SECTION 1.

Teeth are hard calcified bodies of various forms, some irregularly pyramidal, conical and cubical, aligned in an arch-like series in the maxilla and mandible to form the dental arches. Of the arches, the "upper (maxillary) is elliptical and the lower (mandibular) parabolic in outline" (16), see Fig.1. The differ-

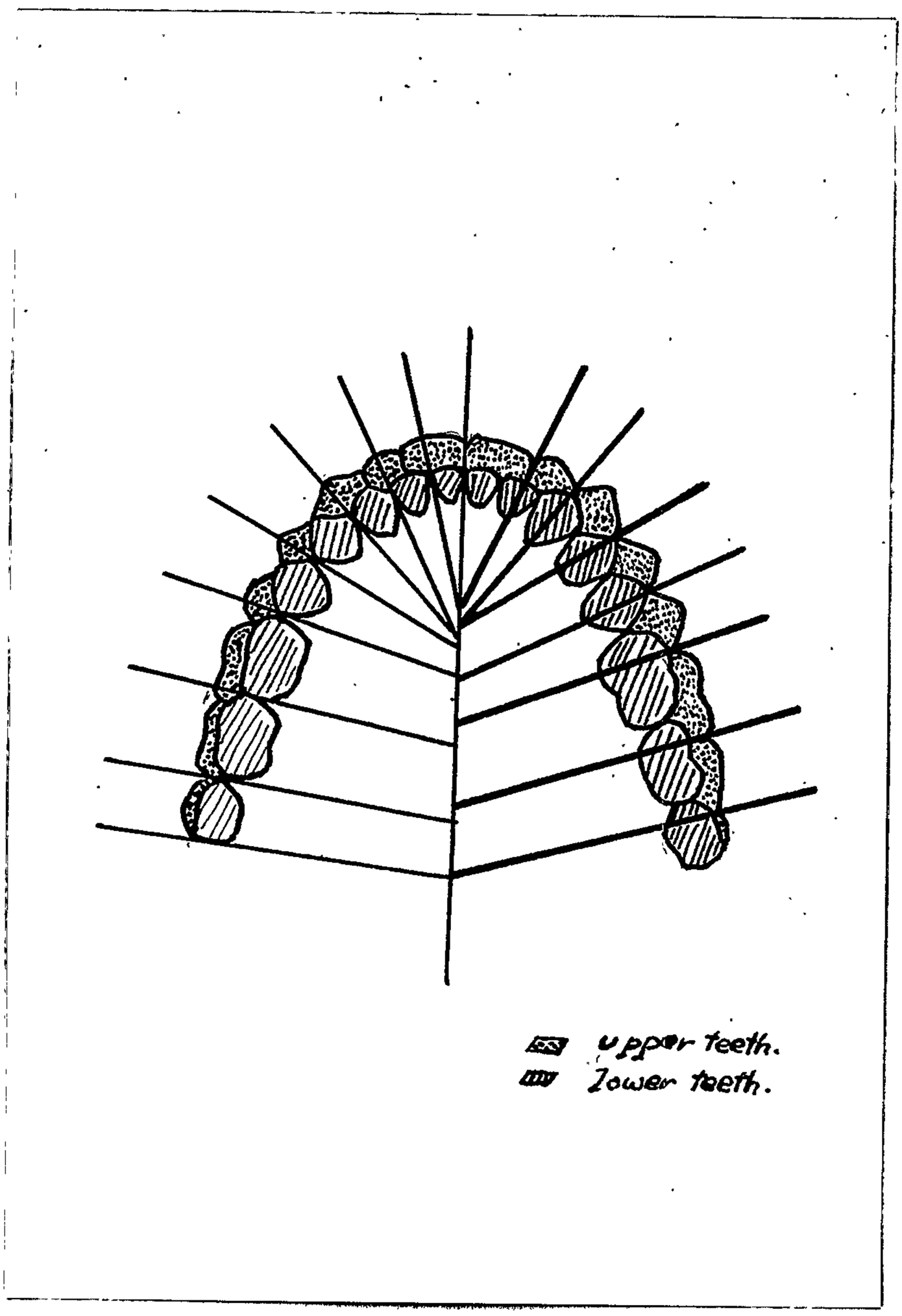


Fig. 1.

Fig. 1 shows diagrammatically the arrangement of the dental arches and the relationship of the lower to the upper teeth.

ences in form correspond to the position that the teeth occupy in the dental arches; the pyramidal and cubical forms respectively correspond to the anterior and posterior regions of the mouth

(16) Hopewell-Smith A. "Dental Anatomy and Physiology", 1913 Ed. p. 233.

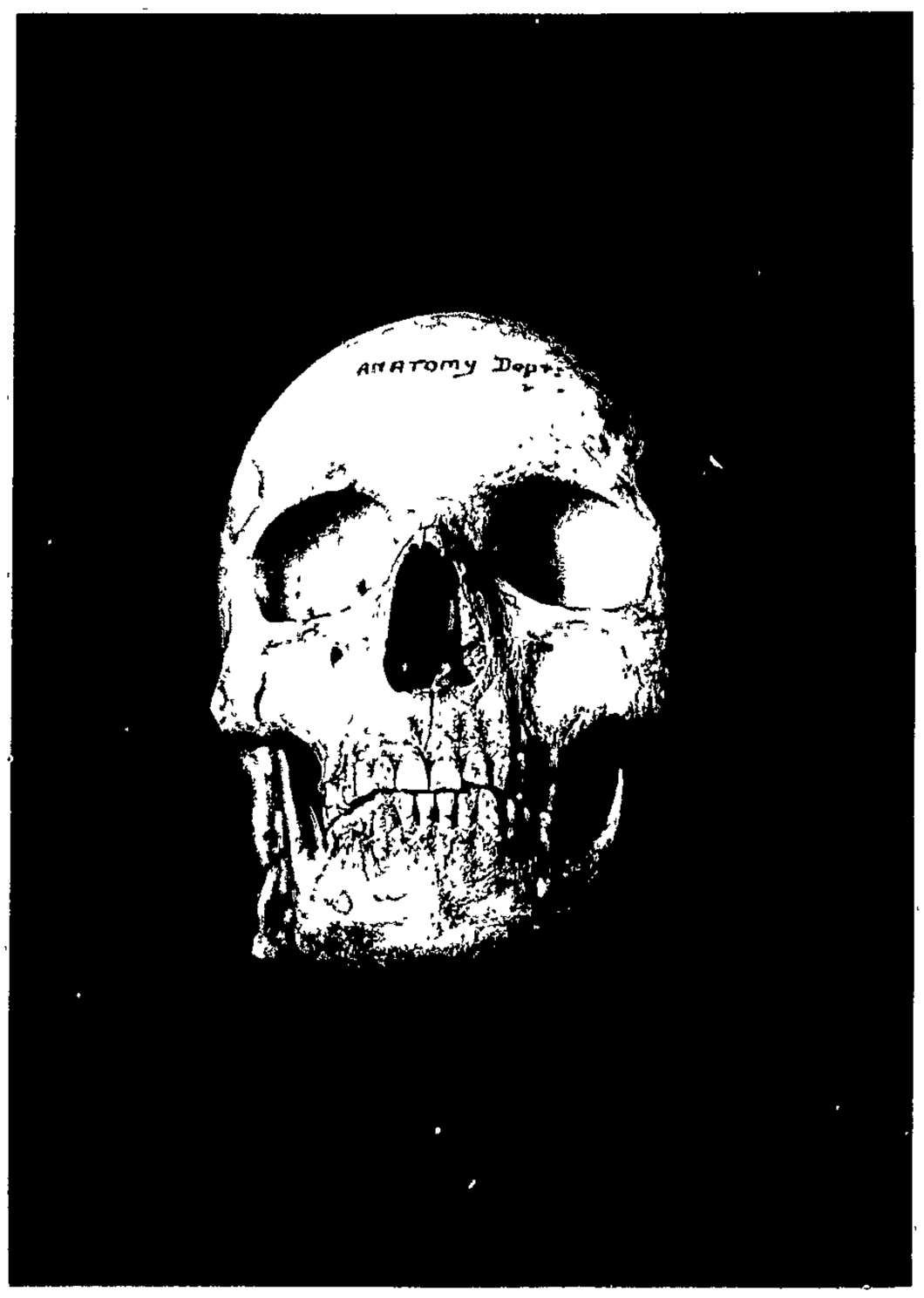


Fig. 2.

Fig. 2 illustrates the overhang of the upper teeth when the arches are in contact.

being separated by the conical forms. The three groups are composed as follows:- pyramidal consisting of the central and laterial incisors, the conical consisting of the canines, and the cubical consisting of the bicuspids and molars. When the teeth are fully erupted it will be observed that in some cases the upper incisors and canines project obliquely over the lower teeth and the buccal cusps of the upper bicuspids and molars lie outside those of the corresponding lower teeth, see Fig. 2.

The primary function of the teeth is the grasping and comminution of food; they are also used in conjunction with the lips, cheeks and tongue in the formation of articulate sound and also, by their presence or absence, modify facial charm.

The arrangement and development of the teeth seems admirably adapted to undertake the complex function of mastication and in a complete denture this process is readily performed. When the denture is modified by loss of one or more of its members an alteration of stress absorption follows so that some of the remaining teeth are called upon to perform an increased function. The highly developed and apparent surfaces of the teeth called the crown are the only portions considered in this discussion.

