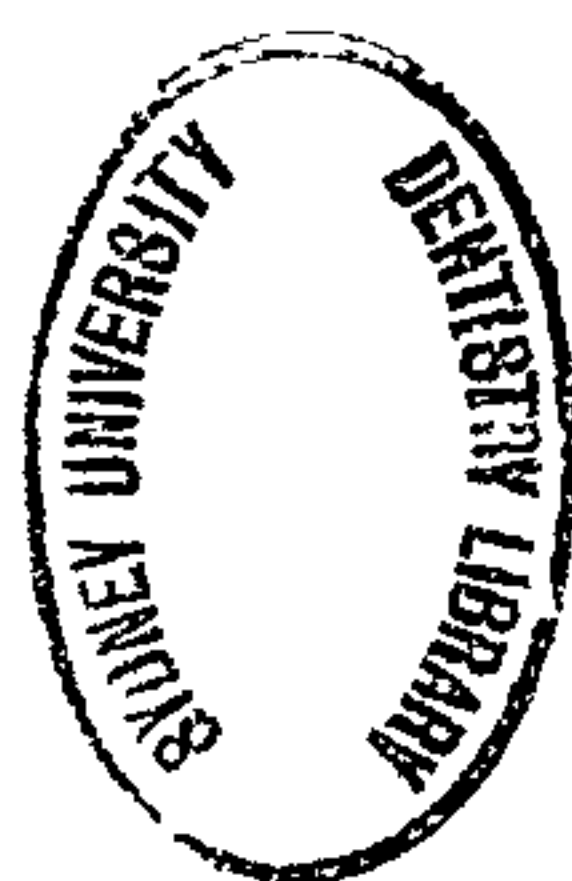


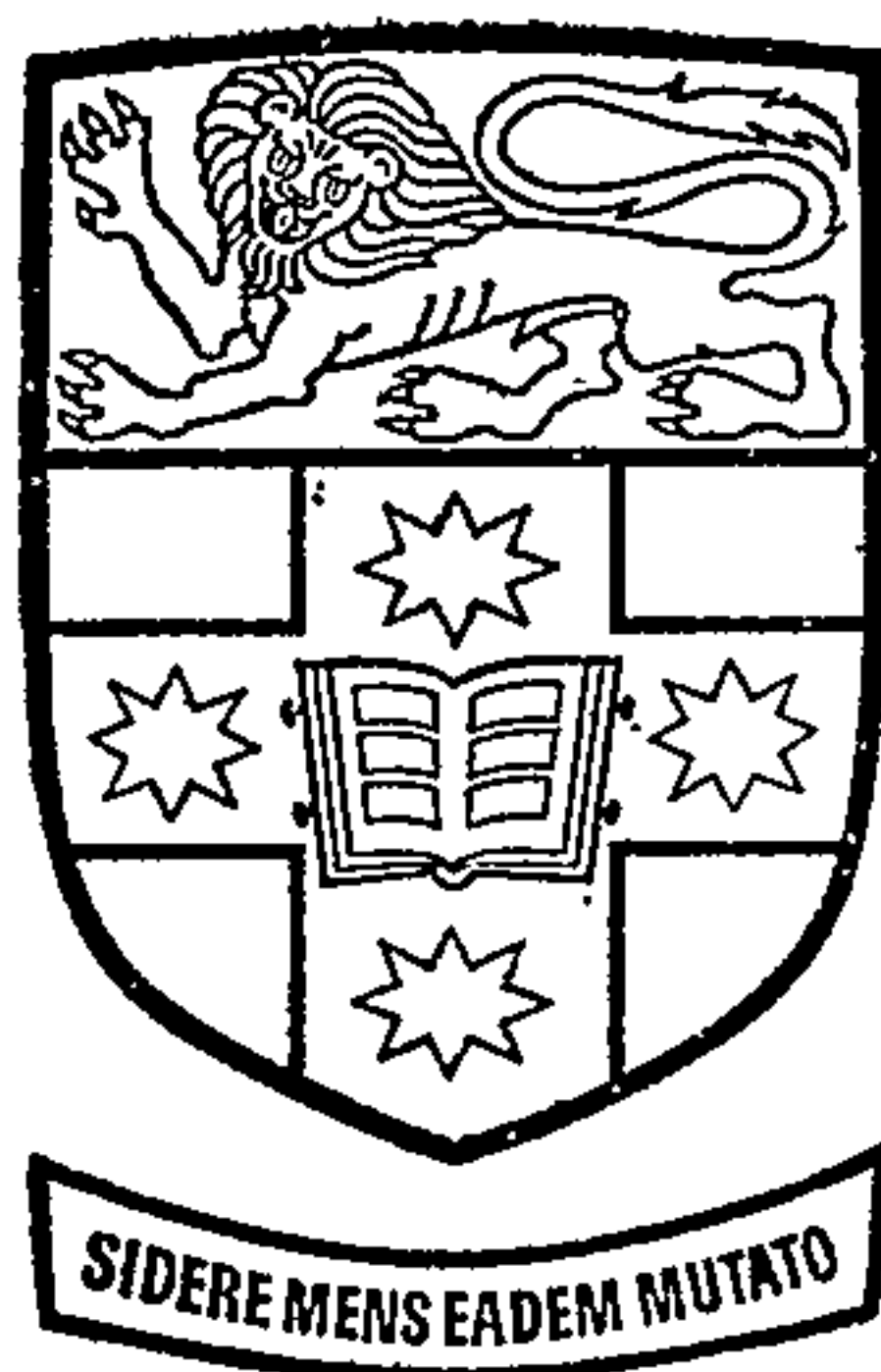
A CRITICAL REVIEW OF THE CURRENT LITERATURE CONCERNING
PRESERVATION OF THE VITALITY OF THE EXPOSED PULP WITH
EMPHASIS ON THE USE OF CORTICOSTEROIDS.



Submitted in partial fulfilment of the
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TABLE OF CONTENTS

INTRODUCTION

SECTION I

- 1) Anatomy and Physiology of the Pulp
- 2) Pathology of the Pulp.
- 3) Reaction of the Pulp to Dental Caries.
- 4) Aids to Diagnosis in Selection of Cases.
 - a) History
 - b) Radiograms
 - c) Thermal Tests
 - d) Electric Pulp Test
 - e) Percussion, Palpation and Mobility
 - f) Transillumination
 - g) Test Cavity
 - h) Pulp Haemogram
- 5) Mode of Healing - The Dentine Bridge
- 6) Direct Pulp Capping and Pulpotomy
- 7) Internal Resorption
- 8) Indirect Pulp Capping
- 9) Pulp Capping Materials

SECTION II

- 1) Introduction
- 2) The Rationale of Pulpal Treatment with Cortico-Steroids
- 3) Early Experimentation with Cortico-steroids in Pulpal Therapy
- 4) Review of Literature concerning Ledermix
- 5) Ledermix - its composition
- 6) Conclusion.

INTRODUCTION.

It has been considered for the purpose of this review unnecessary to discuss in detail the Morphology of the dental pulp and dentine, as this may be found in any recognised text-book, but to concentrate on the clinical problems involved.

The materials discussed are those in current usage for exposed pulp preservation, whilst other materials may be touched upon and it is the endeavour of the author to review as many results as possible in this field and to draw sound conclusion from statements made. The field of cortico-steroids in dentistry is comparatively new and here it is the aim to provide a basis from which further research may be undertaken.

Thus, this thesis is divided into two distinct sections. The first section dealing with non-corticoid drugs and the second sections dealing with cortico-steroids and their combinations, exclusively, utilising the commercial product Ledermix as their prime example.

However, when considering pulp therapy one must delve into the past to understand the thought and effort that has gone into this realm of dentistry and to note the lack of the true scientific attitude by some into this work. This may then allow us to look again at our own statements to note

how much controversy there was, and still is concerning a question such as "should an attempt on the pulp once exposed ever be made to maintain its vitality?" It will be shown at a later stage that the pulp has marvellous recuperating powers if treated in a conservative manner, something which was hardly considered even early this century.

Castognola,²⁵ Quigley¹⁰³ and Berman¹¹ have all reviewed this subject before. However, my aim is to bring together all of their information as a preface to the important work of considering the immediate study being carried out in this field.

The first attempted vital capping was carried out by Philip Pfaff in 1756 with a small piece of gold foil adapted to the base of the cavity.²⁵

Then in 1826 it was reported that Leonard Koeker cauterized the exposed pulp with a hot iron wire and placed silver or lead caps over the exposures.¹¹

It then appeared that little further was written concerning pulp capping until the middle of the 19th century when Albrecht (1856) utilised opiates, caustics and eugenol on the exposed pulp. Mc Kown (1859) recommended cotton soaked in creosote and tannic acid, whilst Taft (1859) was in favour of cauterizing recently exposed pulps with nitric acid and placing a filling immediately. These results were purely a subjective evaluation. In fact Mc Kown's results were produced on one of his own teeth.¹⁰³

The history of pulp preservation really begins in the early 1860's. Allport (1866)¹⁰³ and Atkinson¹¹ (1866-1868) suggested amputation of all projecting cornua of exposed pulps and placement of a temporary filling until it was healthy. Allport used the blood clot formed during operation as his means of capping. J. Foote (1866) also, believed the blood clot to be the best means of covering the pulp.¹⁰³ This certainly appeared to be a reasonable assumption, considering medical knowledge of the day.

Louis Jack (1873) maintained that preservation of the vitality of the pulp was possible, and especially favourable in those cavities where a new formation of secondary dentine within the pulp sealed off the exposure. He stressed that treatment should be directed to bring about the formation of secondary dentine and believed that repair of the pulp could be brought about in the same way that other tissues may be repaired so long as that tissue is not irritated further by the use of escharotic chemicals and thus destroy the dentinal cells.¹¹

Witzel (1874) introduced true pulp amputation as it is called today. He believed as we do, that if the vitality of the pulp were maintained a building of secondary dentine would occur. He utilised weak phenol to destroy bacteria and prevent decomposition. Although Witzel stressed the principle of antiseptic treatment, and

originally reported only 3% failures in a large number of cases treated, additional failures were later noted.¹¹ This was possibly due to the use of Phenol and caused him to later become discouraged with his results and state that complete healing of the pulp was impossible.

Some exotic means of aiding pulp healing were put forward during the late 1870's e.g. Garrettson (1876) suggested depression of the heart rate to 55 beats per minute, by administration of bromide, to reduce hyperaemia, as an aid to pulp capping.¹⁰³ However this was not followed up.

In 1876 Harris suggested pulp capping with celluloid and ether and in 1878 Cravies utilised Lactophosphate of Lime and in 1879 Stellivagen utilised non-carious dentine scraped from the wall of the cavity.¹⁰³

With regard to Cravies and Stellivagen and the consideration of calcific materials to catalyse healing especially the use of autogenous dentine shows us that some of the oldest methods are again being considered today in what may be termed the great biological and experimental era.

In 1896 Tomes¹¹ laid the foundation of the histophysiology of pulpal healing. Very little has been added since. He described in detail the histological structure of the tooth that had healed by forming a calcific bridge

under a large pulp exposure. He believed treatment should be aimed to stimulate the formation of secondary dentine so that an exposure may be recovered. Therefore, it was improper to use any medicament that was too strong or caustic lest this destroy the formative cells and thus interfere with the healing process. He also thought it was rational not to remove the clot of blood forming over the amputated pulp stumps but to protect it.

Tomes advised against the treatment of inflamed pulps because of the impossibility of thorough drainage and with this Miller¹¹ (1899) agreed. However, Miller did not believe that every pulp should be devitalised, but in certain cases inflammation can be reduced and a cure obtained. This required a true diagnosis of the state of the pulp which was acknowledged by Biro¹¹ (1899) and which even today is impossible, although successful therapy may well depend on it.

Thus a reversion to pulp mummification and extirpation or amputation occurred, especially in the European School, until in 1920-23 Davis¹¹ advocated vital pulpotomy and partial root canal therapy, for he pointed out that complete pulpectomy is seldom achieved since the majority of teeth had multiple foramina. He produced a courageous paper, published at a time when pulpal mummification and the use of strong antiseptics were utilised rather than an aseptic technique. He emphasised that caustics or injurious

antiseptics should be avoided. However, even today this basic rule is not universally accepted.

Daetmyler¹¹ (1921) observed an apparent stimulation of the pulpal tissue to form secondary dentine where dentine splinters were present in the pulp following treatment. This led him to believe that the pulp had a relatively strong resistance against infection.

However, in 1922 Rebel¹¹ published a report of experiments on cats and dogs where all the pulps died. He stated that often quoted maxim that "one must consider an exposed pulp a lost organ".

In 1927 Pabizzi¹¹ confirmed Rebel's conclusion. However, it will be noted that Pabizzi sealed the cavities with phosphate cement which today is known to present marginal leakage shortly after placement.

It is unfortunate that Rebel's influence was so strong that further efforts to use vital pulpotomy techniques in Europe were inhibited for some years. However, despite this, further experiments have been conducted leading to the later work with the corticosteroid compounds.

SECTION I

ANATOMY AND PHYSIOLOGY OF DENTAL PULP.

The dental pulp is of mesenchymal origin and contains most of the cellular and fibrous elements which are present in connective tissue. The primary function of the pulp is the production of dentine. The pulp furnishes nourishment through the odontoblastic processes to the dentine, and possibly to the innermost layer of the enamel. Nutritional elements are contained in the dental lymph.

The pulp also, contains nervous elements. Some of these nerves give sensation to tooth structures, others serve to regulate the blood supply of the pulp itself by ending on the muscular elements of the vessels.

The pulp is well protected against external irritations as long as it is surrounded by an intact wall of dentine.

Development of the Pulp.

This begins at about the fifty-fifth day of embryonic life in the region of the incisors. The first indication is a proliferation and condensation of mesenchymal elements, the dental papilla, at the basal end of the enamel organ. Due to the rapid development of the epithelial elements of the tooth germ into a bell-shaped enamel organ, the future pulp is well defined in its outline.

Anatomy.

The dental pulp occupies the pulp cavity which consists of the coronal pulp chamber and the root canals. The pulp

is continuous with the periapical tissue through the apical foramen. The shape of the pulp chamber follows, in young individuals, the outlining of the dentino-enamel junction. The extensions in the cusps of the tooth are called pulp horns. In erupting teeth the pulp chamber is large, but becomes smaller with advancing age, due to deposition of dentine. Most of the dentine is formed on the floor of the pulp chamber, some is formed at the occlusal wall and, less still, on the side walls of the pulp chamber. The chamber may be further narrowed and its shape may become irregular by formation of irregular dentine.

Advancing age induces similar changes in the root canals. During root formation the apical foramen has a wide opening, limited by Hertwig's epithelial root sheath, which is arranged as a diaphragm at the root end. In the course of root formation Hertwig's sheath breaks up into epithelial rests, and cementum is laid down on the root surface.

At any distance from the apex of the tooth side branches of the root canal may be present. This may be due to a defect in Hertwig's sheath during development of the root at the site of a larger supernumerary blood vessel.

There are variations in shape, size, and location of the apical foramen. A regular, straight apical opening is rare, occasionally the cementum can be traced from the outer surface of the dentine into the pulpal canal. Sometimes

The apical opening is formed on the lateral side of the apex, although the root itself is not curved. Frequently there are two or more distinct apical foramina, separated by a band of dentine and cementum or cementum only.

Structural Elements.

1. Odontoblasts.

Dentine development begins approximately in the fifth embryonic month, and shortly before this, the odontoblasts begin to differentiate.

The odontoblasts are highly differentiated connective tissue cells, columnar in shape, with an oval nucleus. From each cell a cytoplasmic process extends into a tubule in the dentine matrix. These are Tomes Fibres. The ends of the odontoblasts, adjacent to the dentine are separated from each other by terminal bars and are connected to each other and with adjacent cells of the pulp by intercellular bridges.

The odontoblasts are more cylindrical, lower in the crown, and become cuboid in the middle of the root. Close to the apex of an adult tooth they are flat and spindle-shaped.

The function of the odontoblasts is not as yet fully known. Doubtless they play a part in the nutrition and sensitivity of the dentine and also in the formation of dentine matrix.

2. Korff's Fibres.

Korff's Fibres between the odontoblasts are the primary elements in forming dentine matrix. They originate from among the pulp cells as thin fibres, thickening at the periphery of the pulp, to form relatively thick bundles which pass between the odontoblasts.

3. Connective Tissue Cells.

As the development of the tooth germ progresses, the pulp becomes increasingly vascular, and the cells develop into star-shaped connective tissue cells (fibroblasts). These cells are more numerous in the periphery of the pulp.

In the course of development the relative number of cellular elements decreases whereas the intercellular substance increases. With advancing age there is a progressive reduction in the number of fibroblasts, accompanied by an increase in the number of fibres.

4. Defence Cells.

Several types of cells belong to this group, they are classified partly as blood elements and partly as belonging to the reticulo-endothelial system. In the normal pulp these cells are in a resting state. A group of these cells is that of the histiocytes which are generally located along the capillaries. Their cytoplasm has a notched, irregular, branching appearance with dark and oval nuclei. It is believed that during inflammation the cells withdraw their

cytoplasmic branches, assume a rounded shape, migrate to the site of inflammation and develop into macrophages. Another group is the undifferentiating mesenchymal cells. These as in the case of histiocytes are found in close association with the capillaries. They have oval elongated nuclei and faintly visible bodies in their cytoplasm. In inflammation they form macrophages.

Also present is the amoeboid wandering cell. Its cytoplasm is sparse and shows fine extensions. The dark, often kidney-shaped nucleus fills almost the whole cell. In chronic inflammation reactions they migrate to the site of injury and change into macrophages. They may also develop into plasma cells, characteristic of chronic inflammation.⁹⁷

Intercellular Substances.

This consists of fibres and gelatinous cementing substances. The fibres are for the greater part, fine collagenous fibres arranged in a fairly regular network. The ground substance is an amorphous, gel-like material composed to a great extent of muco-polysaccharides.¹¹⁶

Blood vessels.

The blood vessels of the pulp enter through the apical foramen. Usually one artery and one or two veins. The artery branches out into a rich network of blood vessels soon after entering the root canal. They are clearly

identified by their straight course and thicker walls, while the thin-walled veins are wider, have no valves and frequently have an outline similar to a row of beads. The capillaries form loops close to the odontoblasts, near the surface of the pulp, and may even reach into it.

The walls of the arterioles are thin and limited to a single layer of muscle in the tunica median.

Lymph Vessels.

Schour¹¹⁶ claimed the existence of some distinct lymph vessels whilst Snyder and Kaufman¹²⁹ only agree to their possibility. However, Orban⁹⁷ states that lymph vessels are present in the pulp but require special methods to render them visible.

Nervous Supply.

This abundant supply enters the apical foramen as a thick myelinated bundle which splits into numerous fibre groups and ultimately into single fibres which lose their myelin sheath whilst passing through the sub-odontoblastic layer.

The unmyelinated fibres of the sympathetic nervous system are also present.

All stimuli elicit the one sensation pain. This feature is peculiar to the pulpal supply. There is no mechanism for differentiating between heat, cold, pressure, or other stimuli because the only fine nervous endings present are specific for the reception of pain.

PATHOLOGY OF THE PULP

The etiology of pulpal injury may be divided into "Mechanical", "Bacterial" and "Chemical".

(Injuries due to Mechanical and Bacterial causes will be dealt with at this stage).

Mechanical.

These injuries are due either to trauma or pathological wear of the teeth. Traumatic injury may or may not be accompanied by fracture of the crown. Trauma is less frequently the cause of pulp injury in adults than in children which injury may be due to a fall or a blow. In addition certain dental procedures are occasionally responsible for injury of the pulp. Among these operations may be mentioned accidental exposure of the pulp while excavating carious tooth structure, or overzealous preparation of retentive areas in cavity preparation. The pulp may also become exposed as a result of pathological wear of the teeth either from abrasion or attrition if secondary dentine is not deposited rapidly enough.

Bacterial.

The most common cause of pulp injury is bacterial. Bacteria or their products may gain entrance to the pulp through a break in the dentine or the above reason, from extension of infection from the gingiva, or by way of the bloodstream.

The species of bacteria recovered from inflamed or infected pulps have been many and varied. Although, Lactobacilli (acidophylic) organisms are commonly found in carious dentine, they are seldom recovered from the pulp because of their low degree of evasiveness. Bacteria need not be present in the body of the pulp to produce inflammation, since sufficient irritation may be produced on the surface of the pulp to cause an inflammatory reaction. The bacteria probably most often recovered from infected vital pulps are streptococci and staphylococci but a large variety of other micro-organisms from diphtheroids to anaerobes have been isolated. (A full discussion concerning bacteria infecting dentine and pulp will be found in Chapter 3.)

Mechanism of Pulp Injury and resulting changes.

According to Grossman⁵¹ once the pulp is exposed either by caries or by trauma, it may be considered infected since micro-organisms gain access to it almost immediately. The invading bacteria, however, may be confined entirely to the small area of pulp exposure.

Although the coronal area of the pulp may be involved by a mild or even severe infective process, the body and apical portion of the pulp may be entirely normal. The reaction of the pulp in the involved area is that of inflammatory response. Polycorphonuclear leukocytes reach the area and further dissemination of bacteria deeper into

the pulp is for the time, warded off. The reaction in an inflamed pulp differs from an inflamed organ in that little room is provided during the inflammatory state for swelling of the pulp, as it is enclosed in a hard unyielding dentinal wall except at the apical foramen.

If the inflammatory process is severe, extension will progress deeper into the pulp. Considerable inflammatory exudate will accumulate giving rise to pain from pressure on nerve endings. Areas of necrosis will set in, owing to disturbance in nutritional supply, many of the polymorphoneuclear leukocytes will die, and pus will form. If the process is less severe, lymphocytes and plasma cells will take the place of the polymorphoneuclears and the inflammatory reaction may be confined to the periphery of the pulp. Such a state may be localised for quite some time unless the micro-organisms reach deeper into the pulp and set up an acute reaction or else the chronic process may continue until most or all of the pulp is involved ultimately leading to its death. In the course of this development the organisms may be killed off but more commonly they survive and set up a reaction in the periapical tissues.

It was formally considered that owing to the anatomy of the pulp and its environment which favours continued re-infection, that exposure indicated destruction of the organ. However, as indicated above the pulp exhibits a definite defense.

The Inflammatory Response.

Snyder & Kaufman,¹²⁹ Menkin⁸⁶ & Grossman⁵¹ tend to agree upon the nature of the inflammatory response in noting that with excessive stimulation cell permeability becomes increased and the cell membrane ruptures. The exact exudate is still an unknown. Experimental evidence shows that when cells are damaged hyaluronidase is liberated. However, there are those who maintain that histamine or histamine-like substances are factors involved.

As this altered fluid exchange affects the cells of the dental pulp it also affects the capillaries in a similar fashion. This chemical mechanism will cause a loss from the capillaries of plasma, salt, urea, fibrinogen formed elements, lipids, mucin, antibodies, enzymes, antienzymes and hormones. Further alterations are effected by the change in diameter of the blood vessels. The first change seen, which is initiated by the nervous system, is an instantaneous but brief contraction. This is immediately followed by a longer lasting dilatory phase.

The next change is the slowing of the blood stream immediately after a brief acceleration, allowing for migration of the contents into the extra capillary spaces. If the slowing is marked, however it can result in complete stasis with subsequent necrosis. The factors controlling this deceleration are swelling and proliferation of the

endothelial cells and the increased thickness and roughness of the endothelial walls. The increase in size of the endothelial wall is caused by the absorption of the CO_2 and the acids of increased metabolism, increasing its hydrotropic properties. Swelling also occurs in the protein of the plasma, thereby increasing its viscosity. Similarly, the erythrocytes absorb CO_2 and metabolic acids, causing them to swell and clump.

As the current slows the leukocytes tend to gather along the periphery of the vessels or to marginate. This happens because of (a) the lighter weight of the erythrocytes, (b) the lower surface tension and (c) the presence of leukotaxine, which Menkin⁸⁶ believes increases capillary permeability and induces the migration of the white blood cells through the capillary wall. This movement of leukocytes serves two functions (1) the ingestion of the invading bacteria and (2) the providing of proteolytic enzymes.

The exudate is composed of two fractions:

i) A lymphlike fraction containing plasma, urea, fibrin-forming elements, lipids, mucin, antibodies, enzymes, antienzymes and hormones.

ii) The formed element fraction containing:

(A) Polymorphonuclear leukocytes which ingest bacteria by phagocytosis and remove particles of cell and tissue breakdown. These cells also provide proteolytic enzymes which with the

exception of leukoprotease are liberated upon the death of the cell. Polymorphs appear early in inflammation and function only in an alkaline medium.

