient, then it should be removed. If it is through the bone and dentures are to be constructed, then it should be removed, firstly because of possible sharp edges and secondly, because the pressure of the denture will eventually cause exposure.

Some patients who have been wearing dentures for many years may have deeply buried vital roots. Some patients may have almost a full complement of healthy teeth, with a deeply buried vital root. Others may have canine and bicuspid roots high in the alveolus in front of the medial wall of the antrum. These roots will never become exposed. In a similar category are palatal roots of molars high in the antral wall or deeply buried third molar roots. The same can be said of lower bicuspid roots below the level of the mental foramen or molar roots in the vicinity of the mandibular canal. I do not see any justification whatsoever for the routine removal of these vital roots. The root which is judged to be a danger to the patient should be removed. It should be recognised, however, that there are many which will never affect the patient and that it is possible to diagnose those as such, and leave them alone.
64.

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