The anterior teeth of both arches may be considered as pyramids or wedges with the base of the wedge at the cervix or "gingival portion" (17); in this form the act of incision or cutting through food can be accomplished. The upper anterior teeth, like those of the lower arch, have simple contours for their surfaces but often the lingual surfaces are irregular so that mesial and distal marginal ridges are in evidence and play a part in the function of incision.

The upper and lower canines are slightly more complex in shape than the incisors, both series being conical in form and both showing the development of a cusp, so that the incisal edge is divided into two slopes, a mesial and distal; this

(17) Dewey M. "Dental Anatomy", 1920 Ed., p. 19.

produces a more or less pointed cusp which is lost as wear takes place, but which nevertheless is called upon for tearing tough and fibrous foods.

The posterior teeth consist of two groups, bicuspids and molars; taken in a general way these groups have cubical crowns surmounted by two or more cusps developed from marginal ridges in the occlusal surface. The occlusal surface, as originally defined by Black (18), is only that surface of a bicuspid or molar tooth which makes contact with a tooth of the opposite jaw when the mouth is closed; but wear may extend the occlusal surface to all sides and substance of the crown, whilst on the other hand some areas of unworn occlusal surfaces usually lack a contact in adolescence. Furthermore the cuspal zones of the buccal surfaces of the buccal cusps of the lower molars and those of the lingual surfaces of the lingual cusps of the upper molars are also occlusal areas, although they may lie ouside the buccal and lingual marginal ridges. The occlusal surfaces of these teeth therefore include all surfaces which make contact during mastication.

Angle (19) defines occlusion as being the normal relation of the occlusal inclined planes of the teeth when the jaws are closed; therefore the inclined planes of the teeth play a part in opposing stresses during the crushing of food between the occlusal surfaces, the final absorption of these stresses being undertaken by the peridental membrane of the tooth.

The various regions of the mouth show a difference in the amount of stress received during the act of comminution of food and Black (20) has compiled a table showing this stress in pounds weight giving an average of 171 pounds on the molars and considerably less on the bicuspids; he has also demonstrated that the force expressed in pounds weight necessary to crush usual foodstuffs is within 100 pounds.

(18) Black G.V. "Dental Anatomy" 1894 Ed., p. 14.
(19) Angle E.H. "Malocclusion of the teeth" 1907 Ed., p. 7.
(20) Black G.V. "Operative Dentistry" Vol. 1, 6th Ed., p. 161.

Fig. 3.

Fig. 3 shows a view of the articulation viewed from the side.

Referring to Fig. 3 which represents the teeth in normal occlusion, it will be seen that each arch describes a curve and that the teeth are arranged in one arch in such a way as to be in harmony with the opposing teeth in the other arch. The mesio-buccal cusp of the upper first molar is received in the buccal groove of the lower first molar. The teeth posterior to the first molar engage with their antagonists in a similar manner, those anterior interlock with one another in the interspaces, the lower second bicuspid between the upper first and second bicuspids, and the lower first bicuspid between the upper first bicuspid and canine until the anterior teeth are reached. The upper central incisor being broader than the lower it necessarily extends beyond it distally overlapping in addition about one half of the lower lateral incisor; the upper lateral occludes with the remaining portion of this tooth and with the mesial incline of the lower canine; the mesial incline of the upper canine occludes with the distal incline of the lower canine, the distal incline of the upper canine occluding with the mesial incline of the buccal cusp of the lower first premolar.# In the same order the series of buccal cusps of the premolars occlude, the mesial incline of each upper occluding with the distal incline of the corresponding lower teeth. The distal incline of the second upper premolar occludes with the mesial incline of the mesio-buccal cusp of the lower first molar. The mesial incline of the mesio-buccal cusp of the upper first molar occludes with the distal incline of the mesio-buccal cusp of the lower first molar. The distal incline of the disto-buccal cusp of the upper first molar occludes with the mesial incline of the mesio-buccal cusp of the lower second molar. This order is continued with the buccal cusps of the second and third molars; the distal incline of the disto-buccal cusp of the upper third molar has no occlusion.

bicuspid.

Fig. 4.

Fig. 4 illustrates the linguo-occlusal relationship of the teeth.

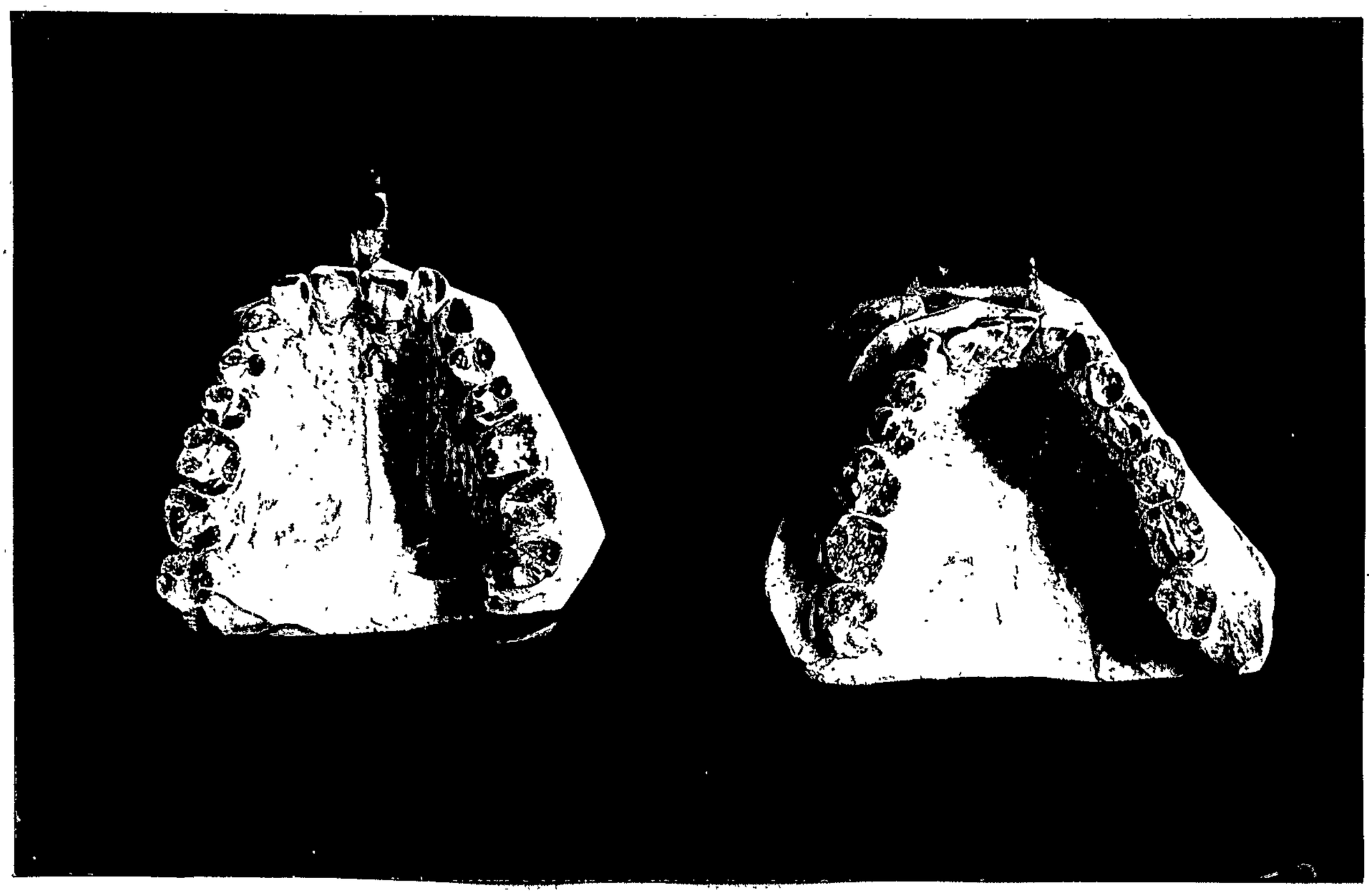


Fig. 5.

Fig. 5. Photographs of models of a skull showing considerable wear; the facets have been coloured to demonstrate their extent.