(B) Macrophages which become more numerous as the pH of the exudate drops. They are mainly phagocytic and produce lymph protease. The fall in pH is a result of a fall in the alkaline reserve as well as the absence of oxygen. Mainly, however, the lower pH is due to the lactic acid produced by the anaerobic glycolysis of glucose.

(C) Lymphocytes which are characteristic of chronic inflammation appear together with plasmocytes as the pH of the exudate turns acid. Their function is believed to be concerned with antibody formation.

(D) Erythrocytes whose function is to carry some oxygen to the cells of the exudate.

(E) Platelets which are found in small numbers in the dental pulp. Their function is obscure, but it is believed that they may liberate fibrinogen, help immobilize bacteria and plug injuries in small vessels.

(F) Eosinophils, which are seen mostly in inflammations of the allergic type and are occasionally seen in the pulp.

(G) Fibrinogen, which coagulates to form fibrin, again according to Menkin, as a response to leukotaxine. Its purpose is to fix the irritant mechanically, to allow time for the assemblance of leukocytes and allow more efficient phagocytosis.

It is the histologic character of the exudate which gives identification of the type of inflammation. Clinically it is rarely possible to know which of these phases of inflammation predominates, since the whole picture is one of constant change.¹²⁹

The stages cited can effect either the entire dental pulp or any part of it.

REACTION OF THE PULP TO DENTAL CARIES.

When attempting to determine the prognosis of an exposed pulp it is necessary to have knowledge of the influence of bacteria in exposure and sequelae of the exposure.

Grossman⁵¹ considers that "once the pulp is exposed by caries or trauma it may be considered infected since micro-organisms gain access to it almost immediately".

This statement however, brings us to the question of whether the bacteria precede or follow the carious process and later the efficacy of what is known as "Indirect Pulp Capping".

Jolly and Sullivan⁶² investigated teeth which had not been treated in any way and chose medium-sized lesions. Those teeth with gross lesions were disregarded. On culture they found that dentine chips removed from the deeper layers between the pulp and the lesions were consistently sterile, whereas the tubes containing the culture of chips removed from the lesions themselves showed growth of micro-organisms. On histologic examinations they found few organisms within the tubules ahead of the lesions and they raised a rather interesting question as to whether many investigators have in fact been observing actual organisms within the dentinal tubules, particularly in the deeper parts of the lesions. They stated that it would be illogical to describe all gram positive intra-tubular particles as bacteria. However, King et al⁶⁵ in their very recent bacterologic study of deep

carious dentine in human teeth refuted the above, finding that of 51 teeth with deep carious lesions, in all instances a positive growth was obtained from the deep layer of residual decay, whilst Canby and Burnett²³ considered that either may be the case and that this may be determined by the consistency of the decalcified dentine. They indicated that if the dentine be tough and leathery and the pulp reacting normally that even though the carious front appears to reach the pulp, that the pulp is not necessarily infected and all precautions should be taken to avoid an actual exposure during operative procedure. This argument is backed up by Black¹⁶ who believed organisms do not begin to grow in the tubules until decalcification has occurred some little distance in advance of the lesion, so that the last layer of softened dentine is still sterile. "When all the softened dentine has been removed by the excavation, all the organisms involved in the carious process have been removed."

The questions, however, which must be considered are:

(a) Is there an inflammatory response occurring in the pulp, even before exposure no matter whether the bacteria do not or do precede the carious front?

(b) Is this reaction detrimental to the preservation of the pulp?

(c) What bacteria are present and are they all detrimental to the pulpal preservation?

Earlier works by Massler and Kuwabara⁸¹ and Robinson and Leftowitz¹¹¹ agreed that the invasion of organisms to the outer zone of dentine does not cause injury in mature fully formed teeth. However, deep caries is injurious to the pulp.

According to Massler and Kuwabara⁸¹ who carried out a correlation of clinical and histological study of reactions to caries in 175 human teeth. "The effects on odontoblasts and sub-odontoblastic cells were relatively mild until the necrotic layer came within 3 μ of the pulp. Pulpal inflammations were conspicuously absent under superficial and shallow lesions in spite of clinical symptoms, relatively mild under moderately deep lesions and prominent under very deep active caries".

A recent full scale study of pulpal reactions to dental caries was carried out in 1964 by Yoshida and Massler¹⁴⁹ with the following results obtained.

A) Superficial Caries.

a. Active Lesions

The predentine was generally increased slightly in thickness, but was normal structurely. There appeared to be a disruption or absence of the pulpodentinal membrane with nuclei migrating away from the dentine. Except for the invasion of pulpal cells into the layer of Weil, the pulp tissue was essentially normal.

b. Arrested Lesions

There was either an absence or a very narrow layer of reparative dentine subjacent to a thin lightly stained basophilic arrest line. The predentine was generally decreased in thickness and the underlying pulpo-dentinal membrane was disrupted or absent. The odontoblastic layer was disorganised, degenerated or dystrophic. Below this layer, slight hyperaemic changes and a few chronic inflammatory cells were sometimes observed.

B) Moderate Deep Caries. (Cavitation less than $\frac{1}{2}$ of Dentine)

a. Active Lesions.

In all cases the pulpo-dentinal membrane was absent and the odontoblasts were disarranged, elongated and reduced in numbers. The odontoblasts contained proto-plasmic eosinophilic granules. Beneath the odontoblastic layer the pulp showed slight hyperaemic changes, but with minor exceptions inflammatory cells were absent.

b. Arrested Lesions.

The predentine as well as the odontoblasts were decreased in size or were completely absent. Sub-odontoblastically new dilated blood vessels were present and inflammatory cells were of the chronic type.

C) Deep Caries. (Cavitation more than $\frac{1}{2}$ Dentine to near Exposure.)

Despite the absence of marked degeneration of the odontoblastic layer, the predentine was increased in thickness and appeared more hyaline-like. Within the pulp

there was a localised moderate infiltration of acute and chronic inflammatory cells in addition to a marked circulatory disturbance. The layer of Weil was absent. In some cases pulpal abscesses were seen.

b. Arrested Lesions. Not studied.

It can be concluded from this lengthy report that except under deep dentinal caries the pulp tissue of most teeth showed no marked inflammatory change and that the human pulp showed high reparative potential.

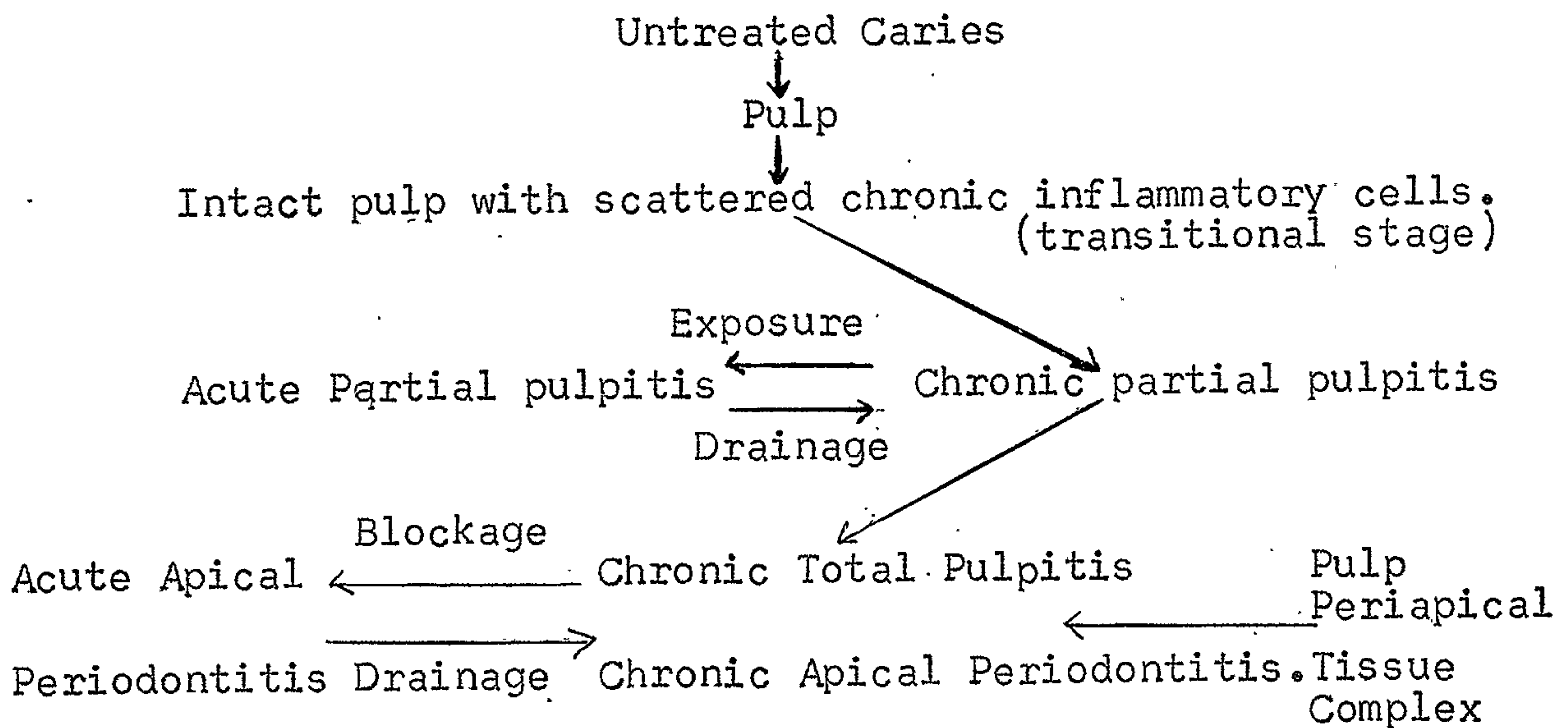
⁷³
Langeland investigated 9 teeth of young patients aged 10-14 years and also noted that under deep lesions a great many inflammatory cells were found in the subjacent pulp.

It thus seems as Leftkowitz and Robinson⁷⁶ found that when caries invades the dentine a contest between the bacteria and the pulp ensues. The pulp attempts to retard disease by establishing a sclerotic dentine barrier at the base of the carious lesion and also forms secondary dentine as a defensive mechanism. This pulpal response was borne out by Seltzer et al¹¹⁸ "The persistence of dental caries for weeks, months or years provides a continuous stimulus for an inflammatory response to occur within the dental pulp. It reacts to a process of dental caries by the formation of sclerotic dentine in the primary dentinal tubules and also by elaboration of reparative dentine under

the region of the involved dentinal tubules. The amount of reparative dentine elaborated tends to keep pace with the amount of dentine removed by the oncoming process of dental caries."

Grossman⁵¹ stated that on exposure there is occurrence of an acute inflammatory reaction. However, Seltzer et al¹¹⁸ have shown that the pulp is chronically inflamed before exposure takes place. "If left untreated a frank exposure occurs and the chronic inflammation becomes acute" (see diagram)

PULP REACTIONS TO DENTAL CARIES



(Seltzer, Bender and Ziontz)

AIDS TO DIAGNOSIS IN SELECTION OF CASES.

"Conservative procedures aimed at preserving vitality of the pulp or healing pulp inflammation can be effective, only if the status of the pulp is correctly assessed".¹¹⁸

No statement could be nearer the truth than the above. However, the difficulty involved in this assessment is still so great that a true scientific method has yet to be devised, although Naylor⁹³ and Prader¹⁰² have approached this problem in a manner fitting its importance. For as Draker³² stated: "Reliable differential diagnosis of pulp disease has only been possible after extraction, by means of histologic slide. The essential objection to the histological examination is the fact that it requires extraction of just the tooth one is trying to save".

The majority of tests utilised rely upon the level of reaction of the pulp in question to stimuli. The main inherent difficulty involved is stated by Bevilacqua¹⁵. "The determination of the extent of tissue damage in the dental pulp has been a crucial problem. The criticism of the so-called vitality test are well founded. The fact that a pulp reacts to the solicitation of different stimuli cannot give us the level of its status as a viable tissue. The inflammatory reaction, acute or chronic can alter the

excitability of the pulpal nerves, but not always in a manner to permit a differential diagnosis."

Cahn²² 1950, called attention to the fact that nerve response could be elicited quite long after irreversible involvement of the pulp. On the other hand Kramer⁶⁹ has shown that severe acute conditions can be present in the dental pulp without pain reaction. This was borne out by Lawson and Mitchell⁷⁵ in a recent double-blind study. A preliminary investigation of a cortico-antibiotic mixture for treating painful pulpitis and surgical exposures was conducted. Controlled diagnostic treatment and re-examination procedures were used.

Fifty cases of painful pulpitis were treated, with double-blind control methods used to compare the vehicle of the experimental mixture with the mixture itself. Re-examination periods were up to 164 days, with an average of 91 days following therapy. Several microscopic sections through the pulps of 7 teeth were studied.

They concluded that:

1. Clinical and histopathological observations did not always correlate well; perhaps indicating that some of the so-called "clinical successes" ultimately may prove to be failures.

2. Painless pulpitis occurred without being obviously clinically detectable.

The most advanced work in this field appears to have been carried out by Mitchell and Tarplee⁸⁸ and by Seltzer et al.¹¹⁸

Mitchell and Tarplee⁸⁸ in their earlier work showed that in one case an excess of two hundred sections were inspected before the exposure with the pathology to which the symptoms could be attributed was encountered.

Seltzer et al.¹¹⁸ studied 166 teeth, taking complete history of symptoms and making the following tests prior to extraction. 1) Electric pulp test, 2) Thermal Tests and 3) Roentgenograms. After extraction the teeth were examined microscopically and findings recorded without prior references to the clinical data. They found that unless serial sections of the teeth were examined, small areas of inflammation could easily be by-passed, resulting in false impressions of existing conditions. Such were the findings of these experimentors that it was necessary for them to reclassify pulp diseases -- a state which had remained unchanged for 28 years.

a. History.

The chief symptoms this will elicit is the presence or absence of pain. This pain may be sharp, dull, throbbing or boring, of long or short duration and may be evoked by stimuli or unprovoked.

Other symptoms such as swelling, fistula openings, adenopathy . are important and should be recorded.

Lawson & Mitchell,⁷⁵ and Kramer⁶⁹ have shown that acute pulpal pathology may occur without painful symptoms whilst Grossman⁵¹ set great store on the character of pain. However, Seltzer et al¹¹⁸ stated that they found no significant correlation between the nature of the pain and the histologic diagnosis, although there was a trend towards an increased awareness of the various types of pain in the categories of "chronic partial pulpitis" and "chronic total pulpitis with necrosis". They concluded that a previous history of pain is an important diagnostic means of establishing the presence of destructive pulp pathology.

The above conclusion is of significant interest for much pulp therapy or extraction is carried out purely by diagnosis of the nature of the history of the pain.

However, as can be seen much controversy still exists as to the importance of this clinical sign, other than to establish that the pulp is in a pathological state.

b. Radiographs.

The radiograph will disclose the presence of caries and whether it threatens the pulp but not necessarily whether an exposure exists, fracture of the root of a tooth, the number, course, shape and width of the root canals; the presence of calcified or foreign material in the pulp chamber or root canal; resorption of dentine adjacent to the pulp cavity; obliteration of the pulp cavity, thickening of the

periodontal membrane or resorption of apical cementum and nature and extent of periapical bone destruction.⁵¹

All authors agree that radiographs will not indicate vital pulpal conditions and that the presence of periapical rarefaction is not necessarily indication of necrosis or it may be due to shadows from other structures overlapping the apical area.

c. Thermal Tests.

For many years the application of heat and cold has been utilised to determine the status of the pulp.

Grossman,⁵¹ Gabel⁴⁶ and McGehee⁷⁷ have all stipulated the use of gutta percha or heated burnisher for heat application and ice or cold water or ethyl chloride for cold.

These methods are not all quantitative, they merely show whether the tooth contains vital tissue or not, although at first Grossman⁵¹ and Stephen¹³² generalised by stating:-

- i. Acute serous pulpitis gives a hyper-response to cold but relatively normal to heat⁵¹ and lasts longer than normal.¹³²
- ii. Acute suppurative pulpitis, gives a severe response to heat but an average response to cold¹³² or pain may even be relieved by it.⁵¹
- iii. Chronic pulpitis gives a lower than normal response to heat and cold or may not even respond at all.^{51,132}

iv. Pulp degeneration gives a similar response to that of chronic pulpitis.¹³²

v. Necrotic or gangrenous pulps give no response to cold but may give a severe reaction to heat.^{51, 132.}

However, in 1963 Grossman⁹⁴ qualified his above statements by noting that a response to cold, normal or abnormal indicated vitality of the pulp, whereas response to heat can occur with either a vital or non-vital pulp. In this article for purposes of differentiating between various stages of inflammation he made little mention of the thermal tests.

Dachi³⁰ studied the relationship of pulpitis and hyperaemia to thermal sensitivity in 100 teeth. These teeth were experimentally treated with Cl V Amalgam and silicate restorations and extracted 7 days later. On histologic examination he found the number of teeth sensitive to both heat and cold increased significantly in the presence of hyperaemia. As pulpal inflammation increased in severity the number of teeth sensitive to heat also increased. No correlation was found between the degree of inflammation and sensitivity to cold.

Seltzer et al¹¹⁸ found that there appeared to be no correlation between an abnormal response to heat and the histological diagnosis of the pulp. "Teeth with inflamed atrophic pulps responded to heat abnormally in the same manner as those with inflamed pulps. Even where liquefaction

necrosis was present, there was no apparent increase in response to heat as compared with the response of inflamed pulps.

Abnormal responses to cold were equally distributed among the pulps of teeth in all diagnostic categories. No single pathologic state of the pulp produced more response to cold than any other state."

Lawson and Mitchell⁷⁵ in a preliminary controlled double blind study utilising G.P. and ethyl chloride as clinical tests for thermal reactions found that clinical-histopathological observations did not always correlate.

When considering the above results of experimentation we must consider is the test exacting enough. There has been much disagreement among authors concerning the ability of these tests to differentiate between the various pulpitic states although most seem to agree now, that one cannot expect to determine more than a vital or a near-vital state within the tooth. However, when we consider Mumford's⁹² work on the evaluation of Gutta Percha and Ethyl Chloride in Pulp Testing, the reason for this variation becomes obvious and it becomes even more obvious that we require a more exacting technique for determining the effects of thermal stimulation before any attempt at differential diagnosis can be carried out. Possibly Naylor's "Thermo-Electric Tooth Stimulator"⁹³ is a step in the right direction. Although Reynolds utilizing the Naylor tooth Stimulator has found no correlation

between the state of the vital pulp and response readings to thermal stimulus - even normal pulps (histologically) showed varied response.¹⁰⁹

However, more results are necessary before an evaluation can be made. Naylor describes an apparatus which is simple to use clinically and experimentally and since it is capable of providing controlled, stimulating temperatures below 0°C. readily overcomes the difficulties encountered with ethyl chloride spray. By reversing the direction of current flow a reversal of the thermal effect occurs and causes a heating. Mumford's recent work⁹² with regard to Gutta-Percha and Ethyl Chloride certainly indicates the urgent need for this more controlled test. He applied heated gutta-percha and cooling ethyl chloride to the upper anterior teeth of dental students on three occasions at intervals of several days and the intensity of sensation was recorded to determine to what extent results were reproducible. Clinical cases were also investigated. He found that:-

i. Methods did not measure the threshold of sensation, but rather the intensity of sensation (sensibility) arising from the application or removal of an approximate amount of heat.

ii. The intensity of sensation reported by the patient is not reproducible, so the methods must be regarded as relatively crude, although in this respect the ethyl chloride

test is not as bad as the gutta-percha test.

iii. Teeth with diminishing excitability may fail to respond, and even normal teeth may not do so, although the chances of this are reduced if both gutta-percha and ethyl chloride are used and if teeth which at first fail to respond are retested.

iv. Unless care is taken there may be severe pain.

v. There are many variables outside the control of the operator and this is undesirable in a diagnostic method, although if he standardises the techniques and interprets the results with caution they are of some clinical value. However, they are crude methods.

d. Electric Pulp Test.

This is a more refined method since the amount of stimulation may be controlled.

As far back as 1921 there was controversy concerning the value of the electric pulp tester as a diagnostic aid.

Raper¹⁰⁶ stated in 1921 that the electric pulp tester is of great value in determining whether a pulp is vital or necrotic but that it is not practical to attempt to determine any pathological state of the vital pulp.

Prinz¹⁰¹ disagreed with this and stated that a normal pulp responds to the faradic current at a special "irritation point" and pathological pulps respond at different points in relation to that. Mead⁸⁵ agreed with this.

However, Reiss & Fueredi¹⁰⁸ found wide variation in response to normal and pathological and Thoma¹⁴⁰ considered the electric pulp tester of little value in diagnosing pulp infection.

Today we are in almost the same position although most experimentors now agree that in conjunction with other diagnostic aids the electric pulp tester is an aid to diagnosis, but is only capable of determining whether the pulp concerned is vital or not. Oliet and Grossman⁹⁴ stated that while electric pulp testing results are somewhat variable and, at times, unpredictable the method is still a valuable adjunct to diagnosis.

Seltzer et al¹¹⁸ found that "the electric pulp test was of some value in suggesting the possibility of an inflammatory state, but was far from definitive. A response similar to that of the corresponding control teeth was given by more than 50% of the teeth with intact-uninflamed or only mildly inflamed pulps and by 6 to 40% of the teeth with more severely inflamed pulps.

No response to the electric pulp tester was shown by 72% of the teeth with "total necrosis", whereas teeth in all categories usually gave a response. Thus, there is a statistically significant relationship ($P < 0.001$) between absence of response to the test and presence of a totally necrotic pulp. If a tooth does not respond, the dentist

can be fairly sure that at least some necrosis is present. The converse is not true since 53% of the teeth in the combined partial or complete necrosis groups did give some kind of response. The difference between these groups is statistically significant ($P < 0.001$). In 32% of the 25 teeth in which partial necrosis was present, the electric pulp test response was above that of the control. It was the same as the control in 28%, and below the control in 12% of the teeth. There was no response in 28% of the teeth. Thus, there was no way of determining partial necrosis by means of the pulp tester.

No significant correlations with histologic diagnosis were obtained where the teeth responded either above or below the corresponding level of response of the control test.

Lawson and Mitchell⁷⁵ again found that clinical and histopathological observations did not always correlate well. Perhaps Mumford in 1961⁹¹ summed up the situation most concisely when he stated, "the current value thus found was considered to give an indication of the excitability of the tooth rather than an indication of the condition of the dental pulp. However, it does distinguish between vital and non-vital teeth and these aid in diagnosis". This again has been substantiated by Reynolds.¹⁰⁹

e. Percussion, palpation and mobility test.

According to Grossman⁵¹ these tests will not demonstrate evidence of pulp vitality but may indicate necrosis with periapical involvement. This statement is backed up by Seltzer et al¹¹⁸ who found that pain of percussion was elicited much more frequently in all pulp conditions in which necrosis, both partial and total was present. (38%) than in these categories in which necrosis was not evident. (8%).

f. Transillumination.

This method is useless for diagnosing the condition of the pulp unless necrosis has occurred. A vital tooth normally appears translucent whilst a non-vital tooth appears opaque.⁵¹

g. Test cavity.

This method is only reliable for determination of vitality but will give no other indication with regard to the pulpitic state.⁹⁴

h. Pulp-haemogram.

This method was advocated by Prader¹⁰² as the only reliable method of determination of the cellular status of the pulp resulting from the different phases of inflammation. This entails a differential leucocyte count in the first drop of blood taken from the pulp.

Bevilacqua¹⁵ and Draker³² both supported Prader in his suppositions and indeed this appeared to be the most

scientific method of determining a reasonably certain differential diagnosis.

The irreversible stages of inflammation are characterised by quantitative and qualitative changes in the neutrophils. Massive neutrophilia (70% or more), is interpreted as a sign of tissue breakdown with suppuration. The presence of toxic granulomatous vacuolization of the cytoplasm and nucleus, chromatin changes and a typical nuclear segmentation, are all indicative of a severe toxic process. The predominance of lymphocytes or monocytes denotes a favourable response.

Although Guthrie et al⁵³ found no clear cut relationship between the pulp haemogram and the extent of pulp pathosis, some degree of relationship was observed between the pulp haemogram with an elevated neutrophil count from teeth with extensive inflammation as determined microscopically. The presence of neutrophils exhibiting degeneration and karyolysis was found to be indicative of a pulp with extensive inflammation.

Prader's Method for Pulp Haemogram

All carious material is removed from the cavity under anaesthesia, in which case it should be noted that the pulp has not yet been exposed. After a thorough cleaning by means of a spray, the cavity is disinfected with Desogen and the important step of alcohol-fixation, with drying in a strong current of warm air, is carried out.