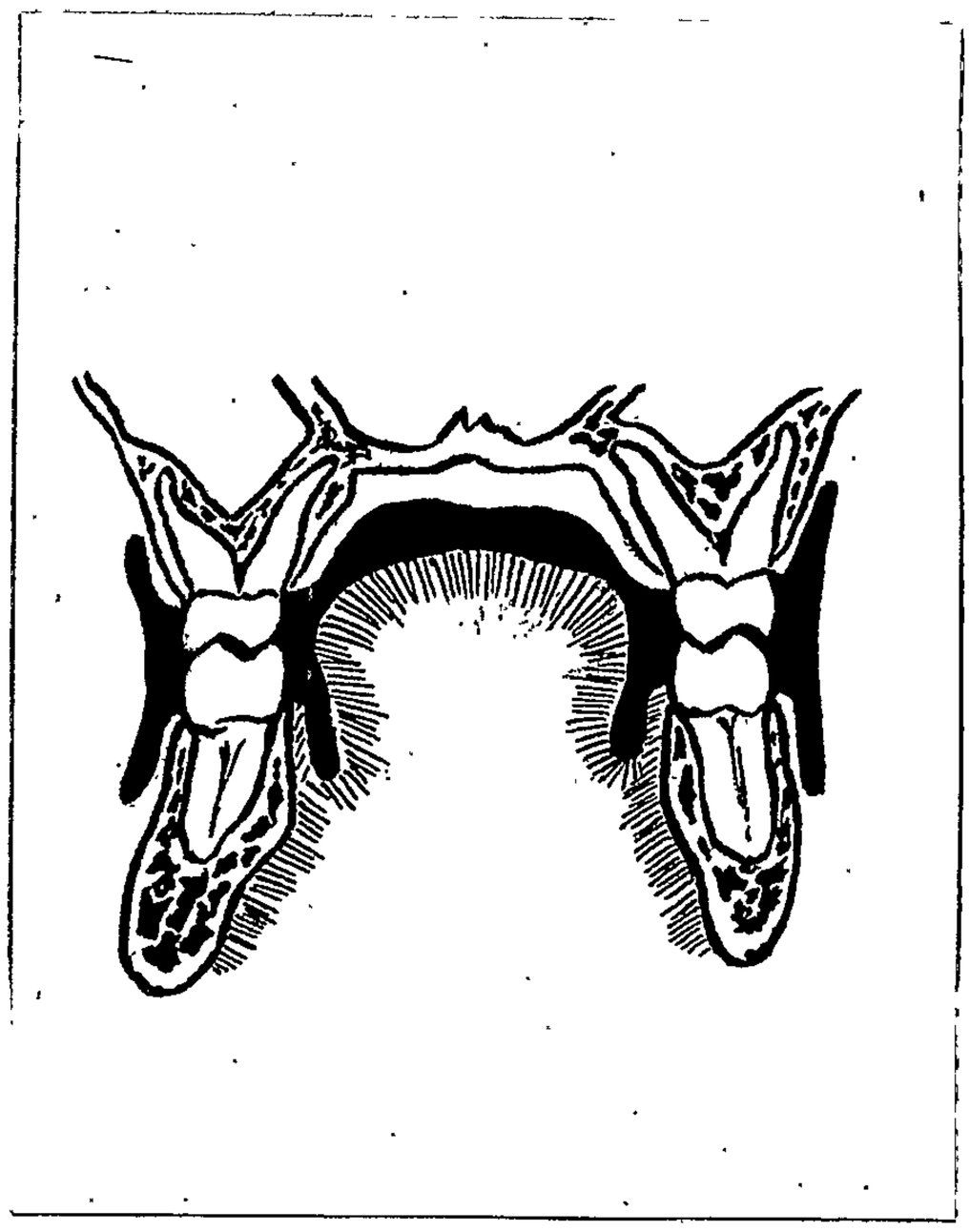


Fig. 6.

Fig. 6 illustrates the bucco-lingual arrangements of the posterior teeth.

There exists an arrangement similar in harmony to this bucco-occlusal relation in the linguo-occlusal relation except that the lingual cusps of the lower molars project beyond those of the upper molars towards the palate as shown in Fig. 4.

This interdigitation of the occlusal surfaces of the masticatory apparatus permits an efficient mechanism for the crushing, tearing and scissor-like movements carried out during the function of mastication. It is also observed that each tooth of both jaws has two antagonists in the opposite jaw to carry out these movements except the lower central incisors and upper third molars.

The relationship which exists between the various surfaces becomes evident as wear introduces facets upon the antagonising surfaces as shown in Fig. 5. In transverse arrangement the buccal cusps of the lower posterior teeth lie between the buccal and lingual cusps of the upper posteriors, the lingual cusps of the upper posterior teeth lie between the buccal and lingual cusps of the lower posterior as shown in Fig. 6. In this way the grinding surfaces of the teeth obtain an increase in efficiency.

The important movements of the mandible and hence of the mandibular teeth are (21) (a) a hinge movement, (b) a protrusive movement preparatory to incision and (c) a right and left lateral movement.

(a) The hinge movement is employed in opening and closing the mouth for the introduction of food and also in the crushing of brittle foods. In a normal arch relationship the lower incisal edges approach the upper incisal edges, pass through the food, meet them on the lingual line angles and then shearing through the food glide along the marginal ridges of the palatal surfaces of the upper incisors to a position of rest. If there

(21) Prothero J.H. "Textbook of Prosthetic Dentistry" 4th Ed. pp. 18.

is a marked overbite, the act of incision without protrusion resembles a chiseling process (22), the upper teeth corresponding to the bench block and the lower corresponding to the chisel, the food being represented by the piece of wood being cut, see Fig. 7, the food in this way being held from moving by the upper teeth whilst the lower teeth cut deeply into it.

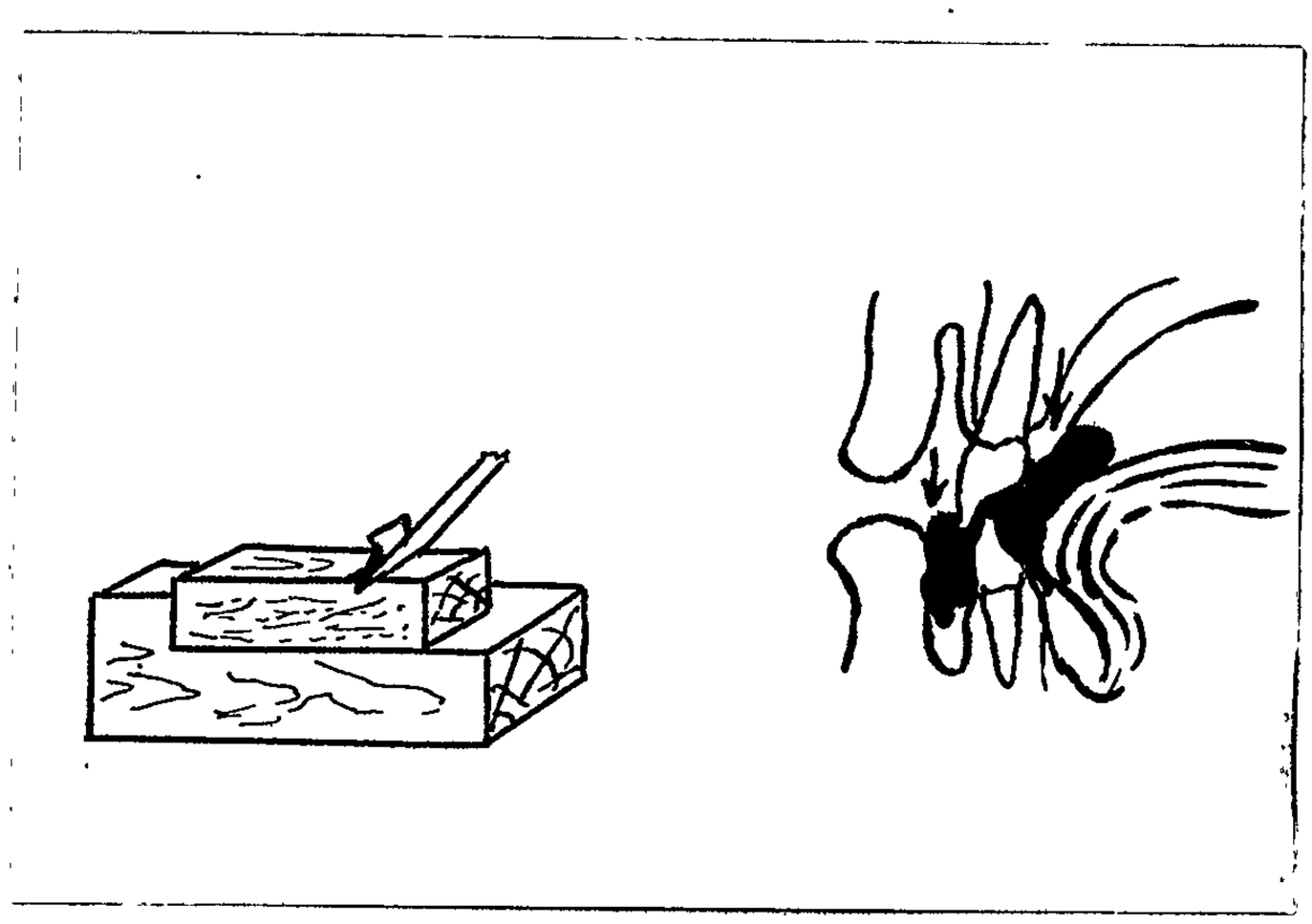


Fig. 7.

(b) A protrusive movement is employed in the grasping and incising of food and in rearranging or changing the position of the food in the masticatory grooves in the process of its reduction to small particles. This protrusive movement carries the incisal edges of the lower anterior teeth forward and downward against the lingual surfaces of the corresponding upper teeth. If the mandible is protruded sufficiently, the incisal edges of the lower anteriors will occlude with the incisal edges of the upper anteriors in an end to end relationship. The distance traversed by the incisal edges of the lower teeth from the position of rest or normal occlusion to that of edge to edge contact or incision is known as the incisor path. This path controls the movements of the mandible anteriorly, since, with the exception

(22) Stallard H. Journ. of the Amer. Dent. Ass., October 1926, pp. 1392.

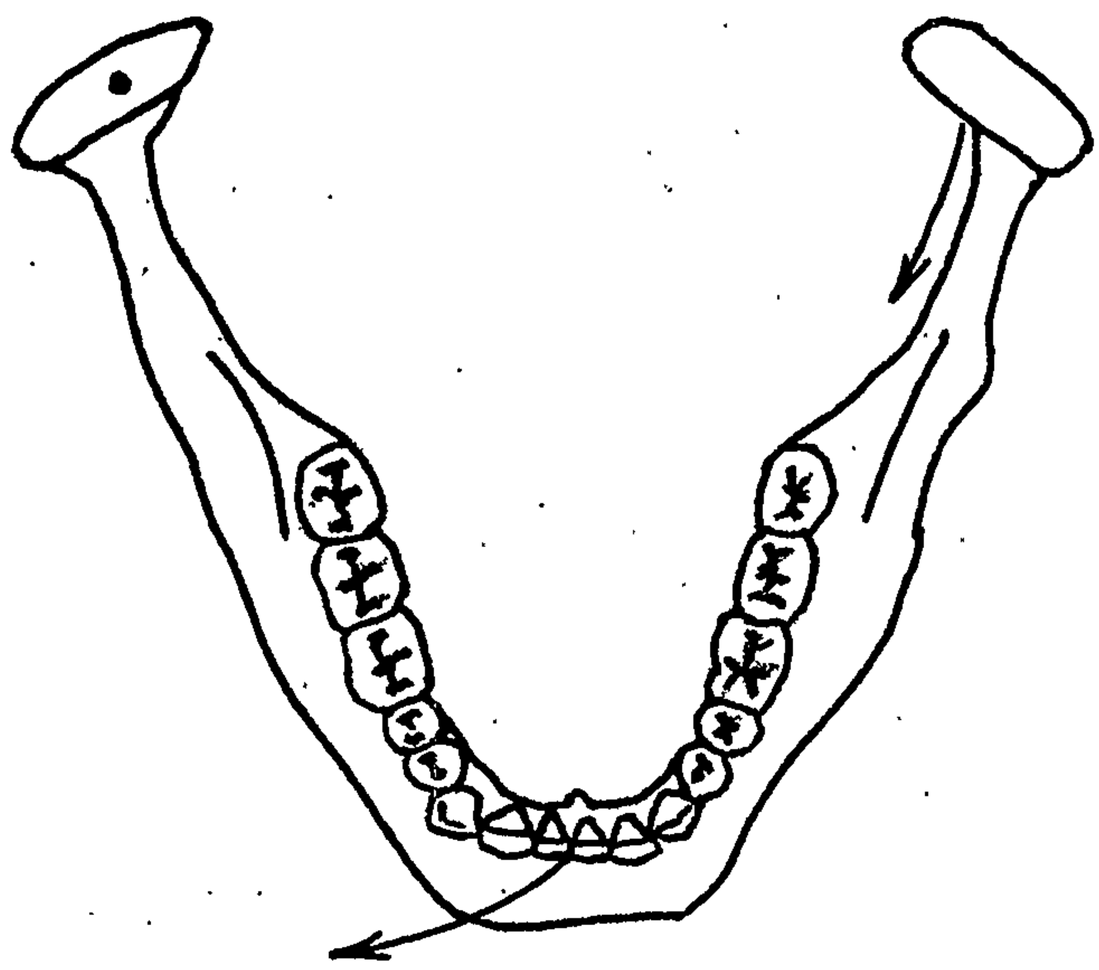


Fig. 8.

Fig. 8. The pivotal centre of the mandible during lateral movements.

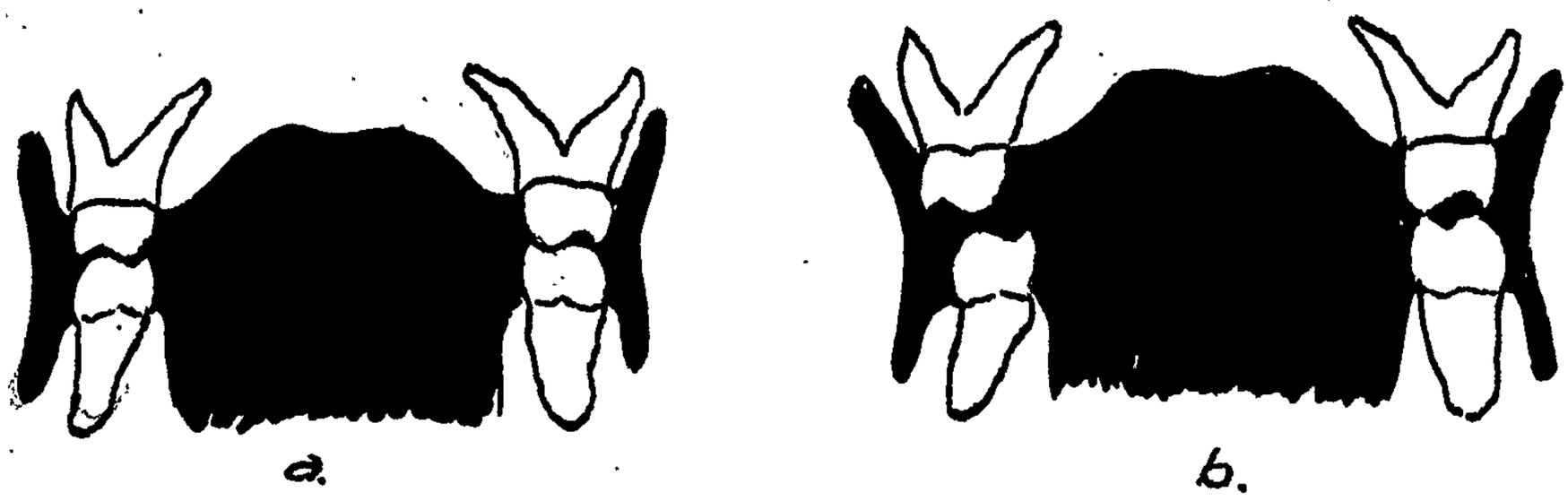


Fig. 9.

Fig. 9 a. shows the bucco-lingual relation at rest.
Fig. 9 b. shows the bucco-lingual relation in lateral protrusion.

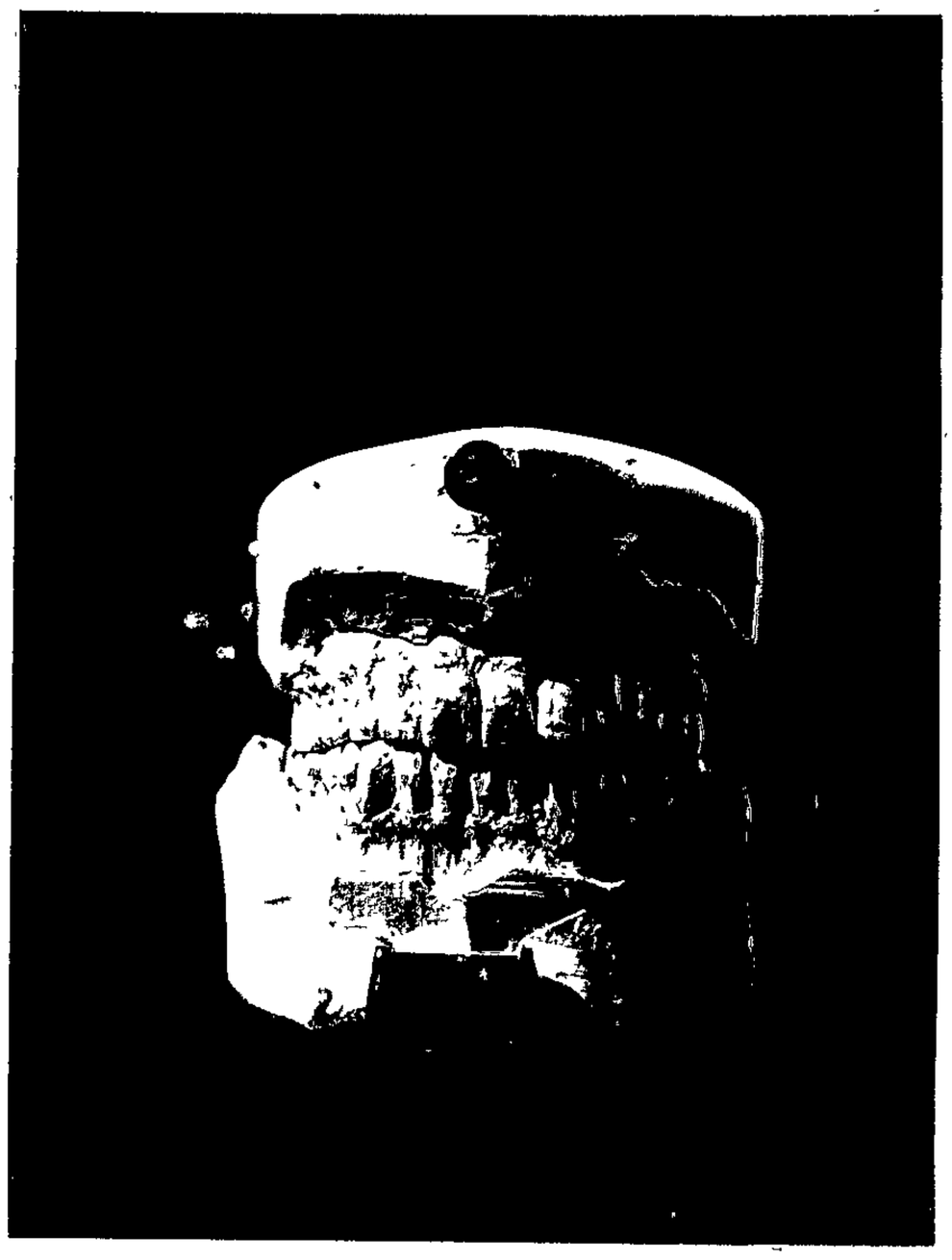


Fig. 10.