Trephening is effected with a special sterile rosette-drill, and the first drops of blood are trapped in a closed smoothly polished forceps and immediately smeared on a slide. The most suitable colouring agent is May-Grunewald-Giemsa or rapid-dyeing with Methylene blue.

It is important that the very first drops of blood be employed for the smear if a guaranteed diagnosis of the pulpitis is to be established. The blood which oozes out later is poorly representative of the local condition of the pulp and as time goes on, is superimposed by the general blood picture of the patient. After succeeding in stopping the bleeding a small amount of the pulp capping material is applied and the cavity closed with ZnO-eugenol cement.

Conclusion.

So many variables are present that when comparison of a questionable pulp is made with that of what is known as a "control", Seltzer et al¹¹⁸ noted that it seemed apparent that control teeth often gave abnormal readings. There is no way of knowing whether the control tooth had a normal pulp or whether the reactions to the pulp tester are within normal limits.

Examination of the teeth in the mouth would be inadequate, since non-carious and unfilled teeth sometimes

have atrophic pulps. This may help to explain differences in accuracy of electro-diagnosis reported by various investigators.

"The diagnosing of a vital pulp may be accomplished in the majority of cases. but differential diagnosis between that and a vital infected pulp is subject to too many variables for it to be classed as a scientific procedure.

It is only by the close comparison of the different methods of pulp testing, that a provisional diagnosis of such a pulp can be made and this must be confirmed by long-range post operative examinations"⁵⁶.

MODE OF HEALING AND THE DENTINE BRIDGE.

The pattern and chronology of healing as found by Berman and Massler¹³ is reasonably standard for all cases, and has been included for reference when dealing with other chapters.

They found that healing follows a definite pattern under large or small exposures, and took place by the formation of different reaction zones.

1. Layer of medicament.
2. Zone of pulpal injury and degeneration.
3. Primary calcific bridge.
4. Permanent bridge of reparative dentine.
5. Odontoblastic layer.
6. Normal pulp tissue.

1. Medicament Layer.

This is usually composed of remnants of the medicament either alone or mixed with blood or debris.

2. Zone of Pulpal Injury and Degeneration.

The superficial portion of the amputated pulp is usually macerated, necrotic or coagulated. The depth and degree of injury on this area depend on the amount of trauma caused by the operation and the coagulating effect of the medicament used.

The deeper portion of this zone is characterised by degenerative changes. The intercellular matrix appears

more prominent and encloses degenerating cells. This layer is first seen at 7 days and becomes more prominent on longer survival.

3. Primary Calcific Bridge.

At approximately 14 days, below the zone of injury and degeneration there appears a layer of dystrophic calcification, characterised by degenerating pulpal cells entrapped within a dense network of fibrous strands.

This zone always appears between the zone of pulpal degeneration above and the normal pulp tissue below. It, thus forms a protective calcific bridge over the vital pulp tissue and precedes the appearance of the true dentine bridge formed later by the odontoblasts. In thickness it may range from a thin line to a thick well-differentiated zone. Its size appears to depend on the nature of the zone below. When the zone above shows a slow progressive and mild degeneration, the primary calcific bridge forms slowly and late, and is not well organised and tends to be wide. When the zone above shows a rapid, coagulating necrosis, the primary calcific bridge appears early, is dense well organised and narrow. In the latter instance, formation of a permanent dentine bridge begins early.

4. Permanent Bridge of Reparative Dentine.

The dentine bridge is visible after 21 days and is made up of 2 components. The central portion is formed of newly differentiated cells and tends to be irregular in structure. The lateral portions are formed by old odontoblasts lining the wall of the dentine adjacent to the site of amputation and form a thick layer of regular tubular dentine.

5. Odontoblastic Layer.

The odontoblasts and predentine over the site of exposure become continuous with the walls of the pulp chamber. The odontoblasts at the site of injury are degenerated. However at a slight distance from the site of amputation, the odontoblasts are strongly stimulated and produce large amounts of 2nd dentine rapidly. At further distance, the odontoblasts appear unaffected.

The primary bridge was probably the product of degenerating cells whereas the permanent bridge was formed as a result of vital cellular processes. It appears that approximately 14 days are required for new odontoblasts to differentiate and at least 21 - 28 days before they produce a regular type of tubular dentine.

6. Normal Pulp Tissue.

Increased vascularisation is a prominent feature of the healing pattern immediately below the zones of

reaction. It is very prominent at 7 days and less prominent but still present at 14, 21 and 28 days until complete normality of pulp returns.

THE DENTINE BRIDGE

It has been considered that the major criterion for success of pulp treatment is the formation of a hard dentine bridge at the exposure point accompanied by a normally reacting, symptomless, vital tooth exhibiting no periapical pathology.

However, Armstrong and Hoffman in 1962⁴ carried out 56 pulp cappings using $\text{Ca}(\text{OH})_2$ diluted with Xylocaine containing epinephrine and placed permanent restorations immediately after capping. They claimed 97.8% success even though 68.8% only, showed radiographic evidence of secondary dentine formation. They suggested that the remainder which remained asymptomatic and radiographically negative were healed by fibrous tissue.

Although no histologic sections were made, this type of repair must be given consideration when assessing the success of treatment. For since injured connective tissue of the pulp may respond as other mesenchymal structures do, and it is not unfeasible that sufficient fibrous tissue may develop at the exposure site and remain uncalcified but offer some protection to the underlying pulp. Armstrong and Hoffman believe that aiding this response may be the blood clot which was allowed to form prior to capping which undergoing organisation forms scar tissue⁴.

However, the consideration is the future of that pulp which has no dentine barrier between itself and the external environment. With ideal restorative process where there would be no possibility of restoration or marginal leakage a fibrous tissue barrier would be adequate and in many cases in practice is reasonably so, considering the number of asymptomatic, pulp capped teeth which do exist without formation of a hard tissue barrier. It must however, be noted that if the integrity of the pulp is to be maintained indefinitely with maximum protection a calcific barrier is certainly desirable. Although teeth which appear otherwise normal and do not exhibit this type of repair should not from a practical point of view be considered complete failures without further observation over a prolonged period. For as Ehrmann³⁵ stated "Symptomless, vital teeth with an unhealed exposure are still preferable to a non-vital endodontically treated tooth (particularly a molar) and certainly preferable to an extracted tooth."

DIRECT PULP CAPPING AND PULPOTOMY.

Introduction.

It is generally accepted that the mechanism of tissue repair is essentially the same as those by which the tissue formed originally in the embryo. It is also true of all wounds that the process of healing involves three phases, (1) inflammation during which irritants are a factor, (2) repair of the exposed surface and (3) regeneration of lost tissue. There is no reason why this sequence of events should not, also, occur with wounds of the dental pulp¹²⁷.

However, because the pulp is normally enclosed by a hard unyielding wall of dentine and the blood vessels are terminal in nature, and enter and leave the pulp canal through a minute opening at the apex, even continued mild inflammation favours the development of many degenerative processes.

Shroff¹²⁷ has shown that the pulp normally possesses the power of healing its exposed surface by the production of a calcified collagenous barrier beneath which regeneration of normal dentine may occur and that these events may occur in quite unfavourable circumstances and in the absence of any form of treatment. However, as with any other tissue it does not proceed to completion unless it is assisted by the removal of irritants and the encouragement of normal growth processes.

Although pulp capping and pulpotomy differ in indications for treatment and method of treatment, they are essentially similar and will be treated as such.

Massler, Berman and James⁸² considered that teeth which are still vital can be treated more easily by pulp capping or by amputation, than by total extirpation and root treatment. Whilst Hess⁵⁷ stated that direct capping of the pulp in suitable cases results in the maintenance of a vital functional pulp in 85% of cases.

Patterson and Van Huysen⁹⁹ stated that there can be no future for a pulp that has been exposed more than an hour or two, whether it be due to caries, fracture or any other cause. Whereas Rosenstein¹¹² agreed that provided certain requirements are met, pulp capping and pulpotomy are most desirable. For as Wannemacher¹⁴⁵ in 1960 stated "the vital pulp without pathologic changes secondary to infection is the most important biological barrier between the environment and the apical paradatium, the body system".

Pulp Capping

Indications and Contra-Indications.

There are various opinions regarding pulp capping indications.

Rosenstein¹¹² who claimed great success (90.4%) where more than 50% of 1232 were pulp capped and less than

10% subjected to pulpotomy stated his indications as:-

- a) Sensitivity to touch.
- b) Slight haemorrhage at the points of exposure.
- c) Normal light colour of dentine adjacent to the exposure region (less important)
- d) Exposure size of not more than 1 m.m. in the occlusal or axial wall.

The results of this study were all obtained on children although it was not stated that age was a primary factor.

Patterson and Van Huysen⁹⁹ stated that pulp capping should not be attempted when pulpitis is present and that the exposed healthy pulp should be protected immediately with a non-irritating material. They, also, indicated that age is not an important factor governing success.

Tannanbaum¹³⁹ based his selection of cases on the following:-

1. Slight haemorrhage of pulp at the point of exposure.
2. Sensitivity of the pulp to touch of an explorer.
3. Absence of necrosis (dry or putrescent).
4. Absence of periapical radiographic areas of rarefaction.
5. Negative history of chronic disease.
6. Negative history of intense, prolonged pain in the tooth involved.

He carried out pulp capping of 128 permanent and primary teeth with either ZnO-eugenol or Ca(OH)_2 and claimed success with (89%) ZnO-eugenol and Ca(OH)_2 (92%).

Again age was not a factor, the group varying in age from three years to sixty years.

Castagnola and Orlay²⁵ stated that direct capping is indicated in all cases in which the attempt to excavate the softened dentine the pulp is accidentally exposed without deeper penetration into the pulpal tissues themselves. However, vital amputation is indicated where such penetration can be expected.

These experimentors believed that increased age is a definite contra-indication as well as general debilitating disease, chronic pulpitis, advanced paradontal disease and poor oral hygiene. They also indicated that rubber dam and sterile conditions are essential.

Grossman⁵¹ believed that repair can be expected only from a simple exposure of a healthy uninfected pulp and particularly if rubber dam and an aseptic technique is utilised. He regarded increased age and apparent infection as definite contra-indications.

Cohen¹⁵⁷ indicated that the essential criteria for successful pulp capping are:-

1. The exposed pulp must be vital.
2. Bleeding if present should be slight and easily controlled.

3. Ideally, the pulpo-dentinal membrane should be intact, or if penetrated mechanically should be free of lacerations. If these criteria are fulfilled the size of the exposure within fairly wide physiologic limits, is not too important. "No longer must a tooth with an exposure larger than a pin-head be considered as having a poor prognosis for survival".

He does not recommend pulp capping if there is:-

1. Contamination by saliva.
2. Laceration forcing contamination into the deeper structures of the pulp, or
3. Pus, serum or necrotic cells indicating long-standing infection not limited to surface pulp.

Kutscher⁷² only required the tooth to be sensitive to heat and cold and no relation to a sterile field or infection was considered necessary. Sharkle and Brauer¹¹⁹ noted that pain before a subsequent pulp capping suggests possible failure, whilst size of exposure and age did not seem a factor. However, Berk⁹, Gabel⁴⁶, Cohen¹⁵⁶, McGehee⁷⁷ and Patterson⁹⁹ all agreed that after removal of all caries, if the exposure is a simple one, it may be capped, but if it is contaminated, the pulpotomy is more desirable.

Pulpotomy

Berk⁹ stated that the presence of injured contaminated or necrotic tissue requires more aggressive treatment if the pulp is to be saved.

The objective of the vital pulpotomy treatment is to remove surgically the infected area of the pulp, by amputating the entire bulbous portion, and thereby retain the vitality of the tissue in the root canal.¹⁷

This can be accomplished in a reasonable percentage of primary and young permanent teeth, as well as in the adult dentition.³⁸

Stockwell¹³⁴ made the following general observation. "The coronal portion of the pulp undergoes change before the pulp in the root canals is obviously effected." Thus can be seen the reason for the above statements, for as most clinicians indicate - Vital amputation is indicated where deep penetration of the pulpal tissue can be expected by the injurious agent.^{25, 9, 46, 77, 99, 156.}

Much success has been claimed by men such as Englander, Massler and Carter,³⁸ Castagnola and Orlay,²⁵ Easlik,³³ Ellis,³⁷ Strange¹³⁵ and Rapaport and Abramson¹⁰⁷ when dealing with human teeth and marked success indicated on experimental animals such as rats by Berman and Massler.¹³

Strange¹³⁵ reported 90% success in primary and 75% in permanent teeth. This entailed a study of 29

primary teeth and 16 permanent teeth in the period of observation being 7 - 36 months whilst Rapaport and Abramson¹⁰⁷ requiring no other qualification than that the pulps were vital, claimed 93% success in 60 cases. However, they stated that there were no controls utilised and also no radiographs and histological follow up examination. Only vitality tests and relief of pain were indications.

Englander et al³⁸ reported on 228 teeth. The patients' age ranged from 18 - 24 years. The teeth were treated with various materials and extracted 4 days to 9 months following treatment. The preliminary report based on clinical evaluation revealed that of the 125 teeth treated with Ca salts, 94% were judged successful.

Much disparaging evidence has been presented with regard to the failure of the vital pulpotomy treatment. Via¹⁴³ reported a study of 123 deciduous molars observed from 9 - 72 months. These teeth were subject to an aseptic technique with Ca(OH)_2 as the medicament. Of 103 molars, 71 (68.9%) were judged as failures. Of these 48 were the result of internal resorption and the remainder exhibited absence of dentinal bridge on radiograph examination.

Also, Law⁷⁴ reported results from 251 cases of which 227 were deciduous and 24 permanent. These cases were examined after 6 - 9 months, both clinically and radiographically. Of these 51% were judged unsuccessful.

However, Shoemaker¹²¹ appeared to judge the present position regarding vital pulpotomy results when he commented on his own results. He selected 28 teeth which exhibited no history of pain or tenderness and appeared normal except for extensive caries. Of the 28 teeth, 19 were deciduous molars and 9 permanent molars and incisors. Six of the 19 pulpotomies of the deciduous teeth were considered successful after 9, 12, 18, 24 and 25 months, whilst 5 of the 9 pulpotomies of the permanent teeth were considered successful after a period of from 11 - 22 months.

He stated - "Pulpotomies were successful in 39% of these 28 teeth. It is obvious that the number of cases reported is small. However, one would expect that routine radiographic examination in pulpotomies which had been judged successful and which had shown no symptoms would reveal infection. An operation that is successful in 39% of cases treated is undoubtedly better than an extraction. However, it appears that the profession has been and is advocating pulpotomy with more optimism and less proof than is justified."

Thus there are times when both pulp capping and pulp amputation fail. Even though a new bridge of dentine may form, contamination or penetration of the deeper tissue of the pulp by bacteria or their toxins may stimulate an inflammatory response leading to eventual necrosis.⁹

Stanley¹³¹ also, attempted to explain this failure. "Pulp capping failures can often be explained when teeth are examined histopathologically. $\text{Ca}(\text{OH})_2$ is an excellent agent for stimulating the formation of reparative dentine but, unfortunately, it can stimulate reparative dentine formation in all directions if not properly applied. If the capping material is placed unevenly at different levels of the pulp instead of forming a rather typical bridge, stalactitic formations of reparative dentine may occur and choke off areas of vital tissue. This circumstance might lead to degeneration and the formation of intrapulpal abscesses."

A pulp amputation may leave behind many open and dilated vascular channels. Sometimes particles of the capping material may enter these channels and travel as emboli until lodged by the diminishing size of the vessel. At these sites the caustic effect of the material produces perivascular foci of necrosis and inflammation. If too many emboli occur, these foci may coalesce and cause so much destruction of the pulp that its reparative capacity can no longer cope with the situation.

INTERNAL RESORPTION.

This is an unusual form of tooth resorption which begins within the confines of the pulp chamber or pulp canal of the tooth. It has been referred to in the past as chronic perforating hyperplasia of the pulp, internal granuloma, odontoclastoma and pink tooth of Mummery. There are many etiological factors, some are more clearly understood than others. Most believe it to be due to pulpal activity and begins within the confines of the pulp chamber or canals.

Rabinowitz¹⁰⁵ classified internal resorption according to permanent or deciduous teeth. Under the heading of deciduous teeth he discusses^d the idiopathic type, the infected type and the post-pulpotomy type. He stated that internal resorption was likely to follow a pulpotomy procedure in cases where there was too much infection, trauma or strong medication with a large necrotic area. Secondary dentine may develop and seal off the vital stump. However, chronic inflammation remained and in time many of the teeth will show evidence of internal resorption.

Verda et al¹⁴² stated that "there appears to be a direct relationship between the severity of inflammation and the evidence of internal resorption". They found in a study of 135 teeth subjected to pulpotomy and covered with various medicants over a time interval of 4 - 181 days, 19% exhibited internal resorption.

Via¹⁴³ in his report of a study of 103 deciduous mandibular molars subjected to an aseptic vital pulpotomy technique, noted that of 71 failures 48 were due to internal resorption and Bennet and Poleway⁸ reported an interesting case of rapid internal resorption occurring on adjacent mandibular molars following aseptic vital pulpotomy procedure.

Cabrini et al²⁰ studied 28 cases of pulp amputation and revealed internal resorption of dentine in 8. Of these 8 cases there is histological verification of internal resorption in 7. In the remaining case evidence is only clinical and radiographical. They found the most frequent location of the resorption process was the radicular portion of the canal, generally near the pulp chamber which at the same time coincides with the region of the dentinal reparative area. No inflammatory picture was observed in any tooth, except for an isolated focus of infiltration in 2 cases. They concluded that it would appear that traumatism of the pulp has a direct influence in bringing about the lesion, whilst Masterton⁸³ in a more recent study concluded that "Resorption may occur where the pulp was the seat of chronic inflammation". He made the following observation:-

1. Internal Resorption Associated with Ulceration of the Pulp Wound

A typical pulp ulcer, arising in these circumstances has a well defined flat or slightly concave surface. It is usually situated near the site of amputation and there is

no evidence which would indicate destruction of pulp tissue has taken place. There is considerable infiltration with round cells, which obscure the normal pulp characteristics, and fibrous tissue is laid down presumably in an attempt to wall off the wound. Frequently irregular disorganised, calcific masses are observed deep to the ulcer but they do not constitute a complete hard tissue barrier. The pulp usually exhibits a normal appearance towards the apex.

The teeth examined had no marked lacunae formation but resorption had taken place, along a broad front. The resorption site is filled with tissue which resembles normal pulp but it is infiltrated with round cells. A few giant cells can be identified.

2. Internal Resorption Associated with Deep Pulp Abscesses.

Where abscesses are present there may be observed sites of active resorption. A curious feature of some of these resorption sites is the persistence of the integrity of the pre-dentine. The tissue within resembles normal pulp but large blood vessels are sometimes present. The dentine exhibits lacunae resorption and giant cells are present in some of these recesses. They are not numerous.

Thus, it may be concluded that internal resorption may be the result of direct trauma or infection producing persistent chronic inflammation, placing further emphasis on

the need for better diagnostic techniques and for the minimum of trauma during the instrumentation phase of treatment.

INDIRECT PULP CAPPING.

Bevilacqua¹⁵ stated that the most frequent route of bacterial invasion of the dental pulp is the carious lesion. The pulp can be inflamed or infected even before exposure by the growth and progress of micro-organisms through the dentinal tubules.

It is now necessary to consider the types of bacteria found in deep cavities and the fate of bacteria left in the cavity following restoration, and thus the efficacy of Natural or Indirect Pulp Capping as opposed to a direct technique.

According to Burnett and Scherp¹⁹ the micro-organisms isolated from the advancing carious lesions are streptococci, staphylococci, lactobacillus and filamentous forms. They found gram positive cocci regularly, both aerobically and anaerobically. Lactobacilli only constituted 5%. Canby and Bernier²³ found Lactobacillus acidophilus in 91.3% of deep cavities in contrast to the findings of Burnett and Scherp. These experimentors considered that an unsoftened area between the carious lesion and the pulp chamber is often sterile.

"The marked acidity of deep carious dentine together with the presence of a zone of high H-ion concentration at the point of liberation of acids of L. acidophilus organisms, probably prevent the ingress of pathogenic

organisms into the pulpal tissues by way of the dentinal tubules in dental caries." They considered that the optimum pH for acidophilus organisms is about 6.2. However, the deeper layers of decalcified dentine were at a pH of 5.5 to 4. King et al⁶⁵ also found that lactobacilli and streptococci predominated and Fisher⁴² supported this in his study of the bacterial flora of carious dentine in 16 teeth prior to placement of amalgam fillings, lined with plaster of paris. Repeated bacteriological examinations of the carious dentine were carried out after given periods of time, following removal of the fillings under sterile conditions. He found that almost always the persistent organisms were lactobacilli, whereas Besic¹⁴ stated he found no particular type of organism in decayed dentine which seemed to be associated directly with either so-called acute or chronic decay.

Gabel⁴⁶ implied that the remaining organisms under a deep restoration are still viable even after being cut off from the oral cavity by the restoration. Although Besic¹⁴ cultured 10 cavities prepared in carious teeth and subsequently sealed with zinc phosphate cement and found that:-

1. In no case was there any gross indication of progress of decay.
2. It appears as though the caries process in dentine definitely stops or gradually ceases

2. It appears as though the caries process in dentine definitely stops or gradually ceases as soon as the lesion is closed from the oral environment even when organisms remain alive, and the bacteria have a tendency to die out. However, in 30% of cases studied, a positive culture of streptococci persisted after being sealed for more than a year.

3. One of the three cases which remained positive after 1½ years had all clinical traces of decay removed.

However, Schouboe and McDonald¹¹⁵ studied 17 mandibular molars in a group of 12 children. Occlusal cavities were prepared under clinically sterile conditions and carious dentine was left in the floor of the cavity and protected by a sterilized 24 carat gold plate. The teeth were then restored with amalgam. About 95 days later the cavities were re-opened. No culture organisms were recovered in 16 of 17 teeth. In 11, gram-positive cocci were noted, while 12 yielded lactobacilli.

Those who advocated the sealing of caries beneath a restoration (Indirect Pulp Cap) claim much success. The most vociferous in this last decade being Canby and Burnett.²³ They claimed that if pulps are vital, normal in their response and have no history of untoward reactions, operative procedures which will not traumatise and expose them should be used even though all carious dentine is not

removed before the final restoration is placed.

Their technique is based upon the assumption that the bacteria have not already infected the pulp and that there is no alteration to the vitality of the pulp. They considered that some pulpal infections arrive via the bloodstream and admit that this is of no consequence as long as the final restoration is adequate. However, no definition of adequate is put forward.

Besic and others^{14, 115, 46 & 42} showed us that some viable bacteria may remain for a year or longer after placing of the final restoration, and diagnoses such as these on purely clinical grounds is quite empiric.

Whilst ignoring the fact that viable bacteria may be still present, advocates of this technique also ignore the actual histological state of the pulp owing to the carious process, as was shown earlier. Thus, although Bevilaqua¹⁵ considered that the living dental pulp seems able to dispose of viable bacteria up to a certain limit and when the pulp is vital the presence of bacteria is limited to the periphery, amputation when indicated with subsequent flow of blood may eradicate infection.

There are many others who have claimed major success with natural pulp capping although as Hess⁵⁷, one of these, states so truly, "The indirect capping of the pulp is an empirical method of prophylaxis for which sufficient scientific foundation is yet lacking." Another to advocate the technique is Held-Wydler⁵⁵ who claimed 60% success although it was not stated if exposure would have occurred if all caries had been removed.

Kraus⁷⁰ claimed great success with the Baldwin technique and rated his success at 90% claiming that acidogenic bacteria soon die out under tight fillings, and Gale⁴⁵ followed Kraus' technique and claimed success in 46 cases. He based his claims on failure to elicit pain after 1 year or note increase in the amount of caries present. His is a very unscientific approach where he even fails to utilise a vitality test.

Recently Gilmore⁴⁷ has again stated a case for this technique and based his claims on the result of Barber and Massler⁷. "The arrested carious lesions were almost completely impermeable to the dyes and radio-isotopes. These tracers failed to penetrate into the underlying dentine and pulp chamber. Clinically these lesions were characterised by a dark brown, hard, leathery surface and were not painful when hot and cold stimuli were applied to the tooth. Histologic examinations showed a distinct sclerosis of the underlying dentine, with large amounts of reparative dentine formation in the pulp chamber underneath the lesion.

Lesions in the process of being arrested showed some penetration of the tracers. However, penetration into the underlying dentine was absent and none of the tracers penetrated the pulp."