Fig. 10. Photograph of casts mounted on an anatomical articulator shows relationship between the arches during lateral protrusive movement. The right side is the pivotal side and a more or less continuous contact exists between the buccal cusps of the teeth of this side; the left side is the moving side and a space exists where lack of contact between the occlusal surfaces occurs. The lack of contact covers the region from the distal aspect of the upper first molar as far forward as the lateral incisor. A similar continuous contact occurred when the left side became the pivotal side. The space on the moving side in this case was of the same extent when the left side was the moving side.

of the last molars in occlusion, the remaining bicuspids and molars in one arch are not usually in contact with those in the opposite arch in protrusive effort. In cases of marked overjet the incisor path may not play any part, on the other hand a marked overbite may influence the mandibular movements and the incisor teeth may show signs of attrition. The incisor path and the incisal relationships require examination so that suitable forms of resistance and retention may be developed for inlay restorations in these regions.

(c) Right and left lateral movements are employed during which one condyle is drawn forward or protruded in its path while the other condyle remains comparatively stationary serving in a general way as a pivotal point or rotation centre to guide the mandible in this radial movement, see Fig. 8. The working limit of the mandible in lateral masticatory effort is reached when the buccal and lingual cusps and marginal ridges of the lower bicuspids and molars on the pivotal side are directly under and in contact with the corresponding cusps and marginal ridges of the upper teeth, see Fig. 9. The amount of side movement necessary to bring the teeth into this relation to form the masticatory space was designated the "differential limit" by T.W. Pritchett. Used in this sense it means the limit of side movement of the teeth for doing effective work.

In some cases when a lateral movement is made the marginal ridges and cusps of the pivotal side maintain a contact and form the masticatory groove, the arches on the moving side make contact at a position in the molar region and a space occurs in the bicuspid and canine and first molar regions. Fig. 10 illustrates this space with models from the skull mounted on an anatomical articulator. During mastication the opportunity is taken at this stage for the tongue and cheeks to force more food between the teeth and as the mandible is brought back to its centre position further crushing of the food on this side is possible.

Playing a large part in the efficient trituration of food in these lateral movements is the masticatory or rectangular groove, a very complex groove developed during lateral movements and formed from the central sulcis or mesio-distal grooves of the individual teeth. The mesio-distal groove of the bicuspid and molar teeth traverses their occlusal surfaces as a general depression or sulcus formed by the planes which slope lingually from the buccal marginal ridges and buccally from the lingual marginal ridges. These planes meet at varying angles near the centre of the tooth to form definite grooves. The grooves which cross the mesial and distal marginal ridges are accordingly named mesial and distal marginal grooves, and that which divides the central portion of the tooth is called the central groove. In normal occlusion these depressions or sulci in the upper teeth receive the buccal cusps and marginal ridges of the lower teeth, while the central sulci of the lower teeth receive the lingual cusps and marginal ridges of the upper teeth. In addition to the central grooves, the various cusps and planes sloping away from them mesially and distally result in the formation of other grooves which traverse the occlusal surfaces of the teeth from buccal to lingual; these grooves run nearly at right angles to the mesio-distal grooves with the buccal slightly in advance of the lingual end. Each pair of cusps such as the mesio-buccal and mesio-lingual cusps of the upper first molar are situated approximately the same distance from the mandibular rotation centre of that side of the arch; the planes which slope away mesially and distally from these cusps meet in the central groove and finally emerge with those from the adjacent pairs of cusps, and enter into the formation of grooves which represent arcs of circles developed from the same rotation centre. This arc-like bucco-lingual arrangement of cusps and grooves of the upper teeth permits the cusps and sloping planes of the occluding lower teeth,

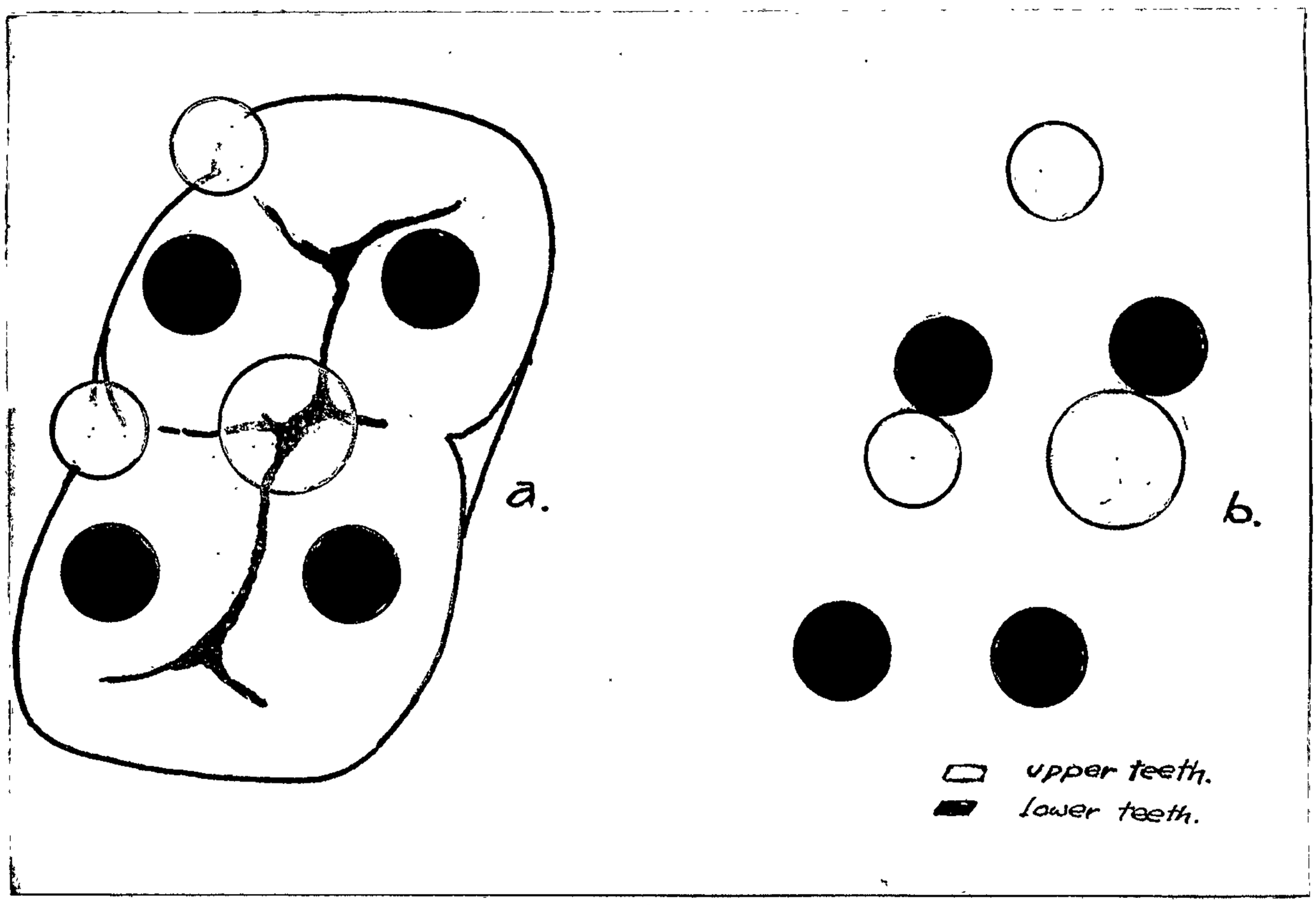


Fig. 11.

Fig. 11 a. illustrates the approximate relation existing between the upper cusps and lower cusps at rest.
Fig. 11 b. illustrates the approximate relation when the mandible is moved into lateral protrustion so as to form the masticatory groove.