King et al⁶⁵ recently reported in their study of

especially selected teeth which radiographically indicated a deep carious lesion closely encroaching upon the pulp but not actually into it. Each gave a "vital" response when tested with a vitalometer, and was free of apparent periapical involvement.

Capping materials were ZnO-Eugenol with Zn.Acetate accelerator, Ca(OH)_2 plus methyl-cellulose and as a control Ag Amalgam. Complete sterility was maintained and all teeth permanently restored with Amalgam.

After periods of ranging from 25 - 206 days patients were recalled and all treated teeth examined before re-opening.

Results were as follows:-

1. Complete sterilisation of the carious dentine was obtained in 13 of 21 (61.6%) teeth treated with Ca(OH)_2 and 18 of 22 (81.8%) teeth treated with ZnO-Eugenol. All teeth treated with Ag-Amalgam were positive on re-entry.
2. Of teeth satisfactorily completed, all but 3 plate cultures showed a decrease in the maximum number of bacteria detected at the end of the treatment period regardless of the type of treatment employed.

However, as Berk¹⁰ stated that a basic necessity in operative dentistry is the removal of all caries, anything

short of removal of all caries represents a therapeutic compromise, then the only acceptable method related to that of indirect pulp capping is the one put forward by Brauer¹⁷ who removed all soft carious dentine at the initial operative visit in cases where there is pulpal exposure expected and ZnO-Eugenol cement is inserted. After a 3 - 4 week rest period, the remaining carious dentine is removed and the tooth restored. Massler⁸² found that with this method many exposures were healed when the tooth was reopened. This was supported by Dimaggio and Hawes³¹.

However, it is to be noted that these authors did not recommend the leaving of caries within the cavity before final restoration.

C O N C L U S I O N

As this paper deals with actual exposure of the pulp or cases where further excavation of the caries would have produced exposure, on the preceding evidence and lack of factual scientific proof it is not advocated by the author at this stage that the above methods be utilised. Even in cases such as put forward by Schroeder¹²³ where he recommends to cap indirectly unless a diagnosis of partial purelent pulpitis (which requires drainage) has been made since the drug (Ledermix) is so dependable in its effectiveness.

This method places great stress on the antibiotic

nature of the drug involved, to overcome the remaining bacteria, for although the steroids will reduce the inflammatory process already present in the pulp, it also reduces the natural defense mechanism so that later invasion may take place in a pulp which cannot resist.

This will be dealt with in detail in Section II.

TECHNIQUE OF INDIRECT PULP CAPPING.

When a favourable prognosis is established for cases in which the deep dentinal carious front approaches or even reaches a vital and normally reacting pulp whose carious dentine is tough and leathery rather than soft and mushy, one should gain access to the cavity and follow by removal of leathery dentine. All essential decay is removed but the pulp is not exposed, until there is a mild response. An anaesthetic may then be utilised.

After preparation is completed, the toilet of the cavity is performed, no sterilising agent is utilised and the cavity filled with a thick heavy mix of ZnO-eugenol cement. The permanent restoration is placed immediately.

PULP CAPPING MATERIALS.

It is generally agreed that a pulp capping material should be:-

1. Antiseptic, sedative and non-irritating.^{51, 61}
2. A poor thermal conductor⁵¹.
3. Capable of being applied with little or no pressure.⁵¹
4. Capable of encouraging the formation of a hard tissue bridge.⁶¹

1. Calcium Hydroxide and Zinc Oxide-Eugenol

As Ca(OH)_2 and ZnO-Eugenol are the most commonly utilised materials at this time, it becomes necessary to present a comparative discussion at some length which will be followed by a brief summary of other materials which have limited appeal.

Mohammed et al⁸⁹ carried out experiments on 11 dogs with the following results.

- a. Ca(OH)_2 was found to be the least irritating of pulp capping materials tested.
- b. ZnO-Eugenol produced inflammation in 4 out of 5 cases.

Rosenstein,¹¹² in his treatment of 1232 teeth in children, of which more than 50% were capped and less than 10% subjected to pulpotomy or root canal therapy, found that of 512 exposed pulps treated by capping with various materials, 90.4% (⁺ 1.3) were successful and 9.6% were unsuccessful. Of the deciduous teeth treated with ZnO-Eugenol who returned for re-examination, 68 or 85% were

judged successful. However, Glass and Zander⁴⁸ found no healing in exposed pulps capped with ZnO-Eugenol, and pulps so treated remained vital and unsymptomatic but a chronic inflammatory reaction persisted at the site of exposure, whilst with Ca(OH)_2 a rapid healing process was evident, relatively free of inflammation, and within 4 weeks the original site of exposure was completely walled off by a new odontoblastic layer and a new dentine barrier.

Whereas Hunter⁵⁸ using fresh pulp exposures in 42 dogs' teeth found that utilising ZnO-Eugenol, 2 out of 5 teeth showed some evidence of bridging; 1 showed extensive bridging and the remaining 2 showed none. Whilst with Ca(OH)_2 - 6 out of 10 showed bridging and 4 were destroyed by suppuration.

Hess⁵⁷ claimed that ZnO-Eugenol was definitely contra-indicated and that Ca(OH)_2 or Sero-calcium were materials of choice and Berk¹⁰ suggested use of Ca(OH)_2 in methyl-cellulose paste for ease of manipulation and prevention of pressure. His preliminary experiments on 6 dogs with mechanical exposure showed that after $2\frac{1}{2}$ months healing had occurred in all teeth together with formation of new odontoblasts and a covering of dentine. Further study of 120 cases of pulp capping and pulpotomy over one year indicated that all pulpotomies were successful clinically and radiographically, but that three pulp cappings failed.

Englander, Massler and Carter³⁸ performed vital amputations on 228 teeth cariously exposed in young adults. Ca(OH)_2 exhibited only 2 failures in 34 cases whilst ZnO-Eugenol exhibited no failures in 14 cases; both materials being considered highly successful.

Tannanbaum¹³⁹ treated 128 permanent teeth with either ZnO-Eugenol or Ca(OH)_2 and claimed 116 were clinically successful and in place 5 - 39 months later. The teeth treated with ZnO-Eugenol showed an 89% success and those with Ca(OH)_2 a 92% success. However, only 4% of the ZnO-Eugenol group showed radiographically a secondary dentine barrier after 2 years while 89% Ca(OH)_2 group showed the barrier in 1 year. However, Shroff¹²⁷ feels that Ca(OH)_2 is too irritating for use as a pulp capping agent because of its necrotising action. "Let us not be deluded by the partial clinical success achieved with Ca(OH)_2 ", and as stated earlier, Stanley¹³¹ felt that Ca(OH)_2 although an excellent agent for stimulating the formation of reparative dentine unfortunately can stimulate it in all directions if not properly applied.

Cabrini, Maistro and Manfredi²¹ exposed 7 normally reacting pulps to the oral environment for a period of 5 - 10 mins and then capped with Ca(OH)_2 paste. The teeth were extracted after 62 - 84 days. In all cases histological study showed formation of a dentinal bridge. The under-

lying pulp was normal, containing dilated blood vessels, but no inflammatory cells.

Also, extensive results were published by Berman and Massler^{12, 13}, of pulpotomies carried out in 122 upper first molars of 61 male hooded rats utilising both ZnO-Eugenol and Ca(OH)_2 as medicaments. Each material was found to be equally effective by the 28th day following treatment. Each was placed in 61 teeth, alternating on right and left sides in successive animals. When Ca(OH)_2 was used, the powder was dusted into the cavity and covered with paraffin wax and then sealed with Amalgam. The ZnO-Eugenol cappings were also sealed with amalgam.

Approximately equal numbers of animals were sacrificed at intervals of 7, 14, 21 and 28 days.

The basic pattern of pulpal healing was observed under both Ca(OH)_2 and ZnO-Eugenol. Minor differences were evident at 7 - 14 days. Ca(OH)_2 had a distinct necrotising or coagulating effect on the superficial portion of the amputated pulp and on any intervening blood or exudate. This appeared to cause an early appearance (often at 7 days) of the zone of dystrophic calcification. When the ZnO-Eugenol was in direct contact with the pulp, the underlying tissue appeared to be normal or it contained a large number of polymorphonuclear leucocytes. By 14 days their polymorphonuclear leucocytes number was greatly reduced and at 21 days they were no longer evident.

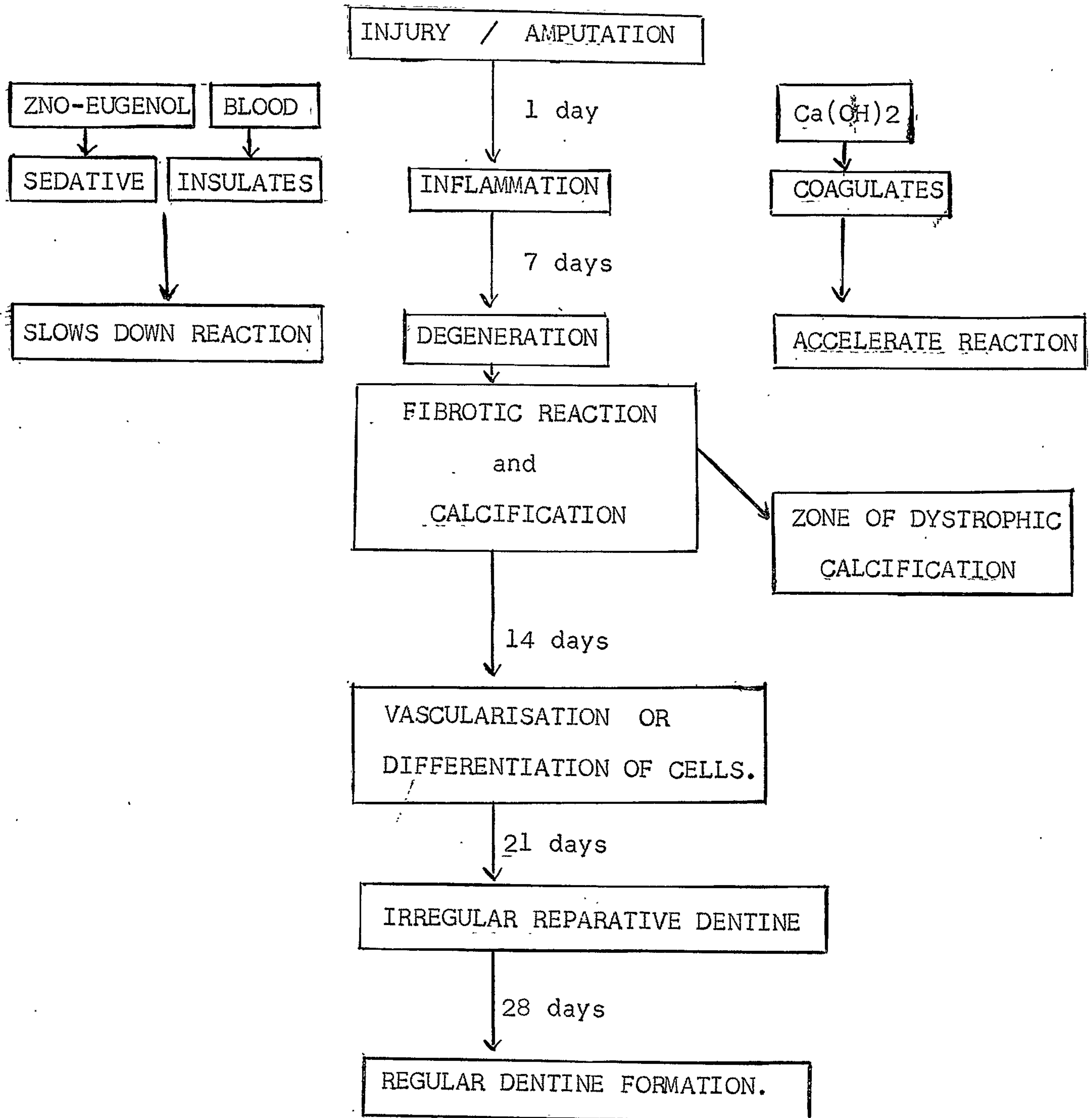
At 14 days it was evident that the basic pattern

for healing was progressing in a parallel fashion below both medicaments. The pattern of healing in pulps covered with ZnO-Eugenol appeared to be slightly delayed.

By 21 days the pattern of pulpal healing under both medicaments was approximately the same. The cells under the ZnO-Eugenol had caught up with those under Ca(OH)_2 and the histological picture was the same in both groups of specimens.

At 28 days it was difficult to distinguish between amputated pulps. The exposures under each medicament were sealed by a newly formed dentine bridge. The pulps were normal and there was no evidence of chronic inflammation under either.

Although these experiments were carried out on rats whose powers of recovery are known to be greater than those of the human pulp, the main conclusion drawn is that the pulp has a pattern of healing which can be accelerated or retarded to some degree but which cannot be altered basically by the medicament used. Thus, from a practical point of view, it appears that Ca(OH)_2 with its less inhibitory actions is the material of choice for clinical purpose. The apparent failure of this material in some cases where success would be expected could in most cases be attributed to poor diagnosis owing to the disadvantage of possession of relatively poor diagnostic aids to the original status of the pulp before capping.



2. Other Calcific and Zinc Oxide Compounds.

Many other compounds have been devised based upon the action of Ca(OH)_2 and ZnO-Eugenol.

Rosenstein¹¹² added thymol to the ZnO and from 28 cases treated proclaimed 24 successful. (85.7%).

Kutscher⁷² treated 10 deciduous teeth and 144 permanent teeth with ZnO-Eugenol and Na Penicillin, without consideration of age, sex, size of exposure, position of tooth in the mouth or pain history. However, all teeth were:-

- a. Negative to x-ray.

- b. Positive to heat and cold.

- c. Haemorrhaged on exposure.

His criteria for use of penicillin were:-

1. Lactobacilli and Streptococci may be the causative agents of dental caries as they are definitely implicated in the disease.
2. Both organisms are susceptible to penicillin.
3. Rosenstein¹¹² and Grossman⁵¹ found penicillin effective against all organisms within the affected teeth which require periapical pulp canal therapy.

After 2 weeks to 2½ years observation he considered that 151 of 154 teeth were successfully treated, as they were:-

- a. Asymptomatic.

- b. Insensitive to percussion.

c. Radiographically negative.

d. Reacted normally to heat and cold.

It is evident that this result is of little value as no histological examination was possible.

Englander et al³⁸ utilised various Ca salts and found that Di and Tri Ca PO₄ yielded 3 failures in 35 cases whilst CaCO₃ was the least satisfactory with 2 failures in 7. They concluded that clinical success is predicted less upon the type of Ca salt used and more upon technique and care taken by the operator.

Jensen⁶¹ compared the reaction of Ca(OH)₂ with the following preparation:

<u>Powder</u>		<u>Liquid</u>	
ZnO	65%	Eugenol	75%
Ca(OH) ₂	30%	Phenol	25%
Iodoform	5%		

pH 7.9

on healthy pulps in dogs and found that a hard tissue bridge was formed in 4 weeks and that no distinguishable difference was obtained in the capping agents used from 4 - 8 weeks.

Berk¹⁰ added methyl cellulose to Ca(OH)₂ to enhance its manipulatory qualities and found that it gives the same result as Ca(OH)₂ without the disadvantages of that material.

Whilst Easlik³³ claimed satisfactory results with

Ca(OH)_2 plus a liquid containing:-

Canada Balsom	7.0
Oil of Cloves	7.3
Silver Nitrate (powdered)	0.7

Verda et al¹⁴² studied 135 teeth subjected to pulpotomy and covered with various medicaments, 76 with 4 Ca compounds, 49 with 4 antibiotics and 10 with antibiotics and one Ca compound. The time interval was 4 - 181 days.

The Ca compounds utilised were Ca(OH)_2 , Ca PO_4 , CaCO_3 and Ca(OH)_2 and methyl cellulose. Bridging occurred under all materials but in varying incidence. Pulp covered with Ca compound (43%) showed significantly greater incidence of bridging and lesser incidence of internal resorption and less severe inflammation than those covered with antibiotics (23%) and in those covered with Ca(OH)_2 and methyl cellulose there was more frequent bridging and less resorption than in those covered with Ca(OH)_2 powder.

With this evidence and that of Berk's it would appear that the addition of methyl cellulose increases the efficiency of Ca(OH)_2 because it helps overcome the following disadvantages:-

1. It is difficult to apply powder to the pulp.
2. Powder exerts a repelling action to the cement base material.
3. When placing a cement base the powder may be forced into the pulp creating undesirable pressure.

4. Any bleeding or seepage from the pulp may dislodge the Ca(OH)_2 .

As was shown earlier, antibiotics have been added to ZnO to enhance its antibacterial action and also to Ca compounds. However, success has been variable and indications are that antibiotics added to these materials are not of any advantage.

Verda et al¹⁴² as indicated earlier utilised a combination of antibiotics with Ca compounds.

They added Chloramphenicol to CaPO_4 and Terramycin to Ca(OH)_2 , CaCl_2 , CaCO_3 and CaPO_4 and found that the response resembled that of the antibiotic more closely than that of the Ca compound.

Feitelson⁴⁰ treated 34 primary and 49 permanent teeth with Ca(OH)_2 plus crystalline penicillin (10,000 units approx.) and later with Ca(OH)_2 and methyl cellulose suspension (Rower) and penicillin.

After 1 year he found 7 developed alveolar abscess (3 primary and 4 permanent) and claimed 91% success in primary teeth and 92% in permanent teeth.

It is a pity that Feitelson used no Ca(OH)_2 controls for his results are so similar to those found with Ca(OH)_2 alone, that it is quite possible that the penicillin was completely unnecessary.

Other Ca containing compounds have been utilised for capping purposes. Anorganic Bone, Ivory and Sterile Dentine itself.

The development of anorganic bone was based on the hypothesis that non-acceptance of heterogenous bone graft materials by the host is due mainly to the response evoked by constituents contained in the organic factors. Bone rendered "anorganic" by extraction with ethylenediamine, a powerful hydrolyzing agent, is, theoretically devoid of potential antigenicity and should therefore provide acceptability regardless of species source, be it autogenous, homologous or heterologous origin.

In many successful experiments in other regions of the body it was found that all cases have one common factor - the reactive proliferation of young connective tissue or granulation tissue - and this is provided only when two conditions are present, viz. (1) Undifferentiated mesenchymal cells and (2) a stimulus adequate to induce those cells to differentiate into osteoblasts. Since dental pulp consists of loose C.T., an abundant blood supply and undifferentiated mesenchymal cells which theoretically have the potential to differentiate into any cell including odontoblasts and osteoblasts, the first condition for ectopic bone formation is present.

Experiments were carried out on 28 adult mongrel dogs and results compared with those using Ca(OH)_2 as controls.⁹⁸

RESULTSETHYLENEDIANE - TREATED BONECa (OH)₂ CONTROL

DAYS	30	60	90	120	180	30	60	90
No. Cases / acute failure	5/0	5/0	10/0	4/0	4/0	5/2	4/2	4/3
Dentinoid Bridging	2I	2I,2C	6I,3C	2I,1C	4I	2I,1C	2I	0
Dentine Bridging	0	2C	2I,1C	1I,1C	2I	0	0	0
Inflammatory Cells	2	3	3	0	1	1	1	1
Intra-vascular Oedema	3	3	2	1	0	1	1	1
Cysts or Extravascular Oedema.	3	4	7	2	3	2	2	1
Necrosis	0	0	3	1	0	0	1	1

I - Bridging Initiated.

C - Bridging Complete.

As shown in the above table, the Ca(OH)_2 was appreciably more injurious to the pulp than was anorganic bone. Although the number of cases was too small for statistical comparison the data would appear to show that anorganic bone was less toxic to the canine pulp than was Ca(OH)_2 . At the exposure site the anorganic bone was walled off by dentinogenesis and little if any of the dentinogenous response penetrated into the mass of anorganic bone external to the exposure site whilst chips which had entered the body of the pulp were engulfed by a dentinoid mass. There was no antigenicity.

Englander et al³⁸ also claimed success with anorganic bone or dentine powder prepared from human teeth. They claimed no failures in 31 attempts, whilst Castagnola and Orlay²⁵ utilising sterilised Ivory powder as advocated by the Basel School (O. Mueller) mixed into a 5% sol. of Vioform in alcohol after 1 year showed 55% as satisfactory although clinically 80% appeared to be so.

However, Subramanan¹³⁷ studying 20 normal or slightly carious but vital teeth in which 3 cases were observed for 2 days, 4 for 10 days and 5 for 38 days and 8 for 56 days, in an age group of 18 - 44 years found that anorganic bone was acceptable to the host and that in contact with pulp tissue the deposition of collagen is induced at 56 days. Although he observed no new odontoblasts or calcification of the collagen surrounding the particles of bone.

From the above experiments it can be seen that Anorganic bone has possible potential as a pulp capping agent. However, much greater examination of the effects on infected pulps is required over longer observation periods.

SECTION II

CORTICO-STEROIDS.

INTRODUCTION.

Pulpitis is an alteration of the dental pulp manifested by inflammation due mainly to micro-organisms and their toxins, and to clinical or physical agents. Until the advent of corticoids and antibiotics, there was no acceptable therapy for pulpitis. However, in recent years, studies have been made on the clinical and physiological effects of adreno-cortical hormones. Because they modify the inflammatory response of the tissue, these hormones have become very important therapeutic agents.