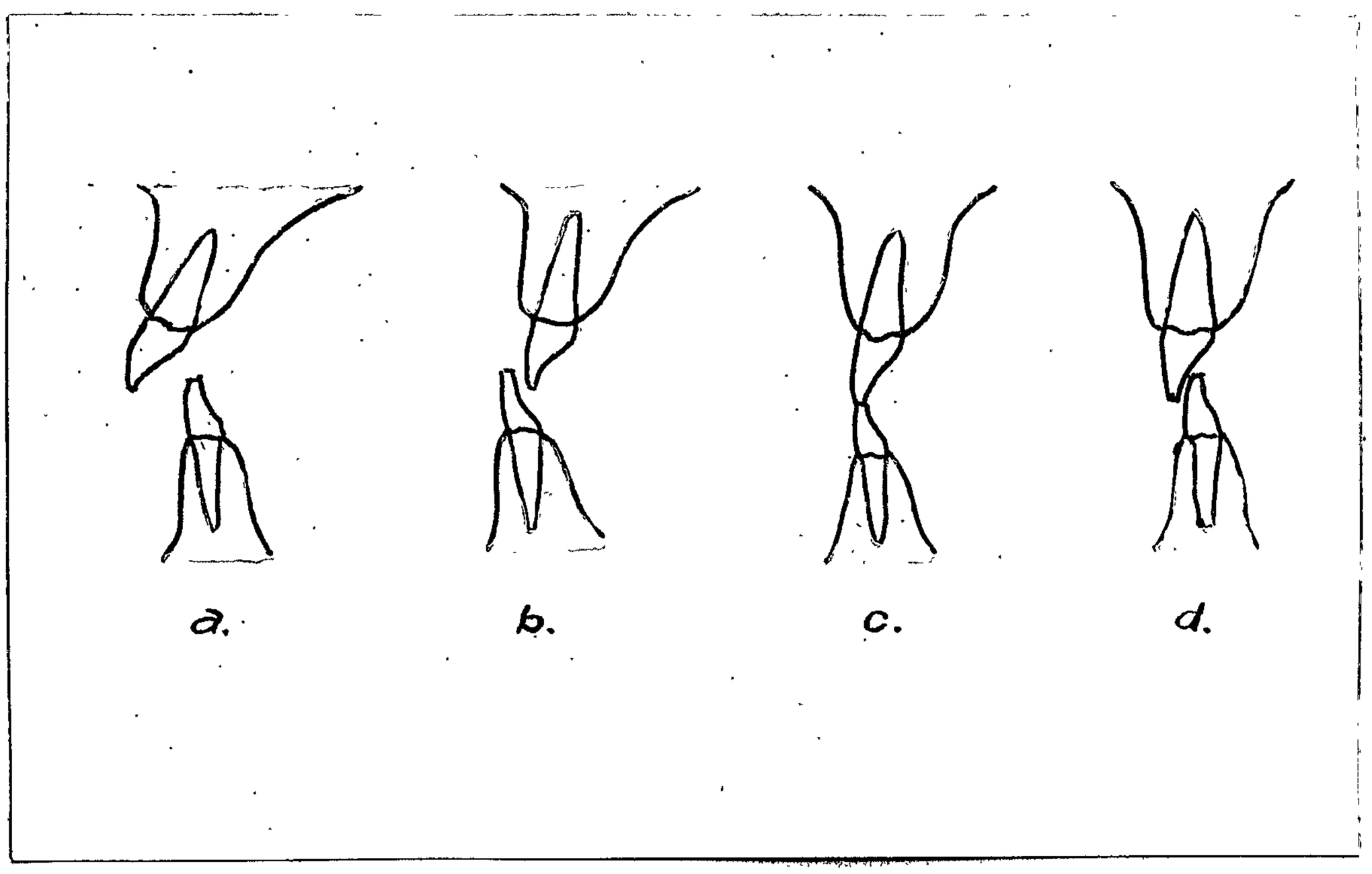


Fig. 12.

Fig. 12 represents incisal relationships.

which bear a similar relation to the rotation centre, to be moved freely back and forth in the lateral swing of the mandible without cusp interference.

The masticatory or rectangular groove consists of the mesio-distal grooves of the posterior teeth and results when the mandible is rotated laterally so as to bring the buccal cusps and marginal ridges of the lower teeth on the pivotal side outward from the central sulci of the upper teeth and directly under the corresponding cusps and marginal ridges of the latter; a fairly close and unbroken line of contact between these wedge-like ridges is effected in this movement. At the same time the lingual cusps and marginal ridges of both lower and upper teeth on the same side are brought into similarly close contact. Fig. 11 is an attempt to illustrate the relation existing between the cusps of the lower first molar and the upper first molar during these movements. A rectangular space is formed bounded above and below by the occlusal surfaces of the upper and lower teeth and laterally by their buccal and lingual marginal ridges. This groove extends from the first bicuspid to the third molar inclusive and forms the receptacle in which food is held and crushed as the mandible is drawn back to normal resting position. The efficiency of the masticatory apparatus is largely dependent on the width of this space bucco-lingually; the wider it is within normal limits the greater the radial swing possible for the mandible. In the complete permanent dentition the movements of the mandibular teeth in relation to the maxillary teeth may be summarized as consisting of:-

1. the hinge movement resulting in a direct impact of the occlusal surfaces of the lower posterior teeth with the occlusal surfaces of the upper posterior teeth. The anterior teeth may or may not impact depending upon a number of separate conditions, viz: (a) upon the amount of overjet Fig. 12 a., (b) upon the

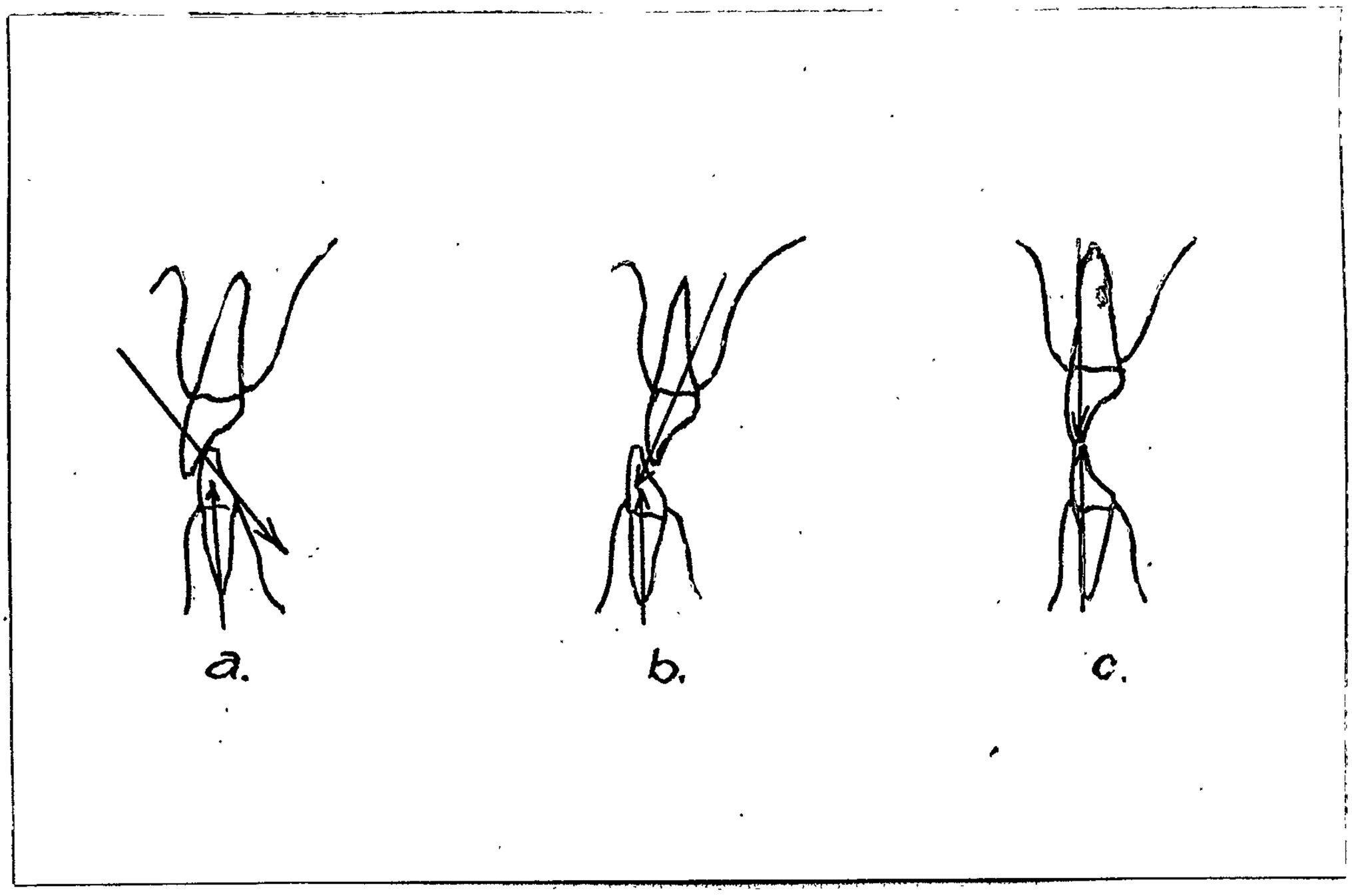


Fig. 13.