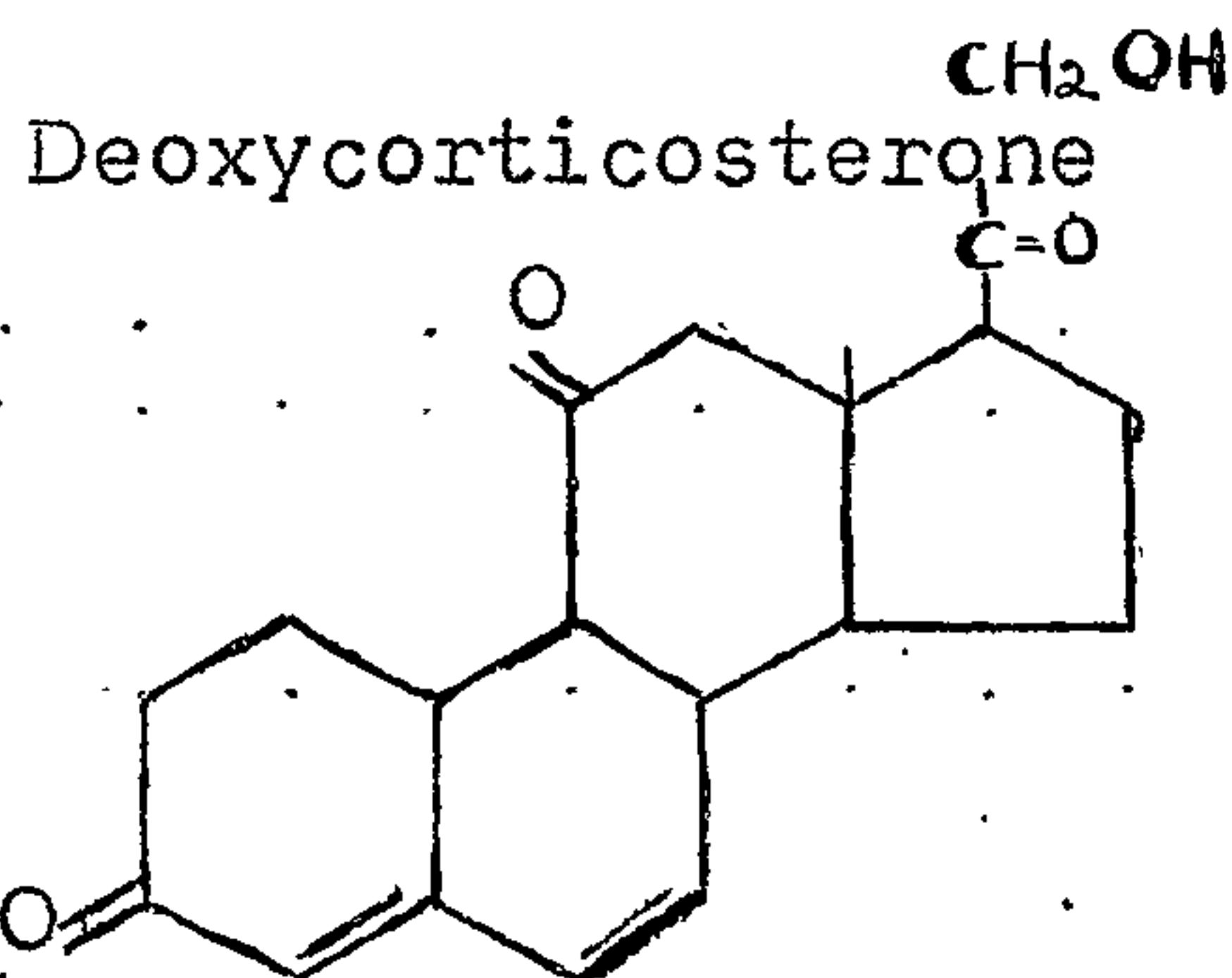
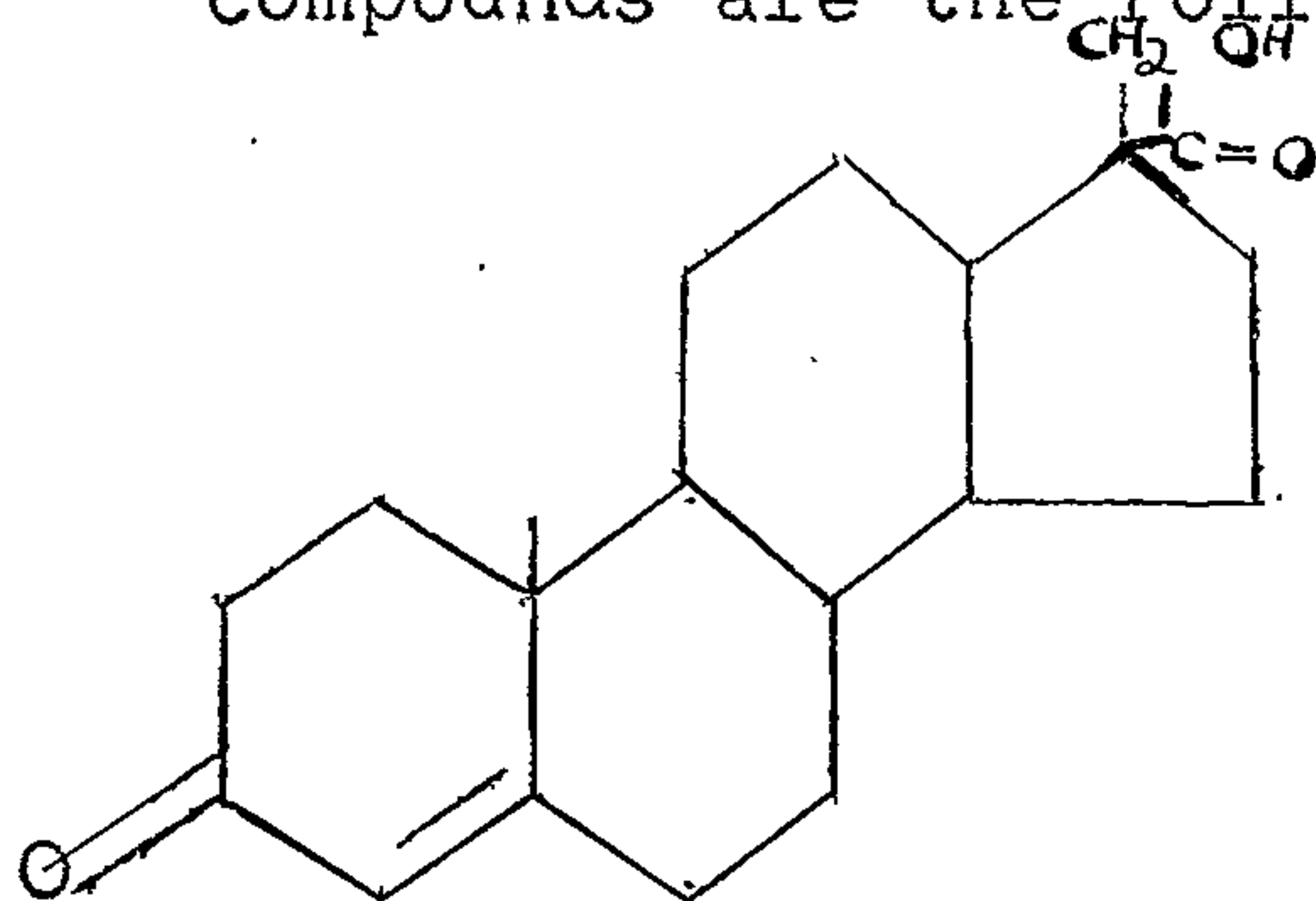
In 1937 Reichstein prepared deoxy corticosterone synthetically and later demonstrated it in the adrenal glands. Although this steroid had powerful effects on salt and water metabolism and became useful in the management of Addison's disease, it was obvious that extracts of adrenal cortex also contained some other compounds which could influence not only salt metabolism but also the handling of carbohydrates and proteins as well. Among the many steroids which were being isolated, there were some which indeed had marked glucocorticoid activity as opposed to the mineral corticoid and deoxy corticosterone e.g. cortisone.

Subsequent research on the glucocorticoids led to the development of a variety of new steroids which have significantly greater anti-inflammatory potency than cortisone,

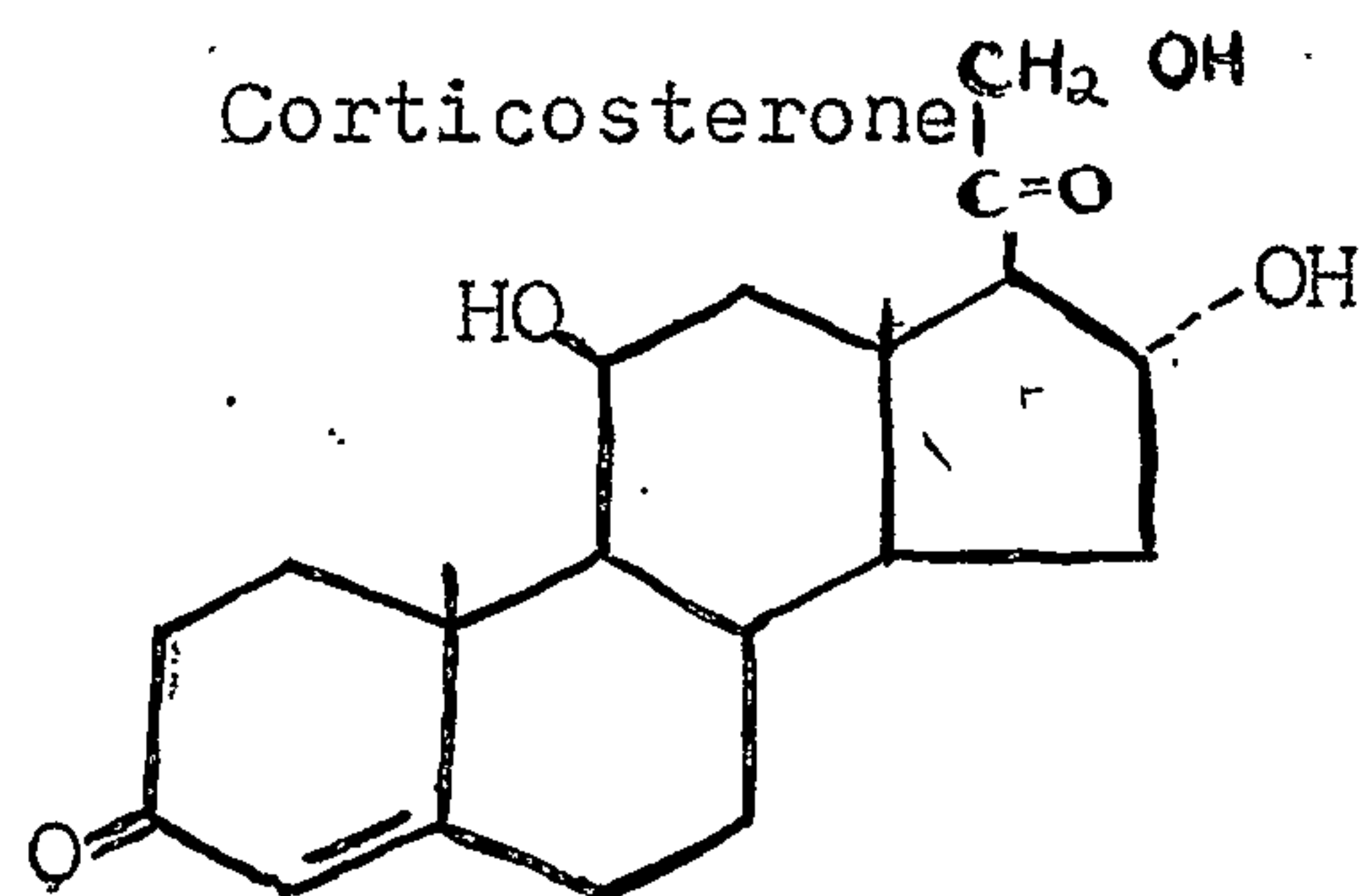
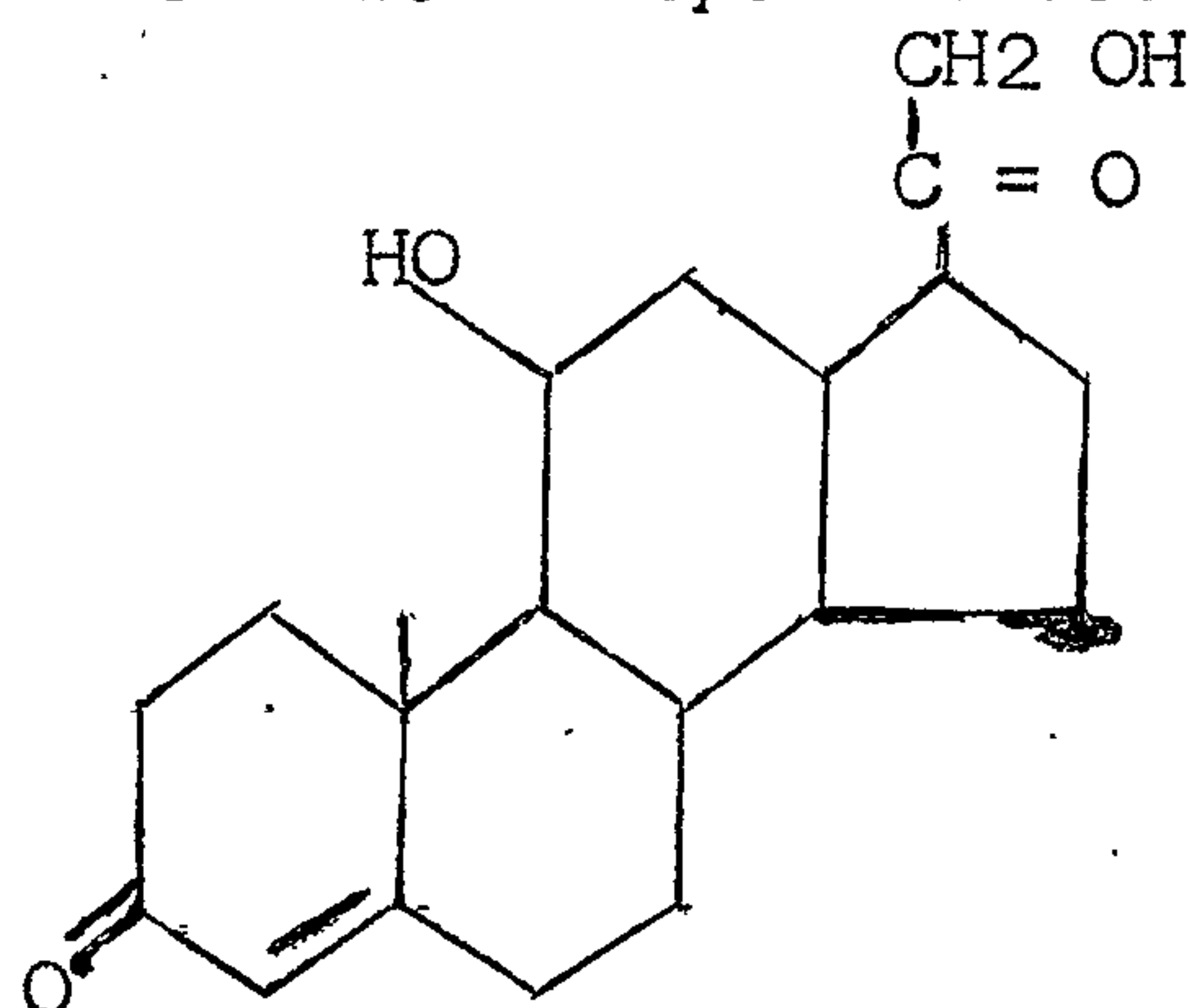
although their influence on carbohydrate metabolism generally parallels their anti-inflammatory activity. A significant advantage of the newer steroids, such as prednisone, methyl prednisolone, triamcinolone and dex amethasone is that these newer anti-inflammatory steroids exert little effect on renal sodium reabsorption while still possessing potent anti-inflammatory activity.⁵⁰

Natural Steroids.

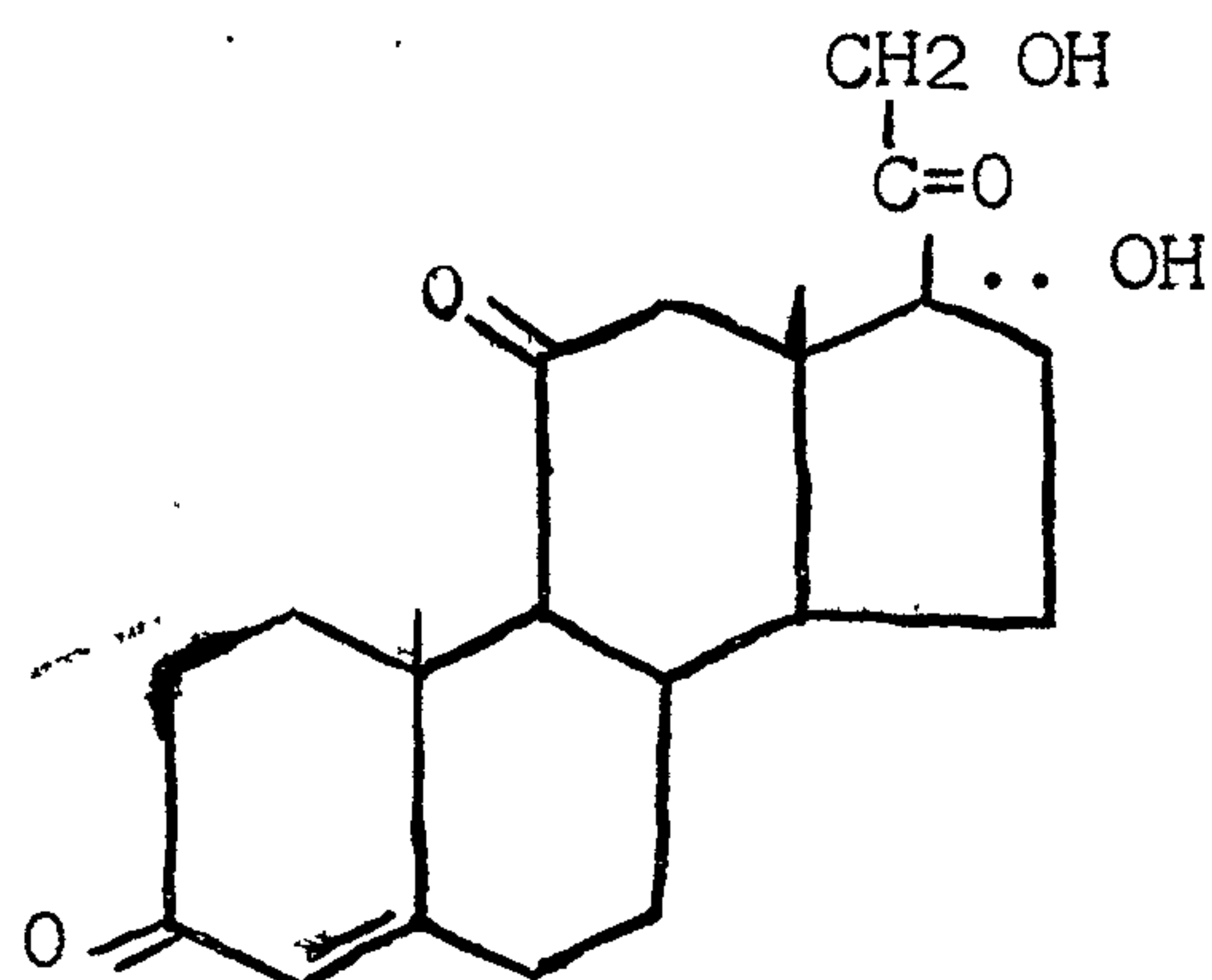
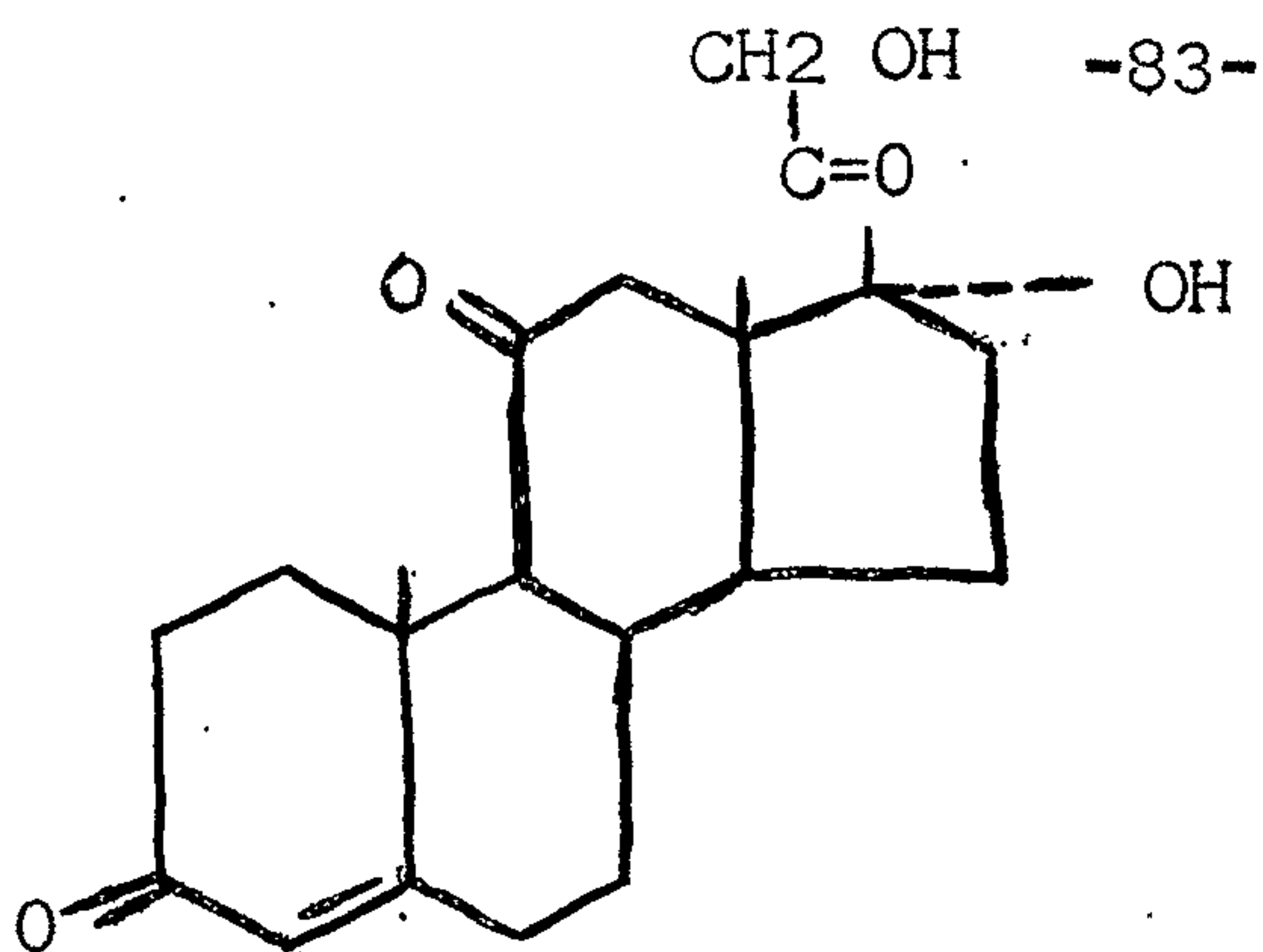
Of the steroids isolated from the adrenal gland seven are of significance for adrenal cortical activity. These compounds are the following:-



11 - Dehydrocorticosterone

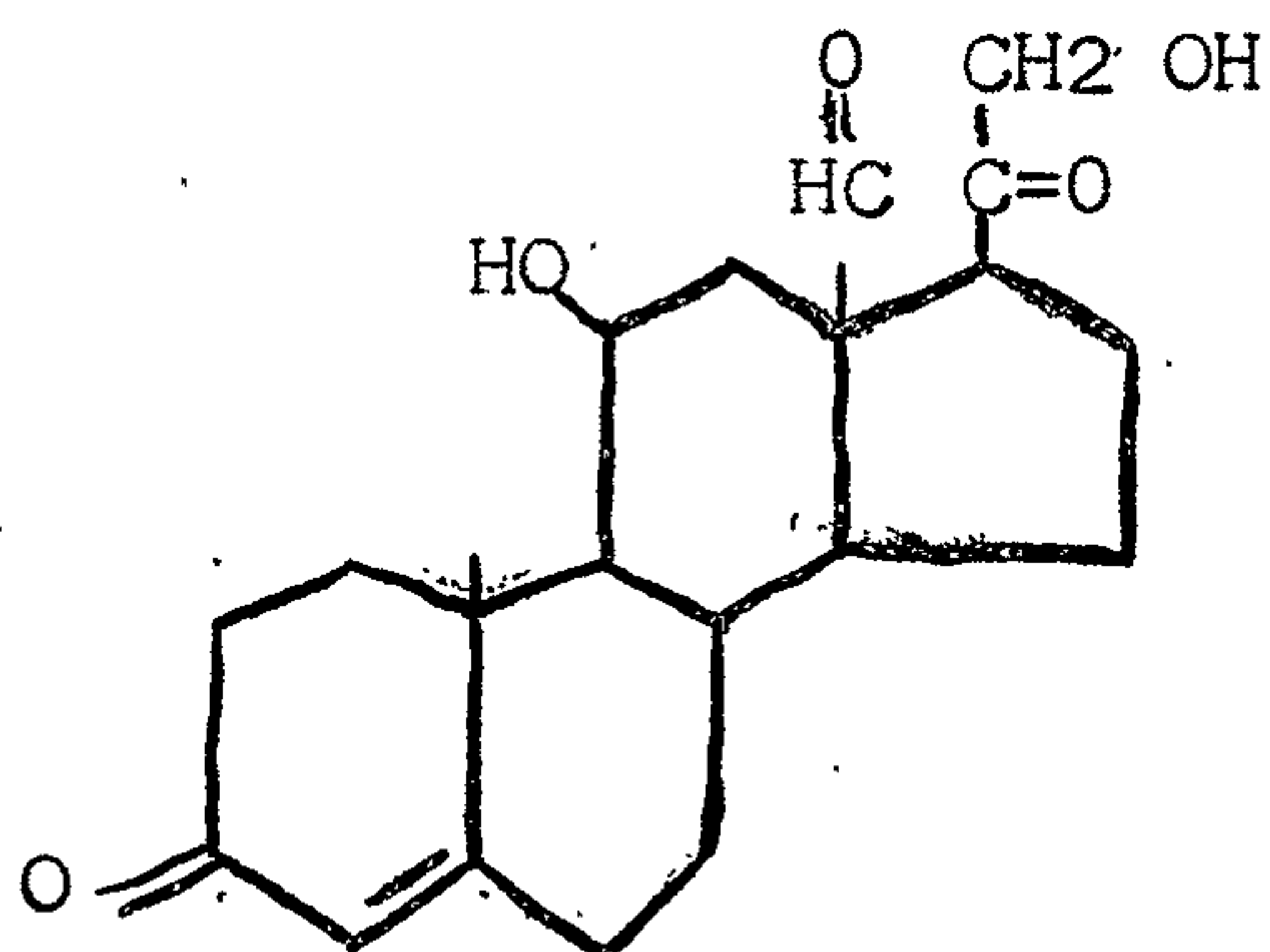


17 - Hydroxycorticosterone
(Hydrocortisone. Cortisol)



11 - Deoxy- 17 α - Hydroxy cortico
sterone
(11 - Deoxycortisol).