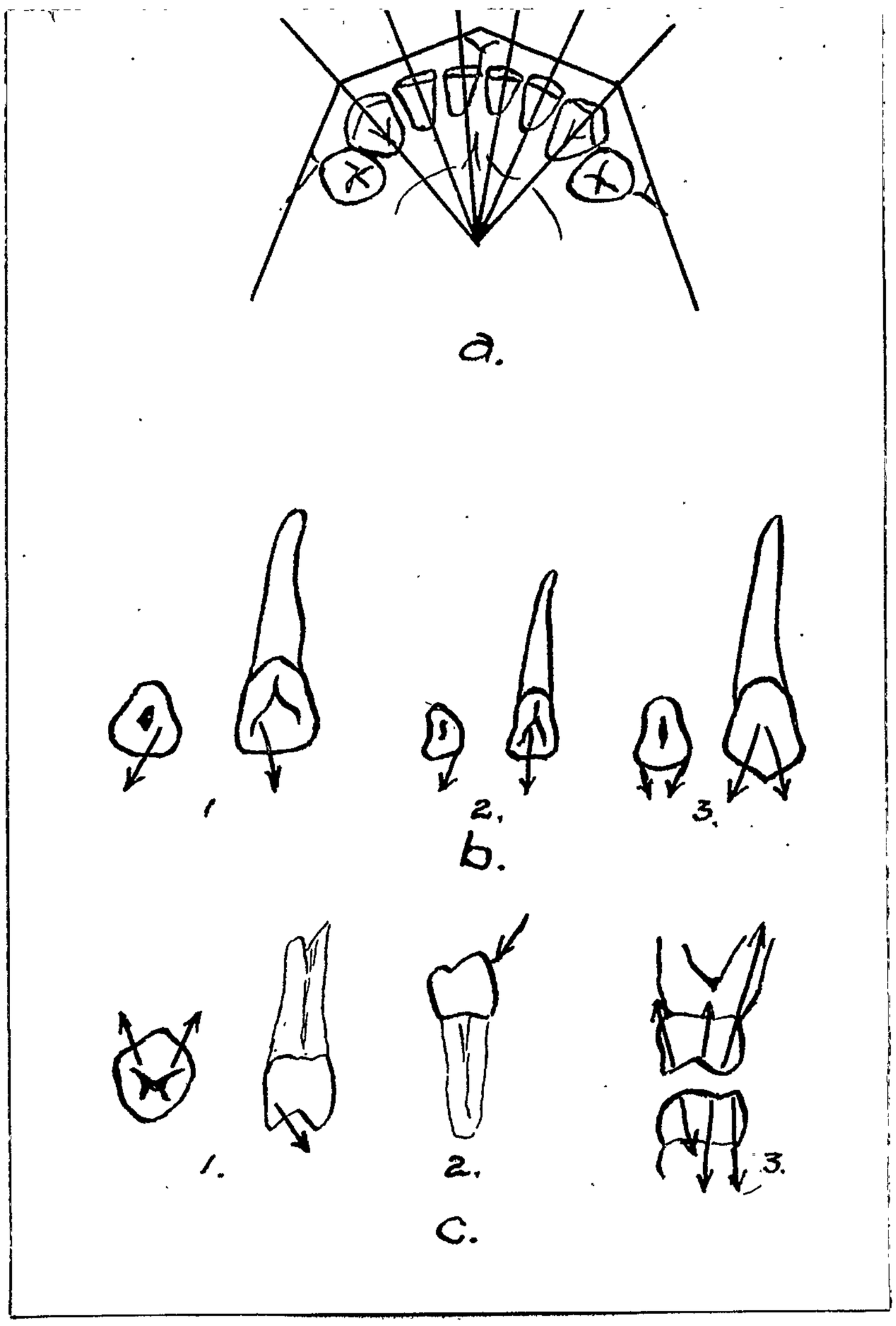


Fig. 14.

amount of protrusion of the lower incisors, Fig. 12 b., (c) whether there is an edge to edge relationship, Fig. 12 c., (d) the amount of the overbite, Fig. 12 d., in which condition the lower incisal edges may make contact with some portion of the lingual surfaces of the upper incisors. It will be seen that overjet and overbite may exist at the same time, with or without contact between the incisors. Whatever the condition which may exist the line of resistance to stress is important and is indicated on the various teeth as follows:- In extreme overjet there is no contact of the lower incisors against the upper incisors, therefore no stress arises; as the amount of overjet decreases there will arise a greater need for resistance to stress until in a normal overbite the direction of resistance to the stress is in the direction of the arrow Fig. 13 a., that is towards the lingual. In extreme protrusion of the mandibular incisors there is again an absence of contact, but, as the amount of protrusion deceases, there will arise the need for resistance to stress in the direction of the arrow Fig. 13 b., that is towards the labial. Between these two sets of conditions there is the 'edge to edge' relationship where the incisal edges contact with stress directed along the long axes of the teeth Fig. 13 c.

There are extreme conditions of overjet or micrognathism (23) and protrusion or prognathism (24) in which normal movements of the mandible do not cause any contact of the incisor teeth and defects which may require restoration with inlays do not make so many demands on the cavity design in these cases. With normal overbite, Fig. 13 a., the direction of stress upon the lower anteriors considered as a group is shown by the arrows in Fig. 14 a. The direction of stress upon the upper anteriors is shown in Fig. 14 b. with the direction in each individual tooth marked by

(23) Thoma K. "Clinical Pathology of the Jaws", 1934 Ed. pp. 7.
(24) Bailey H. "Clinical Surgery for Dental Practitioners, 1937 Ed., pp. 107.

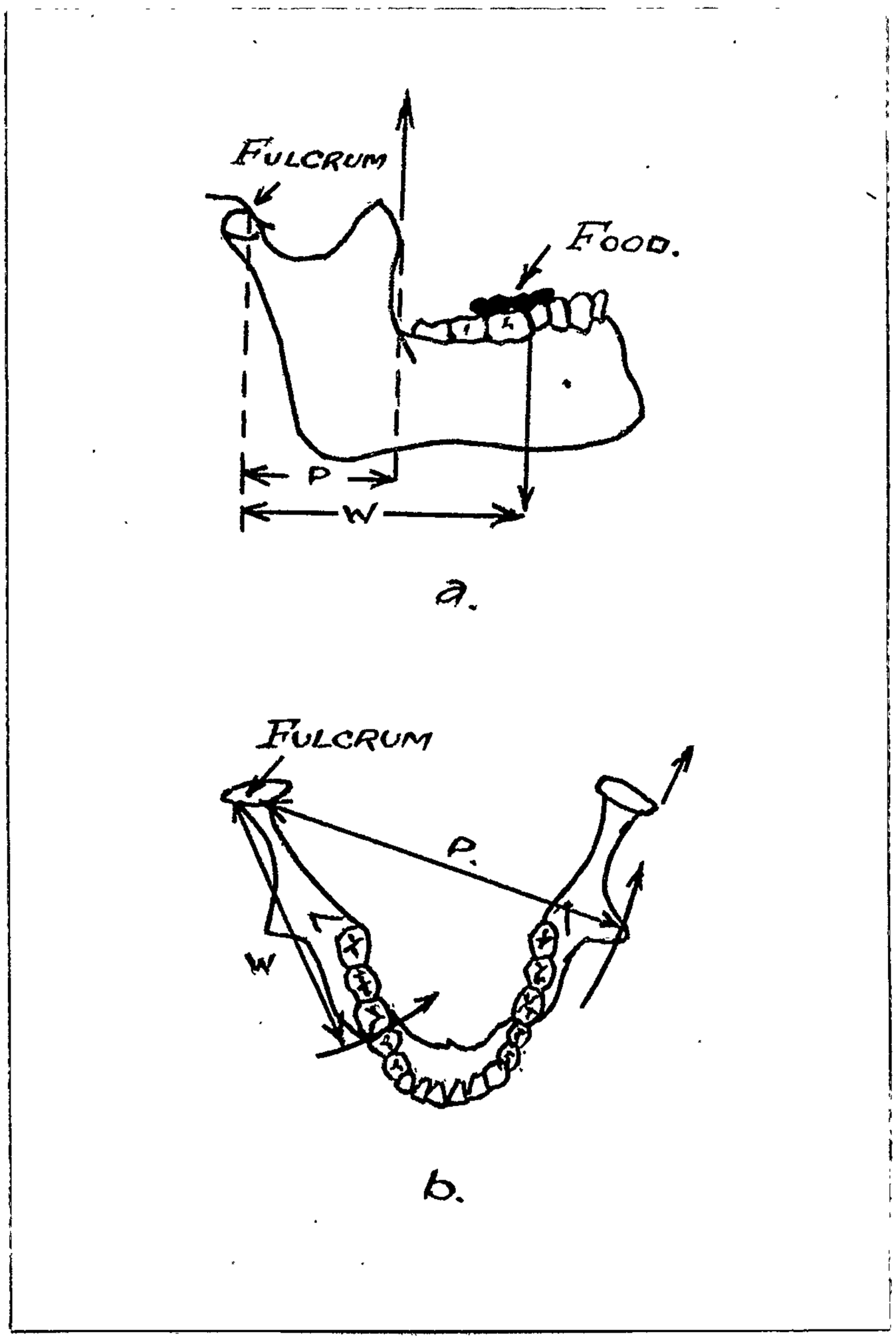


Fig. 15.

Fig. 15 a. illustrates the mandible as a Third Class Lever System. P = Masticatory Force. W = Load or work done to crush food.
Fig. 15 b. illustrates the mandible as a Second Class Lever System.