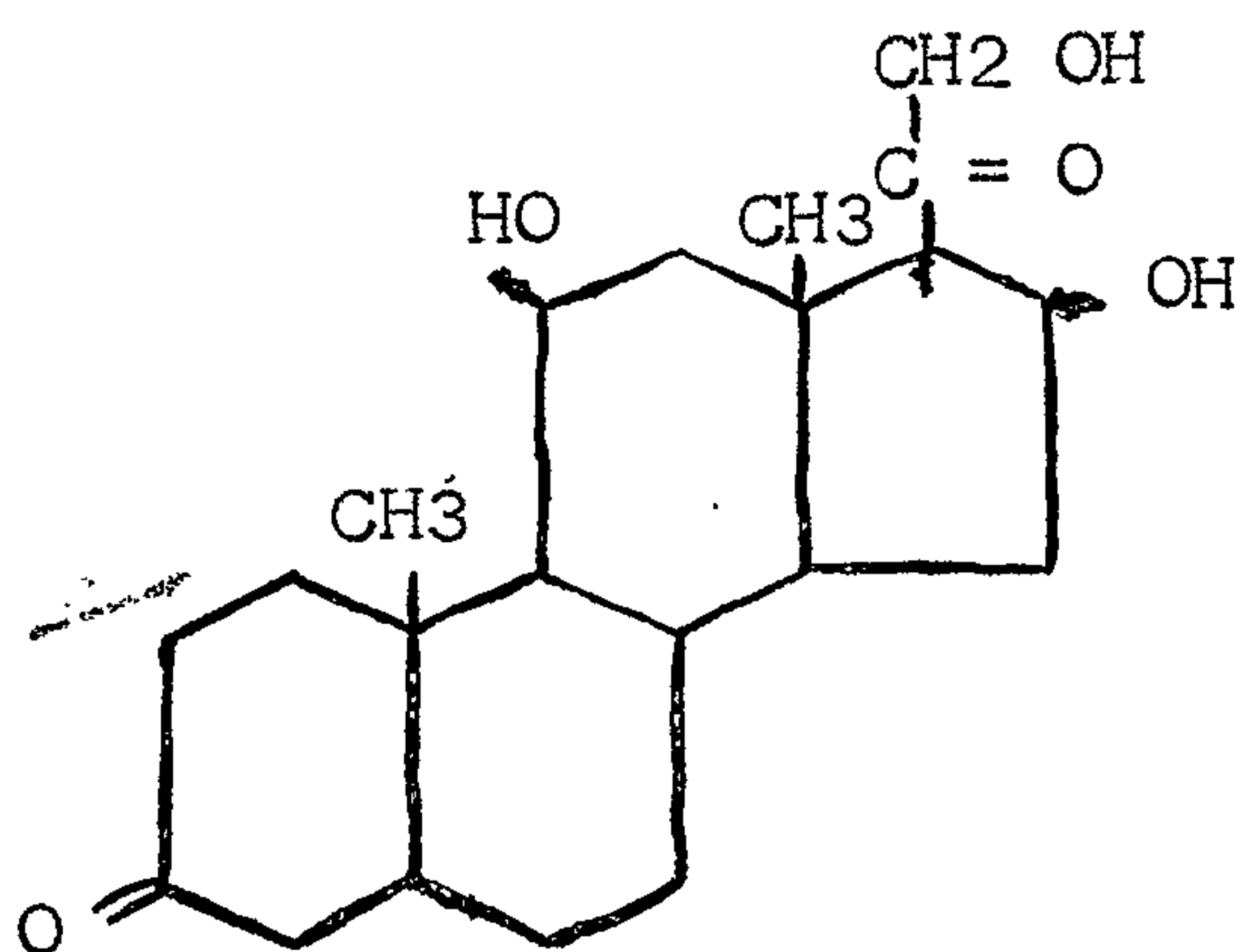
11- Dehydro- 17 α - Hydroxycorticost-
erone.
(Cortisone.)



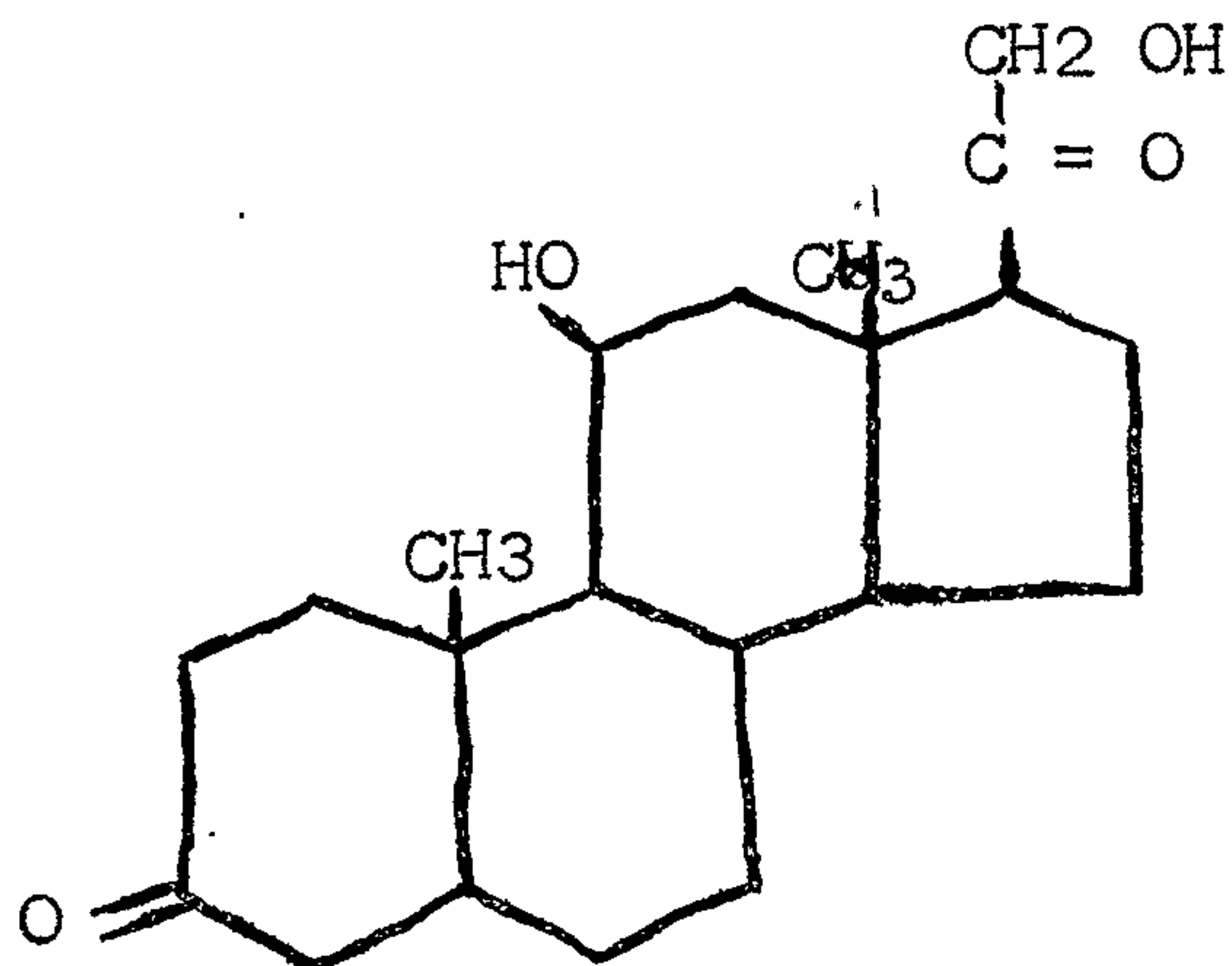
Aldosterone.

(1) Glucocorticoids.

Hydrocortisone and corticosterone are the principle glucocorticoids of the adrenal cortex. The structural formulas being as follows:-



Hydrocortisone



Cortico-sterone

In the human adrenal cortex hydrocortisone predominates whereas in some species such as the rat corticosterone has a greater quantitative importance. Human adrenal glands contain 2.3 to 5.5 μ g of hydrocortisone per gram of tissue.

Secretion is greatly stimulated by ACTH. The effects of hydrocortisone are exerted on the metabolism of carbohydrates, proteins and fats, electrolyte and water metabolism and inflammatory processes. Additional effects are observed on eosinophils and other formed elements of the blood, growth and wound healing, skeletal muscle, the secretion of uric acid, the central nervous system, and gastric secretion. Inhibition of endogenous ACTH secretion with subsequent adrenal atrophy is also an important result of prolonged hydrocortisone administration.

Effect on Carbohydrates, Protein and Fat Metabolism.

Hydrocortisone increases gluconeogenesis and also

tends to inhibit peripheral glucose utilization. As a consequence it causes a marked accumulation of glycogen in the liver and can produce hyperglycemia and glycosuria. Because of these effects it tends to aggravate diabetes and may bring out an insulin-resistant disturbance of carbohydrate metabolism in latent diabetes.

It is likely, however, that under physiologic conditions its predominant function might be to provide amino-acids and carbohydrate for repair processes through stimulation of protein catabolism and glycogenesis from amino-acids.⁵⁰

Although the primary mechanism is unknown, certain adrenal cortical steroids markedly inhibit protein synthesis in muscle and other tissues. Since protein degradation in the same tissues is continuing, amino-acids leave these structures, resulting in wasting and softening. However, there is evidence that under these same circumstances protein synthesis in the liver may actually be exchanged. This is sufficient to offset the amino-acids from other tissues, as indicated in an elevated amino-acid concentration.¹⁴⁶ Thus hydrocortisone not only promotes the breakdown of proteins but also tends to inhibit anabolism or synthesis.⁵⁰

Little is known about the basic action of hydrocortisone on fat metabolism but could be due to an associated increase in insulin release.⁵⁰ Unusual accumulations of fat occurs in the patient treated with glucocorticoids and exerts

complex effects on ketone metabolism¹⁴⁶.

Effects on Electrolytes and Water Metabolism.

The adrenal corticosteroids have a regulatory influence in this metabolism particularly in relation to the concentration of Na^+ and K^+ in extra-cellular fluids. The administration of hydrocortisone or cortisone result in increased sodium retention, increased potassium excretion and hypokalemic alkalosis in patients on prolonged treatment.

Lowering of serum Potassium ions leads to deleterious and toxic effects on cardiac muscle, elevation of extracellular Sodium ions causes decreased excitability of brain tissue.

Haematologic Effects.

The 11 - oxygenated adrenal cortical steroids other than aldosterone influence the numbers of blood lymphocytes, erythrocytes and eosinophils as well as the structure and function of lymphoid tissue, viz involution. The basis of this phenomenon is not understood¹⁴⁶.

They exert a striking effect on the number of circulatory eosinophils. These elements may completely disappear from the blood following the administration of the glucocorticoids or upon injection of ACTH. The reason for this is unknown⁵⁰.

Other Miscellaneous Effects.

The urinary excretion of uric acid is increased by cortisone.

The prolonged administration of cortisone and related drugs inhibits the secretion of ACTH and leads eventually to an atrophy of the adrenal cortex. This problem has received much attention recently on the basis of clinical observations which indicated that stress, particularly associated with surgery may be catastrophic in patients whose adrenal cortex is unresponsive as a result of previous hormonal treatment.⁵⁰

The 11 - oxygenated adrenal cortical steroids augment secretory activity of the gastrointestinal tract. Hydrochloric acid and pepsinogen secretion by the gastric mucosa, and trypsinogen secretion by the pancreas are increased following steroid administration. The effects may be the basis of the precipitation of ulcerative lesions of the gastro-intestinal tract during prolonged therapy.¹⁴⁶

Anti Inflammatory action.

Most of the clinical uses of glucocorticoids and of ACTH may be attributed to the remarkable ability of the steroids to inhibit the inflammatory process,⁵⁰ i.e. they prevent the appearance of inflammatory response, whether such responses are due to physical, chemical or bacterial stimuli. The efficacy of these substances can be demonstrated either locally or at the site of potential inflammation, or by their systemic administration. They inhibit the influx of polymorphonuclear leukocytes from the blood into the local area of inflammation, and inhibit the localised destruction of

fibroblasts, otherwise seen as a consequence of an inflammatory reaction.¹⁴⁶

The mechanism of the anti-inflammatory action of the glucocorticoids has not been elucidated. Since there is a general parallelism between the anti-inflammatory potency and interference with protein and carbohydrate metabolism, it is likely that the hormones may prevent the formation of cellular elements and perhaps endogenous compounds which are important in the genesis of inflammatory process.⁵⁰ Although an effect on histamine formation has been demonstrated by Schayler et al,¹²⁰ it is unlikely that this effect explains the anti-inflammatory action of adrenal steroids. Also, these compounds are not truly anti-histamine, since they do not prevent the actions of histamine on the usual test objects such as guinea pig bronchiole or vascular smooth muscle of the dog. The remarkable effectiveness of the anti-inflammatory steroid in the treatment of a variety of allergic diseases may be due to an influence on immune mechanisms or most likely are simply another manifestation of the non-specific anti-inflammatory action.

Principles of Metabolism of Glucocorticoids.

Both cortisone and hydrocortisone are absorbed efficiently from the gastro-intestinal tract.⁵⁰

The major metabolites of adrenal cortical steroids result from reduction and conjugation reactions. The metabolic

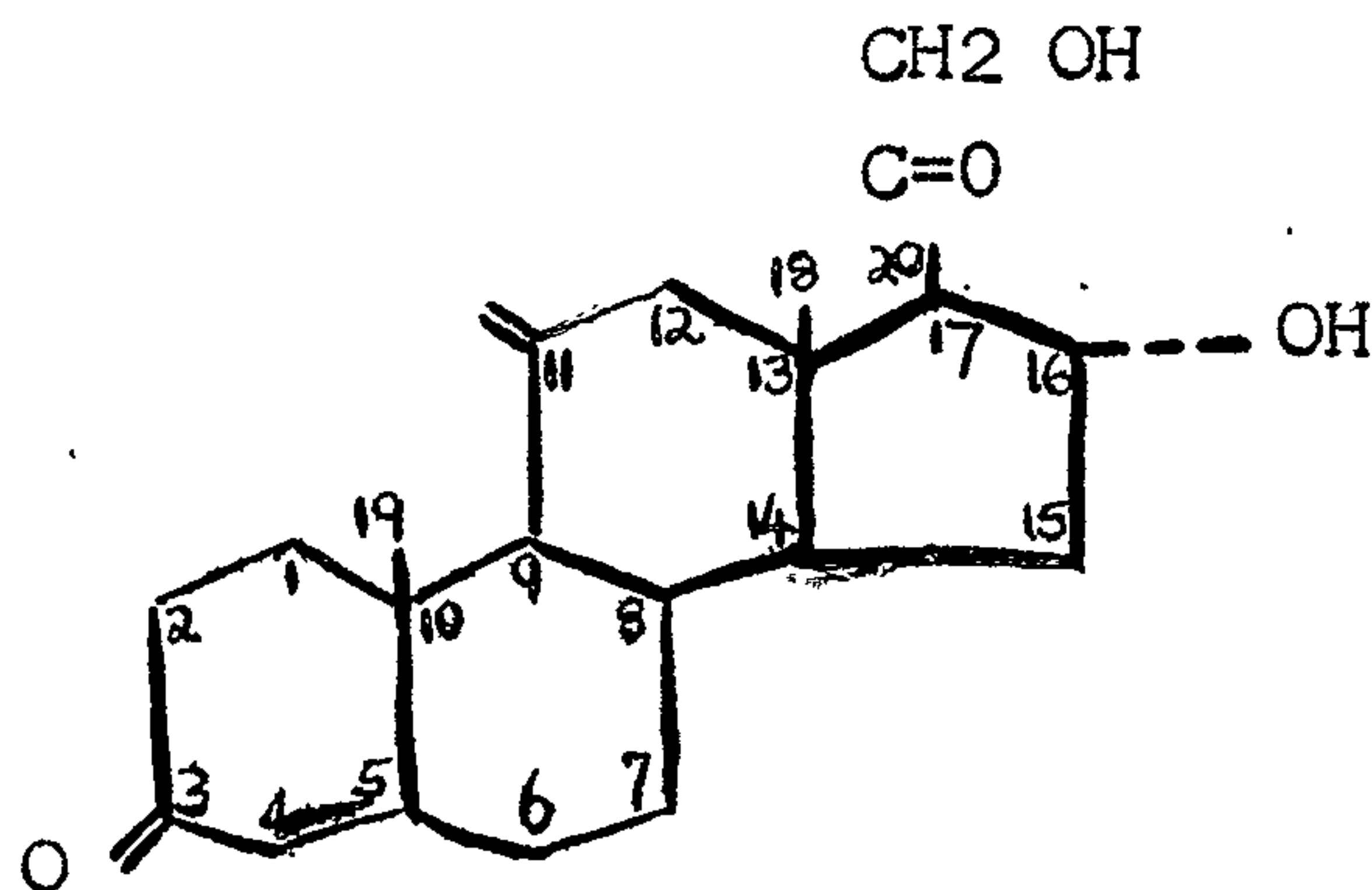
products are devoid of biological activity. The chief metabolites arise in the liver by a two-step reduction. In addition two products are present in the urine which result from further reduction.¹⁴⁶

Cortisone is more suitable for intra-muscular administration, since hydrocortisone is absorbed much more slowly from the muscle. Hydrocortisone is much preferred for local application and for intra-articular injection.⁵⁰

Synthetic Adrenal Cortical Steroids.

A large number of new steroids have been prepared synthetically in an effort to provide compounds with significantly greater adrenal cortical activity. In addition, it has been the goal to seek substances with single actions rather than the multiplication of response seen with normally secreted hormones.

The clinical relationship may be summarised in comparison with the structural formula of cortisone.



Cortisone.

PREDNISONE (Meticorter) is the same as cortisone except that there is a double bond between positions 1 and 2.

PREDNISOLONE (Meticortelone) is the same as prednisone except that OH is in position 11.

Both Prednisone and Prednisolone possess a high anti-inflammatory action which is not coupled with a correspondingly high sodium-retaining potency.

METHYLPREDNISOLONE (Medrol) is the same as prednisolone except that CH_3 is in position 6.

TRIAMCINOLONE (Aristocort) is the same as prednisolone except that F (alpha) is in position 9 and there is an additional alpha OH in position 16.

Methylprednisolone and Triamcinolone are even more potent than prednisolone with regard to anti-inflammatory effects. Triamcinolone is used normally as the Acetonide which is more stable and is applied topically.

There are yet other synthetic glucocorticoids which are more potent than the above although at this stage none have been utilised in the field of our discussion.

Viz. DEXAMETHOSONE (Decadron) is the same as triamcinolone, except that alpha CH_3 instead of OH is in position 18.

BETAMETHOSONE (Celestone) is the same as Dexamethosone except that CH_3 is in position 16 beta instead of alpha.

FLUDROCORTISONE is the same as hydrocortisone except that alpha F is in position 9.

PARAMETHASONE (Haldone) is the same as dexamethasone, except that alpha F moves to position 6.

THE RATIONALE OF PULPAL TREATMENT WITH
CORTICO - STEROIDS

The normal reaction of body tissues to an inflammatory stimulus is that of oedema.

Like any other connective tissue the pulp reacts in the sameway. However, owing to the unyielding walls of the pulp chamber which prevents expansion, and the narrowness of the apical foramen preventing drainage, the pressure of the inflammatory exudate results in death of the organ. "There is a rise of intervascular pressure in the pulp chamber which may extend to the apex of the root and stop the vascular flow or occlude the vessels at their site of entry or exit at the apical foramen. This basic tissue reaction to the stress of caries or to the trauma of restorative procedures resolves itself in time as adaption succeeds, or it ends in a variety of degenerative and repair sequelae.^{43, 44.} For this reason inflamed pulp has hitherto been regarded as a lost pulp.

It thus becomes necessary in order to preserve the vitality of the inflamed pulp to not only remove the noxious agent but also to reduce the inflammatory process in intensity.

Basically, the Glucocorticoids by reduction of the permeability of the wall of the mast cells, preventing the escape of histamine and heparin and reduction of the permeability of the walls of other cells at the site of injury reducing the chances of any free histamine in the tissues,

reduces the inflammatory response.

To determine this effect experiments were carried out by Rapaport and Abramson¹⁰⁷ with human teeth with exposed vital pulps. This was practically the only qualification. The drug used was hydrocortisone acetate (saline suspension) 25 mg/cc administered either by using the suspension previously well shaken and flooding the exposed area or by removing the supernatant liquid and applying the powdered drug. The material was covered with sterile cigarette paper or asbestos sheeting and the tooth restored. After six months approximately 90% of the teeth were found to be asymptomatic and vital.

From this they concluded that the cortical hormones in pulp capping operations rendered to this procedure a higher degree of success than that which may be expected with previously used methods. No controls were utilized for this preliminary study, no histologic methods - the only criteria for success being vitality tests and relief of pain, which makes these results suspect.

When one considers that not only is the inflammatory reaction itself reduced but the inherent defence mechanism of the tissues is also inhibited so that the spread of micro-organisms from a localised region of infection to the entire pulp or by means of the bloodstream to the entire body is a distinct possibility - it is difficult to credit the above authors with such a high degree of success. Certainly after

the bacteraemias produced recently by Klotz et al⁶⁷ are noted. They performed a study on 24 teeth (permanent and deciduous) of five Rhesus Monkeys. Nineteen teeth were tested using prednisolone and five served as controls. Of the nineteen trials in which prednisolone powder was used to treat infected pulps, 21% resulted in bacteraemia. Of the five control trials in which the only change in procedure was the use of raffinose instead of prednisolone powder, none resulted in bacteraemia.

The possibility of bacteraemia has further been exemplified by experiments with H³ - cortisone applied to the exposed pulp by Quintiliano D. de Deus et al¹⁰⁴ who found evidence of the labelled material in regional lymph nodes and liver by radio-autographic means.

The rationale of a combination of cortico-steroids with a broad spectrum anti-biotic is thus emphasised by Sinkford and Harris¹²⁸ although they feel that "because of the lack of adequate controlled experiments, there is no assurance that even combined therapy is acceptable". However none of the authors who will be reported in this review who have experimented with this combination of materials has noted any adverse systemic reaction following treatment.

EARLY EXPERIMENTATION WITH CORTICO-
STERIODS IN PULPAL THERAPY

Although not utilising cortico-steroids with relation to pulpal therapy Wolfsohn¹⁴⁸ in 1954 indicated the anti-inflammatory effect of hydrocortisone on the periapical tissues. He found that 0.5 cc. of hydrocortisone injected into the pulp canals of teeth treated by electro-sterilization resulted in reduction and elimination of severe secondary inflammatory reactions and that similar use at the conclusion of immediate pulpectomy resulted in the elimination and absence of secondary trauma. He did note that this drug when used in the presence of an infected pulp and periapical tissues will produce exacerbation of the disease process. Later Feinschneider³⁹ used Neocortef ointment and Shroeder¹²⁵ used a water soluble cream containing triamcinolone and chloramphenicol for the same purpose.

Stewart¹³³ in 1956 in his study of the use of anti-histamines and cortico-steroids in the reduction of post-operative sequelae following endodontic surgery noted that results showed that antihistaminic compounds and cortico-steroids may reduce pain swelling and discoloration and encourage better wound healing when used individually, but as cortico-steroids do not inhibit bacterial growth it is necessary to combine them with antibiotics.

In 1958 Kiryati⁶⁶ published results of the effect of hydrocortisone plus polyantibiotics upon the damaged and infected dental pulp of rat molars.

He found that treatment with hydrocortisone alone showed 22% complete healing. When the hormone was combined with poly-antibiotics the lacerated pulp covered with the hormone and a mixture of oxytetracycline and chloramphenicol showed a significantly higher incidence of complete pulp healing (63%) than those with neomycin and bacitracin (18%). Lacerated pulp covered with oxytetracycline and chloramphenicol without hydrocortisone gave 35% complete healing. He found that there appeared to be no restriction to new capillary formation and cell differentiation as secondary dentine formation was in no way inhibited by the hormone.

These results appear to be quite inconclusive. It is also to be noted that experiments on rats always seem to produce better results than those carried out on the human.

In 1959 Turrell¹⁴¹ capped exposed pulps of sixteen healthy human teeth with a paste consisting of 6 parts anhydrous Ca Cl_2 , 1 part cortisone acetate and anhydrous glycerine in sufficient quantity as a vehicle. The treated teeth and controls were extracted after 20-45 days. The patients were examined periodically during the treatment period. None of those treated with the cortisone acetate paste showed signs of pulpal disease

whereas the persons serving as controls (treated with $\text{Ca}(\text{OH})_2$) showed hyperaemia of varying degrees. Histologically in the treated teeth was observed an abundant formation of new fibres which had been transformed into a dentinoid substance within 30-45 days after treatment.

From these results Turrell drew an important conclusion "Because the cortisone acetate in the paste must have been absorbed within a comparatively short time, (from 60-80 hours) it can be concluded that cortisone acetate if permitted to cover the exposed pulp long enough to prevent the development of inflammation, but not long enough to impair the defensive reactions of the pulp, possesses properties which increase the chances of preserving teeth with accidentally exposed but healthy pulps."

Also, in 1959 Guilluzzo and Bellami⁵² became the first investigators who tried to heal (serous) pulpitis in man with a corticoid antibiotic combination. The paste consisted of penicillin, streptomycin, tetracycline and prednisone with a lanolin-vaseline ointment base. Over a maximum of six months they reported good results clinically, but gave no further indication of subsequent effects.

Koslov and Massler⁶⁸ in April 1960 published a report on the histologic effects of various drugs on amputated pulps of rat molars. They based their judgments on those of Miyamoto⁸⁷.

and Berman¹³ which suggest that a calcium salt is not essential for the formation of reparative dentine; thus assuming that the formation of reparative dentine is a function of the pulpal cells themselves rather than the medicament placed over them. The following anti-inflammatory drugs were used:

- 1) Chlor-trimatron (Scherg) 100 mg/cc
- 2) Cortisone-acetate (Scherg) 25 mg/cc
- 3) Hydrocortisone acetate USP (Upjohns) 25 mg/cc.

They found that at 14 days although hydro-cortisone is supposed to be a more potent suppressor of inflammation and fibroplasia than cortisone, it did not act this way on the pulp and actually hydro-cortisone caused less rapid healing than cortisone.

Although Vigg⁽¹⁴⁴⁾ later in 1962 experimenting on 66 exposed pulps in humans found that treatment of 18 pulpitic teeth with 1% hydrocortisone and 3% oxytetracycline yielded success in fourteen cases after six months, together with the formation of a calcific bridge.

Further work has been carried out on the use of cortico-steroid properties of reducing inflammation by Fry et al⁴³, Dacchi³⁰, Shroeder¹²², Mosteller⁹⁰ and Mohammed¹⁵² in treating hyperaemia and preventing subsequent pulpitis following restorative procedures. Although this is outside the scope of this paper, it is well to note the results obtained when one considers the traumatic effect upon the pulp of cavity preparation.

Fry's⁴³ results in 1960 were certainly the most promising of those of the early experimentors in pulpal therapy with cortico-steroids. Forty-three teeth with either pulpal exposure or carious invasion were studied and treated topically with prednisolone to which was added camphorated parachlorophenol with metacresyl acetate. No attempt was made to establish an aseptic technique.

Those cases in which pulpal hyperaemia occurred as a result of restorative interference were treated by application of the medication to exposed dentine and sealing of the area with ZnO - eugenol.

When a vital operative pulpal exposure had occurred under aseptic conditions, the paste was applied to the exposed pulp on a small cotton pellet and the cavity sealed with ZnO-eugenol.

When emergency clinic patients reported with pain, and X-ray films indicated a possibility of pulpal exposure if carious dentine were completely removed, the paste was placed after partial removal of caries over the unexcavated carious dentine and the tooth sealed with ZnO-eugenol.

Results

All patients stated that their pain hyper-sensitivity had subsided promptly. After 24 hours pain was absent in the large majority of cases. If pain still existed, the patient

reported for re-evaluation and retreatment, which invariably resulted in comfort. After 4-6 weeks all treated teeth were symptomless, responded normally to vitality tests and showed X-ray evidence of dentine formation. There was only one failure.

As this was only a preliminary study over a short period of time and without histologic evidence as with many of the other reports to be cited it is not completely conclusive of the efficacy of this treatment but was certainly at that time the most impressive evidence to substantiate the high potential of the topical use of a corticoid for the relief of dentinal and pulpal pain and for conserving the vitality of exposed dentine and pulp tissue.

Further, to substantiate this argument is the work later carried out by Lawson and Mitchell⁷⁵ who conducted a preliminary investigation of a corticoid-antibiotic mixture for treating painful pulpitis and surgical pulp exposure.

Fifty cases of painful pulpitis were treated with double-blind control methods used to compare the vehicle of the experimental mixture with the mixture itself, four normal teeth were surgically exposed and treated in the same manner.

The vehicle was starch pH6 and the experimental medicament.

Erythromycin Estolate 10%
Streptonayein Sulphate 10%
Flurandronalene 0.5%
Starch

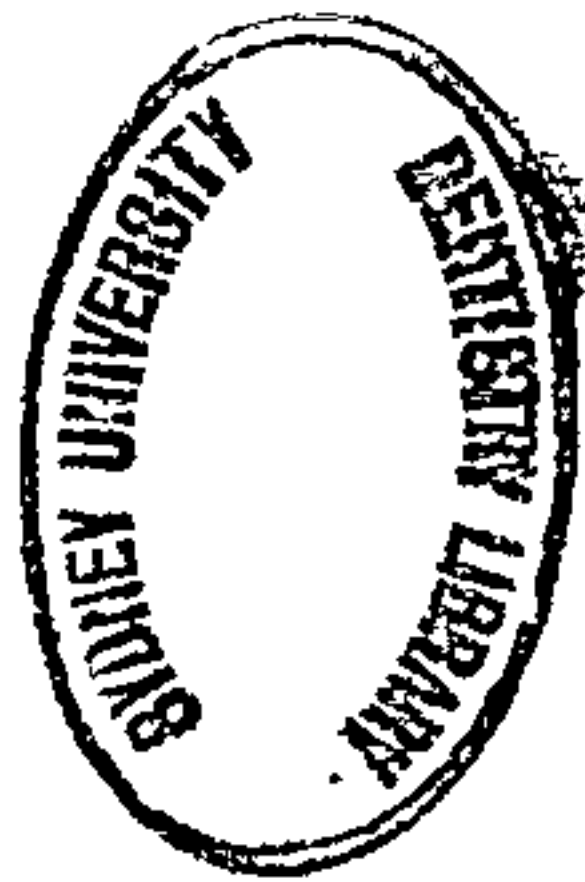
All clinical work was carried out by the one investigator who at first carried out electrical, radiographic and percussion tests. The time interval between treatment and last re-examination ranged up to 164 days.

Of 27 teeth treated initially with the blank control, 15 were judged clinically successful. Of 27 teeth treated with the corticoid-antibiotic all were clinically successful. Of 4 teeth considered as failures when treated with the blank control and retreated with the corticoid-antibiotic all were considered clinically successful. Some teeth were still hypersensitive to some clinical control tests although as Mumford^{91,92} has shown that temperature and electrical response is so variable it is almost impossible to tell. However, the percussion test induced the most consistent sign of hypersensitivity.

It was noted primarily that there appeared to be no dentine bridge formation in any case. This is opposed to Fry et al's⁴³ finding of dentine bridge formation in all cases. However, the microscopic finding of 7 teeth studied by serial sections three representing painful pulpitis (1 experimental and 2 controls) and 4 which were normal surgically exposed pulps (2 experimental and 2 controls) indicated that the reaction to corticoid-antibiotic was unusual but more normal than that of the controls which showed persistent pulpitis.

Thus, the conclusion was drawn that on clinical observation and limited microscopic study painful pulpitis is

reversible when treated with a corticoid-antibiotic preparation and that clinical histopathological observations did not correlate well as has been indicated before, and perhaps indicating that the so-called clinical successes ultimately may prove to be failures supporting Mitchell and Tarplee⁸⁸ in that only mild symptoms may be associated with extensive pulpitis.



REVIEW OF LITERATURE CONCERNING LEDERMIX

As will be seen in the next chapter some of the constituents of this material are unusual. These constituents do not seem to have been questioned to any length by the many experimentors who have now utilised Ledermix, although now the thought may change as the results of some long term studies are at hand.

Ledermix was used extensively in Europe and the data on a total of 484 treated teeth was collected by Shroeder and Triadan¹²⁵ and published in July 1962.

Ledermix was distributed to a number of practitioners for trial purposes with the request that they fill out and return the individual patient record forms, which were simultaneously supplied. Reports were received from twenty-nine practising dentists in Germany, Austria, Italy and Switzerland.

Of the 484 teeth 213 were molars, 167 premolars, 68 incisors and 18 deciduous teeth. A partial serous or purulent pulpitis was found in 315 teeth, 166 of them with pulp exposure. Total serous pulpitis involved 71 teeth, 46 of these with the pulp exposed. No definite diagnosis was given for 33 treated teeth, 27 of which also presented an exposed pulp. Periodontitis affected the remaining 65.

Elimination of pain was achieved within one hour in 67 of the affected teeth, within one to six hours in an

additional 111, and after more than six hours in another 68.

Follow-up examination, on the average 21 days later (maximum 213 days after completion of treatment), showed that vitality of the pulp had been maintained in 312 (99%) of the 315 teeth with partial pulpitis, the three devitalised teeth having had the pulp exposed, and in 70 (98.5%) of the 71 teeth with total pulpitis, the one devitalised tooth also presenting an exposed pulp. All of the 33 teeth affected by pulpitis where no exact diagnosis was given showed vitality of the pulp on subsequent examination. There were three failures among the 65 treated teeth with periodontitis.

From this they concluded that the topical application of Ledermix resulted in rapid subsidence of pain due to pulpitis or periodontitis but because of the shortness of the observation period no positive statements can be made as to whether or not the teeth with pulpitis which responded to treatment will continue to remain vital.

However, altogether to the above stage Shroeder and Triadan had accumulated records on 5,000 patients treated with these formulations and summarized their experience as follows:-

- 1) In general, all inflammations of the pulp and the peridontium respond rapidly to treatment regardless of their nature.
- 2) The disappearance of symptoms does not necessarily signify continued vitality of the pulp. However, if the following basic rules are observed it can be assured in most instances.

- a) Conservative pulpitis treatment is absolutely contraindicated in total purulent pulpitis.
- b) Pre-treatment with the water-soluble form of the preparation is indicated where an open pulp cavity or purulent pulpitis is present.
- 3) Intensive application of steroids is contraindicated and in the presence of infection it is necessary to have an antibiotic in the preparation.
- 4) Based on the consideration that the corticoid component suppresses the defence mechanism one may assume it may be detrimental to the formation of ground-substance. However, histologic studies, so far, have shown that this is not the case, only limited amounts of corticoid are released from the formulation at any one time.

It is interesting to note that in the same year Fiorre-Donno and Baume⁴¹ published results of their experimentation. They noted that all pertinent reports on the beneficial effects of cortico-steroid preparations are almost exclusively based upon clinical observation and that systematic histologic controls have been made only on rat molars.

They reported on 190 teeth affected with painful pulpitis of patients aged from 13-50 years treated by direct pulp capping with one of the following compounds:

No. 1. Mixture of alkaline prednisolone 2.58g and chloramphenicol 0.28g. (85 teeth).

- No. 2 Triamcinalone 0.315g. chloramphenicol 0.28g. xylocain solution 4% excipient 1.5g. (25 teeth).
- No. 3 Mixture of millicortone dexamethasone 25g., chloramphenicol 28g. and methocel ad 100g. (25 teeth).
- No. 4 Mixture of millicortone 25g., chloramphenicol, methocel and pulpdent (25 teeth).

Ninety-five teeth were extracted for prosthetic or other reasons after varying post-operative periods ranging from 15-300 days.

Sixty-two had a pre-operative history of painful pulpitis, twenty-three without symptoms served as controls.

In addition thirty teeth, either symptomless or affected, were treated with only one drug of the above compounds.

Diagnosis of the pulpal state was established with the usual clinical methods including pulp haemogram. A partial pulpotomy was preferred under sterile conditions and after medication the cavities sealed hermetically.

All teeth treated were checked clinically and radiographically at regular intervals.

Results:

- a) Healthy Cl.1 pulps capped with millicortone showed some tenderness until the tooth removed.

Pulps capped with chlormaphenicol reacted with increased pain. The combination of both drugs or admixture of Ca(OH)_2 to one of them elicited no clinical signs.

- b) All painful Cl.11 pulps capped with cortico-steroids containing compounds reported ended with immediate cessation of the subjective and objective signs. Immediate and complete relief was obtained with compounds 2, 3 and 4. Radiographic examinations after long post-operative intervals showed no apical alterations.

Histologic Observations

a) Cl.1 pulps.

The conditions 41 days after application of chloramphenicol showed a necrotic mass covering the pulpal lesion with heavy infiltration by neutrophilic elements in the adjacent tissues and congestion in the radicular portion.

The effects of compound No. 1 30 days after application comprise stunted dentinogenesis with hyperaemia and fibrosis throughout the entire pulp.

Ledermix is characterised by the formation of a dense fibrotic barrier between dressing material and living tissues. Encapsulation was present in all five cases. Calcification however, never occurred even after 300 days. The stroma of the coronal pulp also had undergone fibrosis and dentinogenesis proceeded at some distance from the lesion.

Compound No. 3 produced the least pulpal alterations. However, the fibrotic surface layer remained very thin. A predentine layer was formed but did not calcify.

Class 2 Pulps

With compound No. 1 the tooth remained clinically symptomless.

However, histologically it exhibited marked fibrotic metaplasia and chronic inflammation. The entire pulp-dentinal surface layer had a periosteum-like texture and was actively engaged in the deposition of a bone-like substance.

With Ledermix a similar picture was seen. The amputated area was encapsulated by a densely woven wide fibrous tissue. The zone was heavily infiltrated with inflammatory elements. The rest of the pulpal stroma was relatively free of these cells. Dentinogenesis was arrested while at some distance osteoid formation was observed.

Compound No. 3 engendered the least metaplastic changes whilst compound No. 4 utilising pulpdent was most favourable in results with an almost normal pulpal appearance and formation of a calcified bridge. Thus they concluded that cortico-steroids seem either to inhibit new formation of mesenchymal cells, precollagenous fibrils and ground substance on a primary cellular basis or may accelerate their maturation in a collagenous connective tissue and thus engender in pulpal tissues fibrotic metaplasia while they inhibit the collagenic activity of ordinary connective tissues.

In March 1966 Baume⁵ reported again the use of Ledermix in 170 teeth treated and stated that controlled by clinical means Ledermix showed an almost miraculous effect. The most severe symptoms of pulpitis ceased after a short time giving the impression of complete recovery. Histopathological

analysis however without exception showed.

- 1) Metaplastic change of the pulp tissue.
- 2) Irreversible inhibition of dentine formation.
- 3) Persistent chronic inflammation from which many treated pulps succumbed without symptoms even after years.

The metaplasia manifested itself as an atrophy of the derivative of mesenchymal tissue which disappeared completely. These metaplastic changes were found regularly in the region in contact with the drug and often involved the entire pulp. There was always even after long post-operative periods severe congestion in the radicular portion.

The inhibition of dentinogenesis comprised a blocking of mineralization of the pre-operative formed predentine as well as an arrest of the post-operative formation of predentine. In not one single case did complete fibro-dentinal bridging of the pulpal exposure occur. A radiographic appearance suggesting bridging appeared as condensed dentine splinters without any osteoid formation around the clumps at the dentinal walls.

They thus concluded that the anti-anabolic effect of the corticosteroids which are known to suppress R.N.A. formation and protein synthesis proved to be irreversibly and irreparably effective also in the pulp even when applied in the smallest doses.

The same, unfortunately, was not true for the anti-infectious effect of the antibiotics which appeared to exhaust themselves in a very short time, so that chronic inflammation in primarily inflamed pulps spread slowly over the corticoid weakened tissues giving rise to symptoms. Such focal infection was neither clinically nor radiographically detectable.

Therefore, following these conclusions Baume has made the following recommendations in agreement with the recommendations of the 3rd International Symposium in Endodontics, (Barcelona May 1965):

The endodontic use of cortico-steroids can be indicated as follows:

- 1) For definite management of painful pulps, accidentally exposed or near deep seated caries of primary teeth.
- 2) For the palliative treatment of pulps indicated for a subsequent extirpation and root canal therapy.
- 3) For prevention of exacerbation of pulps involving infection of radicular dentine accessible to antiseptic root canal therapy; and accidental root canal perforation.
- 4) Any contact of cortico-steroids with an exposed pulp whose vitality is to be maintained is contraindicated.

These recommendations concerning pulpal preservation are quite devastating when one considers results of other workers in this field and their conclusions. Prader¹⁰² used a preparation containing Ledercort Triamcinolone and either demethyl chlortetracycline or chloramphenicol in 56 cases of pulpitis. By means of a pulp haemogram he found a lessening of inflammation in 26% and of infection in 13% while both were lessened in 43% of cases. It is noticeable that Baume was unable to correlate pulp haemogram results with histologic findings and that Prader carried out no pulpal histologic examinations at all. Prader concluded that clinically the new preparation has proven to be very efficient and showed new ways in the therapy of pulpitis and this is certainly so within the bonds of Baume's recommendations.

Mohammed¹⁵² produced a preliminary report on 192 patients, from the clinics of the University of Puerto Rico School of Dentistry. 115 patients were diagnosed as having pulpitis in 134 teeth. After removal of all caries and pulp exposures the water-soluble paste was utilized. Four to five days later the wound was closed with Ledermix cement in the manner recommended. 87 teeth diagnosed as suffering periodontitis in 77 patients were treated in the recommended manner also.

In all cases pain relief was evident in an average of four hours with a range of immediate relief to within twenty-four hours.

Of the 221 teeth used in this investigation and diagnosed as having either pulpitis or periodontitis, 198 teeth showed a maintenance of vitality up to and including a six month follow-up examination. Of the total of 87 teeth with periodontitis there were eight failures at the three week follow-up examinations. Mohammed concluded that the application of Ledermix resulted in the rapid relief of pain in patients suffering from pulpitis or periodontitis accompanied by the maintenance of tooth vitality and a lack of radiographic evidence of periapical pathology in a significant number of cases up to six months following the operative procedure.

As no corroborating clinical evidence has been produced by Mohammed since this study together with histologic findings little can be determined from this work concerning long-term effects of the corticoid compound upon the vital exposed pulp.

Rowe¹⁵³ treated 245 teeth by pulp capping with Ledermix. The teeth were divided in the following groups:

Symptomless	39
Painful to cold	69
Painful to heat	46
Mild toothache	56
Severe toothache	35

Some patients complained of more than one symptom from the affected tooth. Thirty teeth received two treatments - the water soluble paste followed by the permanent cement.

After four to eight months four teeth were extracted and five rootsfilled due to persistent pain. The remaining teeth remained vital and symptomless.

As only one histological section was examined by Rowe after six weeks the evidence that normal pulp tissue shown below the exposure is of little consequence, as it would be necessary to have several sections for a true picture. Also, evidence would be required over a longer period on more teeth to be of any worth.

Mager⁷⁹ in 1963 carried out a pilot trial on twenty patients followed up over a six-month period. In cases of carious exposure the cavities were all made caries-free under local anaesthetic, the exposure widened and in the more acute cases Ledermix paste applied as a pulp-cap and the cavities sealed. The cement was used at the second stage and also in the less acute cases which were restored completely at a single sitting.

Vitality was preserved in all except one tooth which was extracted three months after treatment. Relief of pain was immediate. Mager concluded quite sensibly that results to date were encouraging but required prolonged follow up including X-rays, on a greater number of cases.

Also in 1963 Haddad¹⁵⁴ treated several teeth with acute and chronic pulpitis utilising the recommended two stage

technique. In all cases excepting one he claimed success in relief of pain and maintenance of vitality. However as only clinical tests were carried out over a period of one month, this report is of little value excepting for another example of the palliative effect of Ledermix.

In 1964 Olsen⁹⁵ carried out a clinical study involving 370 teeth divided into three categories.

- 1) Pulpitis and pulp exposure; 249 teeth
- 2) Hyperaemia without pulp exposure; 84 teeth
- 3) Pulp gangrene and apical periodontitis; 37 teeth.

"In all instances of exposed pulp, Ledermix paste was applied with a small cotton pledget and the cavity was closed with a temporary filling of ZnO-eugenol. If pain relief was not complete this procedure was repeated. On an average of 4-7 days later the cavity was reopened and the cotton pledget removed. The pulp exposure was covered with Ledermix powder plus hardener". The tooth was then permanently restored. Of these cases Olsen claims a 1% clinical failure rate.

In 1966 Olsen⁹⁶ carried out a further study on an additional 352 patients. Only those patients who required a single application of Ledermix paste for pain relief in pulpitis were evaluated.

He states that only 17 of 414 teeth with pulpitis treated with Ledermix and followed for periods ranging from 2-48 months were non-vital at the follow up examination. In

pulpitis, relief of pain came within a half hour for 279 patients and within 1-2 hours for 49 patients.

Several of the treated teeth that were painless and vital were extracted and examined microscopically. The microscopic findings appeared to confirm the results obtained.

This work bears out Baume and others' findings concerning relief of symptoms, however his findings concerning long-term follow up contradict those of Baume's study earlier that year⁵.

Ehrmann during 1964-1965^{34,35} published articles concerning use of Ledermix. He utilized no histological examination but clinically found that of 10 mechanically exposed pulps, 5 tested more than three months after application were still vital. One tooth tested 10 months afterwards was vital and symptomless. For this treatment Ledermix B. was utilized.

For acute serous pulpitis and acute partial purulent pulpitis. Ledermix A followed eight hours to two days later by Ledermix B was utilised. Thirty cases of acute serous pulpitis were treated. In all patients the pain associated with pulpitis ceased within 1-2 hours.

No patients returned with symptoms. Of a possible recall of 18 patients at this stage two pulps had become necrotic and in others hyperaemia persisted. The remaining thirteen cases were symptomless but when treated with the electric pulp tester three gave poor response. Roentgenographic

findings however were normal in these cases.

Of the teeth treated for the partial suppurative pulpitis, all were vital and symptomless when tested three to six months later.

Ehrmann has commented on the fact that pulp testing appeared to be made more difficult by the fact that some weeks after the application of the cortico-steroids over an exposure some teeth did not seem to react well. He suggested this might be a state of shock as experienced in traumatized teeth.

Following this article Ehrmann then reported on the activities of the 20 members of the Melbourne Endodontic Study Club whose results he collated into the following table²⁶. He suggested that exposure should be avoided at all costs except in partial suppurative pulpitis (see table).

Cowan²⁷ applied Ledermix to exposed or almost exposed pulps in 148 teeth including 22 for extraction and histological study.

Criterion of results was maintenance of vitality.

39 teeth received similar treatment with ZnO eugenol (14 for histological study). He classified the teeth as follows:

- 1) Teeth with clinically normal pulps (72).
- 11) Teeth with acute pulpitis (10) including hyperaemia.
- 111) Teeth with chronic pulpitis (69).

TABLE 10.

B. PULP INVOLVED TEETH

Teeth Still Vital at Beginning of Treatment

	Teeth Treated			Pain Stopped				Vital & Symptomless			Vital but hyperaemic	Non-vital Ants.				Non-vital Posts.			
	Ants.	Posts.	Total	When inj. wore off Within 24 hours	No pain at any time	No relief	1-6 months	6-12 months	1-2 years	Non-vital symptomless		Extracted	Root canal therapy	Total	Non-vital symptomless	Extracted	Root canal therapy	Total	
Mechanical Exposure	13	24	37		30	30	1	21	6	1							1	1	
Carious Exposure without previous symptoms *	88	376	464		53	377	4	152	18	1	5			2	2	2	2	3	5
Hyperaemia (History of previous carious exposure capped with another agent)	7	73	80	40	28		1	36	1		1							2	2
Hyperaemia due to deep fillings? poor linings, deep caries - but NO visible exposure	27	111	138	59	47		8	62	12	2	4	1	1	2	4		2		2
Hyperaemia due to unknown causes	9	5	14	4	2			5			1								
Acute Serous Pulpitis	21	184	205	88	70		5	77	9		6			3	3	3	7	3	13
Acute Suppurative Pulpitis. <u>PARTIAL</u> only	6	49	55	14	16		6	5			1			2	2	7	6	1	14

* Calcification was seen in X-rays of 1 tooth in this group.

- TAKEN FROM MELBOURNE ENDO. STUDY CLUB '76

Exposures were graded according to size - pin-point, pin-head, larger and very large.

Bleeding from exposed pulps also was graded; none; bead and free bleeding.

In cases of (1) (11) the pledget was left for three days and then restorations completed with the cement.

In other cases only the cement was used.

Follow up occurred for six months with checks at intervals.

Criteria for success were:

- (a) No history of pain since treatment.
- (b) Vital response to vitalometer and/or thermal stimulus.
- (c) Any evidence of secondary dentine on radiographs.

Histological results.

Nine carious teeth (7 Ledermix and 2 control) were investigated.

All were symptom free after treatment and remained so until extraction at intervals of 14, 22, 33 and 43 days.

A further 29 healthy premolars for orthodontic extraction were prepared. A tooth on one side of the mouth capped with Ledermix and the corresponding tooth on the other side capped with ZnO eugenol. The period before extraction varied from four to eight months.

Clinical results.

126 teeth treated with Ledermix (62 with normal pulps); 7 with acute pulpitis and 57 with chronic pulpitis); 9 were failed cases from other pulp capping materials but all were vital.

Immediate relief of pain was obtained in every tooth. 114 were classed as successful.

Failures.

12 cases failed after varying periods. The majority were of chronic pulpitis. Abscess in some occurred as little as a month after a positive vitality test.

Control Group.

Of 25 teeth 10 had normal pulps, 3 had acute pulpitis and 12 chronic pulpitis. The average period of follow up was fifteen months ranging up to thirty-six months. Materials used were ZnO-eugenol (19); Zoraline (3); Oxyphosphate cement (2); Ca(OH)_2 (1). Results were complete success in ten, complete failure in six and partial success in nine. Nine of the less successful cases were retreated with Ledermix and of these three later failed.

Histological group.

Of the seven Ledermix cases, the acute inflammations had not been controlled although they were now chronic, with regions of acute inflammation and some suppuration. There was no evidence of secondary dentine although a dentinoid substance

had been laid down on the lateral walls. There was a tendency towards fibrosis of the pulp.

The tooth treated with ZnO-eugenol showed an intense inflammatory infiltration in the coronal pulp with small abscesses. Further apically the pulp appeared normal. In the sound premolar teeth in children there was no evidence of a calcifying response with the Ledermix although recovery of odontoblasts away from the exposure zone appeared. In some of the same mouths, teeth treated with ZnO-eugenol showed very poor results - Cowan attached no significance to this.

With Ca(OH)_2 there was a distinct bridging after three months.

Radiography.

No radiographic evidence of dentine inhibition demonstrated by completion of apex formation in seven developing permanent teeth was observed. No clinically successful case showed periapical deterioration and at least seventeen appeared to show secondary dentine at the exposure area.

He concluded that the prognosis for capping with Ledermix cement was proportional to the size of the exposure (the smaller the better) and the state of the pulp. It was useless as a medium for temporary relief of pain (24-48 hours) in advanced acute pulpitis, e.g. suppuration. It was of limited value in advanced chronic pulpitis. There were no side effects

from the material and Cowan confirmed the unreliability of vitality tests in chronic pulpitis as has been stated by Erhmann³⁵ and Mitchell and Tarplee⁸⁸.

Also in 1966 Harris and Bull⁵⁴ reported on the effect on the healing of traumatised pulps in forty-four teeth recovered from rats when Ledermix and $\text{Ca}(\text{OH})_2$ were used over a period of two to twenty-two days. The similar study was made on fifteen teeth from children aged fourteen to sixteen years for twenty-three to three hundred and fourteen days. In eight of the human teeth treated with Ledermix, atubular calcification was found on the walls of the root canals and on the floor of the pulp chambers. At the site of the pulp exposure there was no evidence of bridging. In all cases treated with Ledermix there was complete cessation of pain and no further symptoms in the teeth. In general the effect of Ledermix appeared to be a reduction in the area of the pulp involved rather than the elimination of inflammatory reaction.

Then Rowe¹¹⁴ again reported on Ledermix, capping fifteen rat molars in twelve animals and examining them over thirteen to one hundred and fifty days. He found a feature was absence of inflammatory cells. However, extensive necrosis of the pulp in most teeth separated from the remaining vital pulp by an ill-defined cellular barrier was noted. One well-defined calcific bridge was observed at twenty-eight days in close relation to some large dentine chips.

It is to be noted that these were uninflamed pulps treated in more resistant pulps than normally found in human teeth.

LEDERMIX - ITS COMPOSITION

A vast amount of experimentation has been carried out in recent years with a more potent cortico-steriod than had been previously utilised. This being Triamcinolone produced by the Lederle Laboratories following results noted by Shroeder and Triadan who reviewed the available clinical data on approximately five thousand patients with pulpitis or periodontitis treated with various preparations containing triamcinolone and a broad-spectrum antibiotic.

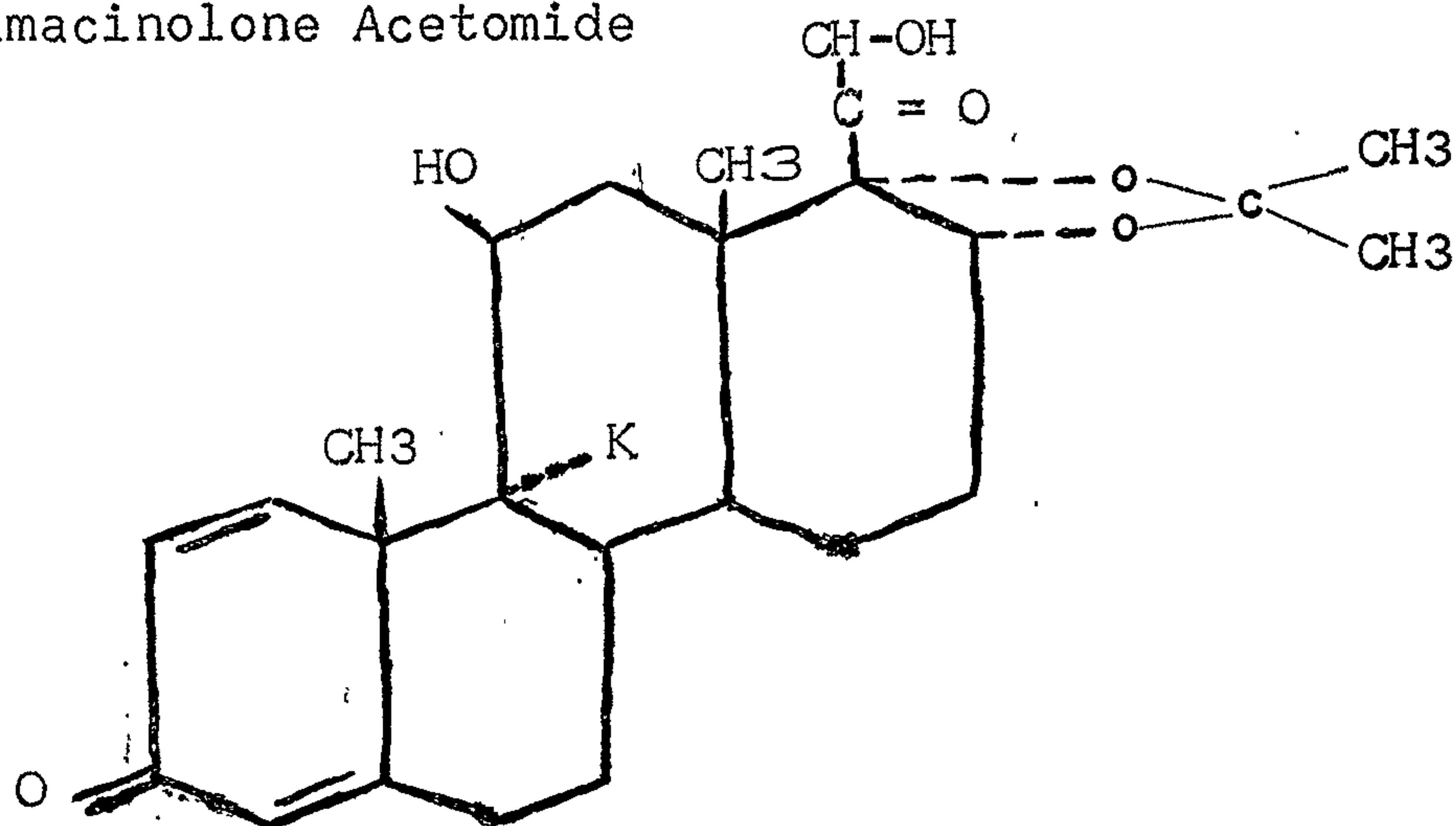
Ledermix consists of three individual units; a 3 gm. tube of Ledermix paste; a 2 gm. bottle of Ledermix powder and a 5 cc. bottle of hardener. Some of the constituents of these units may be described as quite astounding and will be discussed in some detail.

Ledermix Paste (Ledermix A) is formulated with triamcinolone acetomide 1% the antibiotic calcium demethyl chlortetracycline 3% in a water soluble cream consisting of triethanolamine NF, Calcium Chloride USP, Zinc oxide, sodium sulphate (anhydrous), polyethylene glycol 4000 USP and distilled water.

Ledermix Powder (Ledermix B) contains triamcinolone acetomide 0.67% and demethylch lortetracycline hydrochloride 2% together with Zinc Oxide USP Canada Balsam, Rosin NF and Calcium Hydroxide USP.

LEDERMIX PASTE (Ledermix A)

Trimacinelone Acetomide



(9 α - Fluoro - 11 β 21-dihydroxy - 16 α , 17 α isopropylidenedioxy-14 - pregnadiene - , 20-dione

Molecular Formula C₂₄ H₃₁ O₆ F

Molecular Weight : 434.5

Melting point range: 274-278°C

Appearance: Fine colourless needle-like crystals.

Solubility: Soluble in dimethylacetamide; moderately soluble in diethylsuccinate, methanol, ethanol, polyethylene glycol, ethylacetate, propylene glycol, sesame oil, and diethylcarbonate. Very slightly soluble in glycerine and water.

The Hardener or Catalyst is a solution of Eugenol and rectified turpentine oil, NF.

The water soluble cream is applied over the site of exposure in cases of pulpitis in an effort to control both the infection if present and the inflammatory reaction. It contains rather a high concentration of the steroid and continues to liberate this over the site of application for as long as it remains in place.

The cement is basically a Zinc Oxide-Eugenol combination which contains both the triamcinolone and the antibiotic in a weaker concentration.

As stated earlier triamcinolone (Aristocort) is similar to prednisolone except that the F (Alpha) is in position 9 and there is an additional alpha (OH) in position 16. It is more potent than prednisolone with regard to anti-inflammatory effects and is used normally as the acetomide because of the greater stability in that form and therefore ability to be applied topically⁵⁰.

It was suggested that the steroid be applied for three to six days. However, as Fiore-Donno and Baume⁴⁴ have shown triamcinolone has a marked metaplastic effect on the odontoblastic layer of the pulp. The length of application is now limited to a few hours or at least one to two days.

Calcium Demethylchlortetracycline

(7 - chloro - 6 - demethyltetracycline hydrochloride)

Molecular Formula: $C_{21}H_{21}N_2O_8$

Molecular Weight: 501.3

Melting Point Range: 210 - 220°C

Appearance: Yellow diamond shaped crystals.

Solubility: Soluble in methanol and water,
moderately soluble in ethanol,
slightly soluble in acetone,
butanol, isopropanol and
chloroform.

The calcium salt is an amorphous yellow non-crystalline powder with a low order of solubility.

This material is a blood spectrum antibiotic which is bacteriostatic in mode of action.

Tetracycline.

Ehrmann³⁴ puts forward the argument that in the carious cavity the main organisms were lactobacilli and streptococci which were sensitive to tetracycline. However Zeldow and Ingle working on infected root canals found 24.3% of staphylococci and 33.3% of enterococci resistant to tetracycline whilst Goldman and Pearson⁴⁹ found 23% of organisms isolated from root canals resistant to tetracycline. In addition 8-20% of all canals contained yeasts which are not sensitive to tetracycline. However, as it has been shown

that cultures of carious dentine by Ehrmann himself as well as Canby and Burnett²³, Besic⁷⁴, Schouboe and McDonald¹¹⁵, Canby and Bernier²⁴, and Fisher⁴² revealed a predominance of streptococci and lactobacilli, then the choice is reasonable.

The sensitisation of a patient to the drug and subsequent reaction when it is readministered is of importance, although Meyler cited by Ehrmann³⁴ stated that "allergic reactions of any type are extremely rare following the administration of tetracyclines and chloramphenicol".

The penetrating ability of the drug through dentine and pulp has recently been indicated by Harris¹⁵⁵ in his use of Ledermix on rat molar pulps and some human teeth. It appeared to pass rapidly through the pulp and into the periapical tissues.

Triethanolamine $N(CH_2H_4OH)_3$

This is an emulsifying agent utilised as a base for the water-soluble cream. Its normal use is that of an organic base for preparation of amino soaps, hair creams, cosmetics and pharmaceutical emulsions for external use.

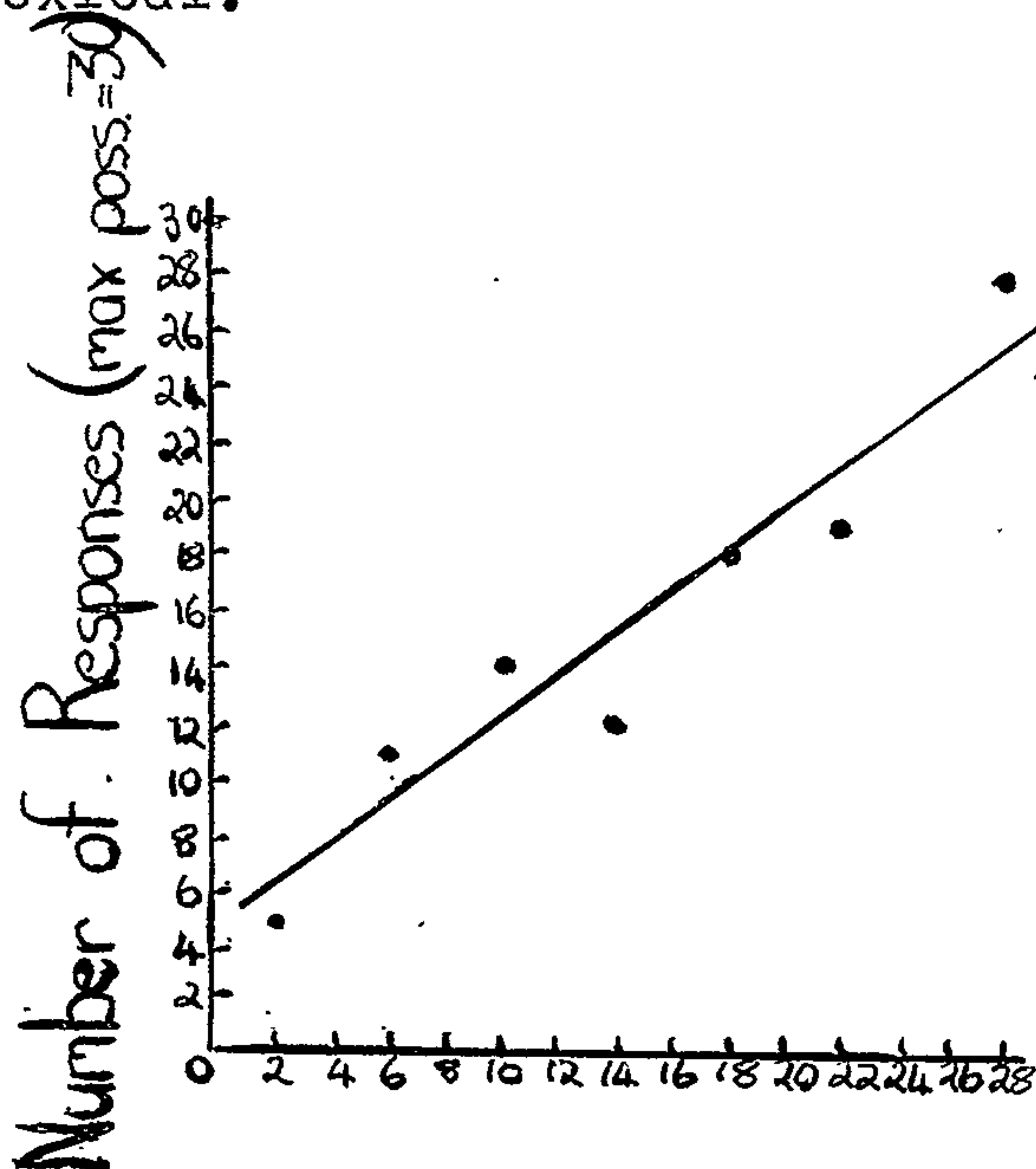
Calcium Chloride $(CaCl_2 \cdot 6H_2O)$ Mol.Weight 219.1

Colourless crystals tasting slightly bitter, odourless and very deliquescent.

Its use in this cream is to stabilize the demethylchlortetracycline by forming the calcium salt which retains the same degree of anti-bacterial activity as the neutral salt⁵⁹.

However, calcium chloride is highly irritant to tissues and produces sloughing in the event of leakage outside veins. So well known is calcium chloride for its irritating qualities that Anderson² in his experiments on sensory mechanisms in dentine used it almost exclusively as a stimulant. He postulated that pain was produced due to the high osmotic pressure of calcium chloride solutions.

We therefore have an irritant included in a cream which is utilized to allay irritation, which appears quite paradoxical.



Osmotic Pressure of CaCl₂(aq) in Atmospheres x 100

Zinc Oxide (ZnO)

A soft, white or faintly yellowish-white powder, free from grittiness, odourless and tasteless.

It is insoluble in water and alcohol (95%) and soluble in diluted mineral acids.

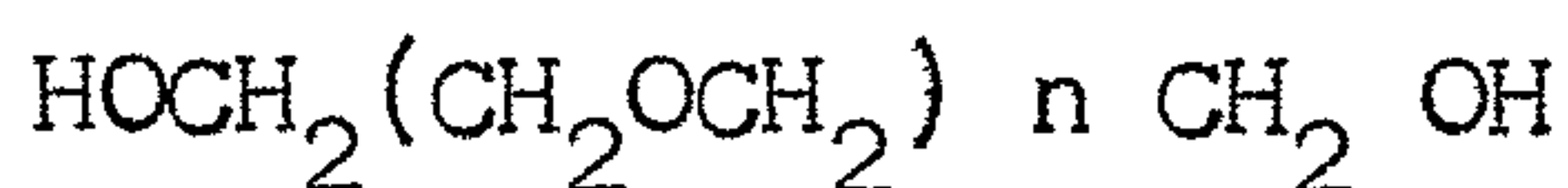
The action and use is that of a sedative and protective and is used in this way in Ledermix.

Sodium Sulphate Anhydrous (Na_2SO_3) Mol. Weight 126.1

A white colourless powder. When in aqueous solution being alkaline to litmus. It is included in Ledermix as an anti-oxidant.⁵⁹

Polyethylene Glycol

This has general formula



Polyethylene Glycol is water soluble and strongly hydrophilic and is a weak emulsifier of the oil in water type but may be used to stabilise oil in water type emulsions that already contain a primary emulsifying agent such as in this case.

Polyethylene Glycol is also a solvent for triamcinolone acetomide which is only very slightly soluble in water.¹³⁰ Thus, with its solvent property, plus stability, blandness and water solubility is an ideal base for this ointment.

Distilled Water H_2O

This is utilised as a solvent vehicle to form emulsions.

LEDERMIX POWDER (Ledermix B)

1. Triaminolone Acetomide.

This has been previously discussed.

2. Zinc Oxide.

Also, previously discussed.

3. Canada Balsam.

An oleoresin from the balsam fir . It is a pale yellow viscous liquid with an agreeable odour and a bitter acrid taste. When warmed for some hours in an open dish until setting, it may then be used in powder form. Its action is obtundent in nature and it is used also for its physical properties.

4. Rosin

The residue after distilling the oil of turpentine from the oleoresin obtained from various species of Pinus.

It consists of translucent, yellow or brownish yellow, angular, brittle, readily fusible, glossy masses with a faint odour and taste.

It is insoluble in water, soluble in alcohol, ether, benzene, carbon disulphide and fixed and volatile oils.

Its use is as an ingredient of ointments, plastics or cements for holding medicinal agents in contact with soft tissues. In a carbonised form it is used as an obtundant antiseptic in carious cavities.

5. Calcium Hydroxide. Ca(OH)_2

The use of Ca(OH)_2 in pulp capping has been discussed at great length at an earlier stage.

At first Ca(OH)_2 was not incorporated in the corticoid materials utilised, with results showing little secondary dentine formation.

Recently Shroeder and Triadan (1964)¹²⁶ stressed the importance of an alkaline reaction in the formation of hard substance after capping which confirm what Baume (1962)⁴¹ had stated, that it appeared essential for Ca(OH)_2 to be incorporated for this to occur.

However, later in (1966), Baume⁵ in further reports showed that histological evidence did not corroborate the favourable clinical and roentgenographic evidence. He noted the absence of a solid barrier; Ehrmann³⁴ also, found no calcific barrier which was later corroborated by Harris and Bull⁵⁴.

Thus the evidence put forward by authors as shown, that the presence of Ca(OH)_2 in Ledermix is adamant for a calcific barrier formation is not fully substantiated.

Also, owing to its necrotising action on the surface of the pulp the presence of Ca(OH)_2 is highly questionable no matter how sure one is of its action. For Shroeder stated in 1964 "that pulp capping with corticoid - antibiotic cement was successful in 70% of the teeth treated;

in maintaining tooth vitality when the cement did not contain $\text{Ca}(\text{OH})_2$. In the presence of $\text{Ca}(\text{OH})_2$, failures did not exceed 10%. However, relatively few teeth were available for histologic examination because of the so-termed success of the treatment. Shroeder¹²⁶ stated further that "teeth that had been inflamed and infected formed cyst-like closed regions. The pulp itself was in a state of chronic inflammation but these teeth did not cause pain and reacted normally to pulp testing. Signs of degeneration together with tissue atrophy were also seen in inflamed pulp. The pulpal defects were covered with dentine-like substance."

Thus even those termed failures exhibited secondary dentine formation which makes one consider what the other so-termed successes might be like if examined histologically.

Ledermix Hardener or Catalyst

Eugenol ($\text{C}_{10}\text{H}_{12}\text{O}_2$) Mol. weight 164.2

This is a colourless or slightly yellow liquid with an odour of clove and a spicy taste.

Eugenol is antiseptic and antiputrescent, obtudent to dentine and exposed pulp. When mixed with Zinc Oxide it forms a cement.

Rectified Turpentine Oil¹⁸

This is an oil distilled from turpentine the oleoresin obtained from various species of *Pinus* and rectified.

It is a clear colourless liquid with a characteristic odour and a pungent bitter taste. On exposure to air it becomes viscous and yellow and acquires an acid reaction.

Turpentine oil is utilised in the Ledermix cement to produce a rapid hardening and is no doubt responsible for the yellow colour taken on by the cement when set. However, it appears to be a strange constituent of a pulp capping agent; especially one which is anti-inflammatory in nature, for by its counter irritant reaction it would be expected that even in small amounts it would increase any pre-existing inflammation.

This view now seems to be shared by the Lederle Laboratory who have now advised that the 15% of turpentine oil has been reduced to 5% by the inclusion of 10% carbowax. The laboratory commented that this minimum amount of turpentine in the preparation which would harden to cement anyway does not exert extensive irritation⁵⁹.

CONCLUSION

When considering that today the public as well as the profession is placing more emphasis upon the preservation of teeth, the study of methods to preserve the vitality of the exposed pulp particularly in a society which is so prone to dental caries reaches a new extreme. Certainly the Endodontist with his increased skill is saving a large number of those teeth which were once extracted, although the root canal therapy is a quite radical operation in many cases, and an almost impossible operation excepting for the extreme case in the second and third molar regions.

After discussion of the efficacy of pulp capping as a means of preserving vitality and a discussion of many of the materials used at the present time emphasis has been placed upon cortico-steriod - antibiotic combinations with the commercial product Ledermix as the prime example.

It appears that there are many conflicting reports as have been shown - some investigators making extravagant claims, without sufficient corroborating evidence whilst those with such evidence being rather reserved in their approach to the material. This reservation is also understandable considering that the manufacturer has several times altered the formulation of the material.

However, Baume's⁵ recommendations for these materials as already stated but which will be re-iterated here appear to be the most scientifically based at this time.

- 1) For definite management of painful pulps accidentally exposed or near deep seated caries of primary teeth.
- 2) For the palliative treatment of pulps indicated for subsequent extirpation and root canal therapy.
- 3) For prevention and exacerbation of pulps involving infection of radicular dentine accessible to antiseptic root canal therapy; and accidental root canal perforation.
- 4) Any contact of cortico-steroids with an exposed pulp whose vitality is to be maintained is contra-indicated.

Therefore, the current literature seems to bear out as Curson²⁸ states. "The water soluble paste is indicated for the treatment of acute pulpitis. It does seem that this paste is more rapidly effective and therefore even if its object of restoring the health of the pulp is not fulfilled, the drug still has an important, although limited role to play." This applies particularly in the relief of painful pulpitis.

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