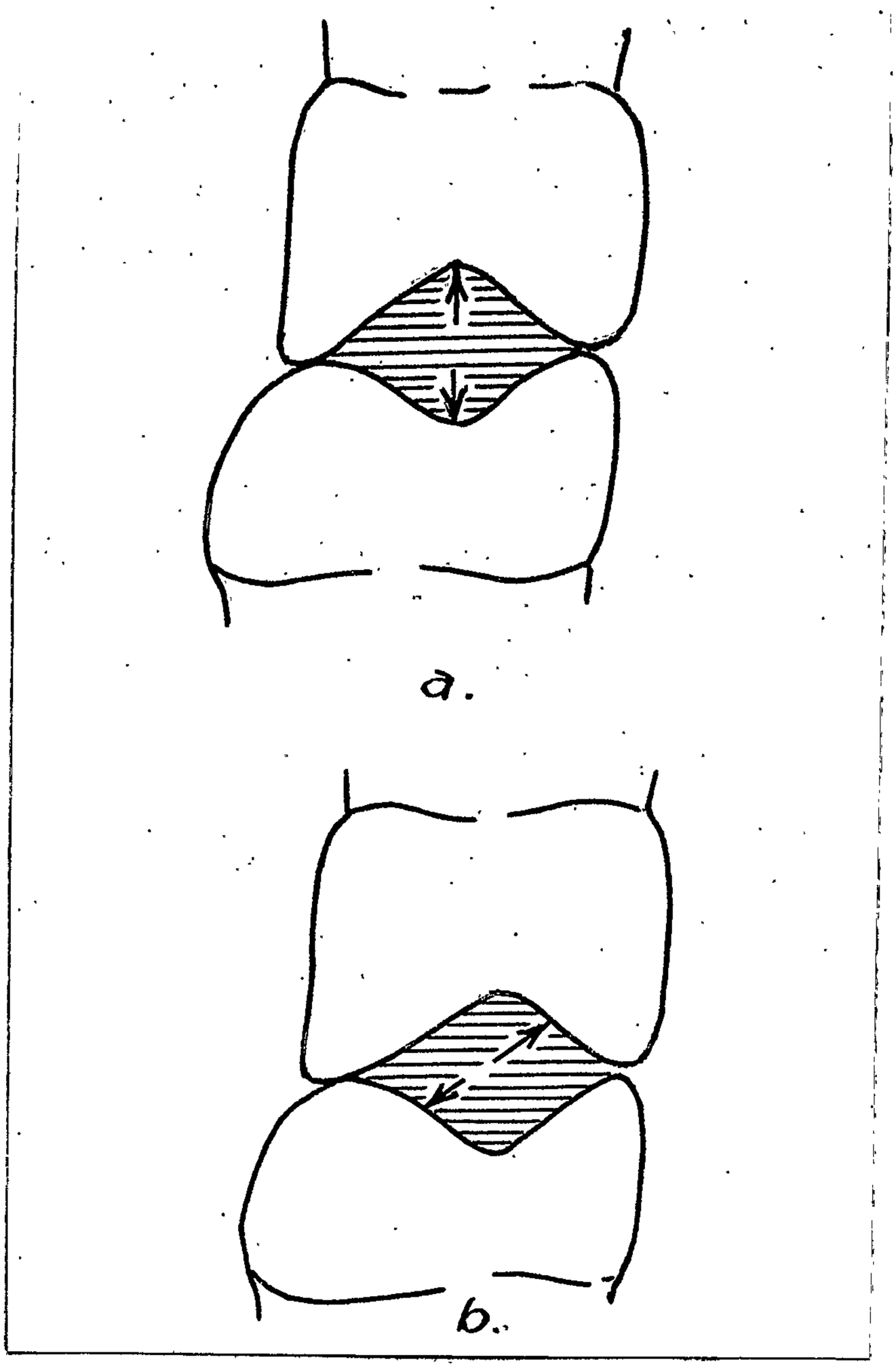


Fig. 16.

Fig. 16. The arrows illustrate the direction of force in the morsal space during the crushing of food during the two sets of conditions seen in Fig. 15 a & b.

an arrow; the stress would appear to be resisted in those regions in which facets of wear appear, cf. Fig. 5. The direction on the posterior teeth is shown in Fig. 14 c.

11. sliding contact of the planes and cusps arising during acts of protrusion and retrusion of the mandible. Here the inclined planes form a sliding impact as the mandible is protruded, the general direction of the stress being similar to that indicated for the hinge movement but the force may have greater magnitude and therefore greater stress will be borne by the teeth in these movements especially when it is remembered that the bicuspids and first molar regions may not be contacting.

111. sliding impact of the inclined planes in lateral protrusive movements. The forces in these movements are generally directed to the comminution of the food in the posterior regions of the mouth; they are of greater magnitude in these regions because of their closeness to the point of application of the force as applied by the muscles of mastication, particularly the masseter and temporal muscles which bring the teeth into contact and the external pterygoid which is the agent producing the lateral protrusive movement. In this lateral movement the external pterygoid of the moving side of the mandible is the active agent and produces the lateral protrusion of the teeth on the pivotal side whilst those teeth are held in contact with the masseter and temporal muscles. When food is filling the morsal space or masticatory groove, Fig. 16, and thus offering some resistance to the force of the masticatory muscles, it is crushed by a force which may be applied by two lever systems. In the hinge movement the mandible belongs to a lever of the Third Class, Fig.15 a, so that the masticatory force is at a disadvantage; during lateral movements that side performing the actual movement becomes portion of the power arm working on the pivotal side and in this case the lever system belongs to the Second Class, Fig. 15 b. The stress is taken up by the buccal slope of the lingual cusps

of the upper posterior teeth and the lingual slope of the buccal cusps of the lower posterior teeth. Fig. 16 a. shows the direction of stress in the morsal space when the mandible acts as a Third Class lever and Fig. 16 b. shows the direction of stress in the morsal space when the mandible acts as a Second Class lever.

Since force is a necessary associate of function it follows that the forces arising during functional movements will play an important part in the stability and permanency of any functioning inlay restoration. As this is true in the complete dentition where an harmonious interdigitation and sliding relationship exists during function, then, in the numerous conditions which may be found between the edentulous and the complete dentition, modification of the stresses may occur, increase stress taking place in individual teeth which may be in contact and isolated, or a decrease in stress up to a point where dysfunction exists.

If, in the masticatory apparatus, the dynamic considerations are investigated they will be found to consist mainly of problems dealing with Forces, Parallelogram of forces, Moments of force, Torque, and Levers. A study of these factors and their application to the problem of inlay construction should yield sufficient information either to support or modify existing designs of inlay cavities.

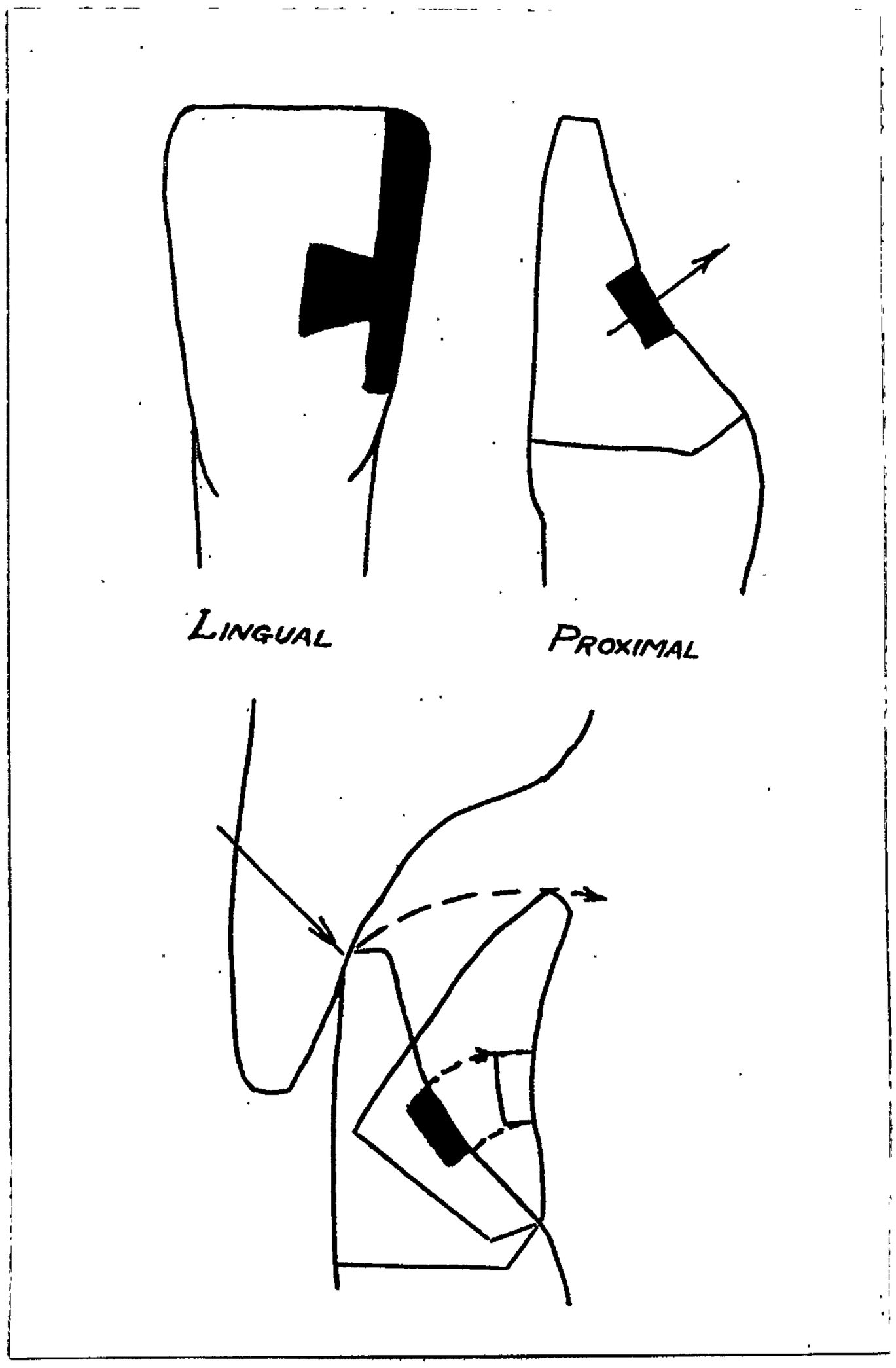


Fig. 17.

SECTION 2.

Loney (25) defines force as anything which changes or tends to change the state of rest or uniform motion of a body. When the mandibular teeth impact with the maxillary teeth during functional movements the direction of those movements is such that the teeth tend to move. In most cases with normal periodontal membranes slight movement of the individual teeth is possible under the stress of mastication; therefore if any restorations are made in the teeth those functional movements which bring forces to bear upon the individual teeth will tend to cause movement in the restorations. Since the important mandibular movements are known and the direction of stress that is set up in the individual teeth in opposing the forces of mastication resistance to these forces by any restorations must be obtained by some method which will oppose any tendency for movement of the restoration. As an example, it may be conceded that a certain type of cavity has a retentive value, but upon the application of a suitable force arising from normal mandibular movements to the restoration made for this cavity, dislodgement of the restoration follows. In Fig. 17 is illustrated a lingual lock for a lower incisor, retention would appear ideal, but when the direction of force is considered it will be seen that there is no portion of the retention form which offers resistance adequately to oppose tendency to movement in the restoration, therefore, during function this type of restoration has a negligible retention value.

When the impact of the occlusal surfaces consists of sliding and direct impact there exists a condition where forces are acting at an angle with the respective planes; e.g. at the moment of incision where a linguo-incisal contact occurs the force

(25) Loney S.L. "Mechanics and Hydrostatics", 1920 Ed., p.1.

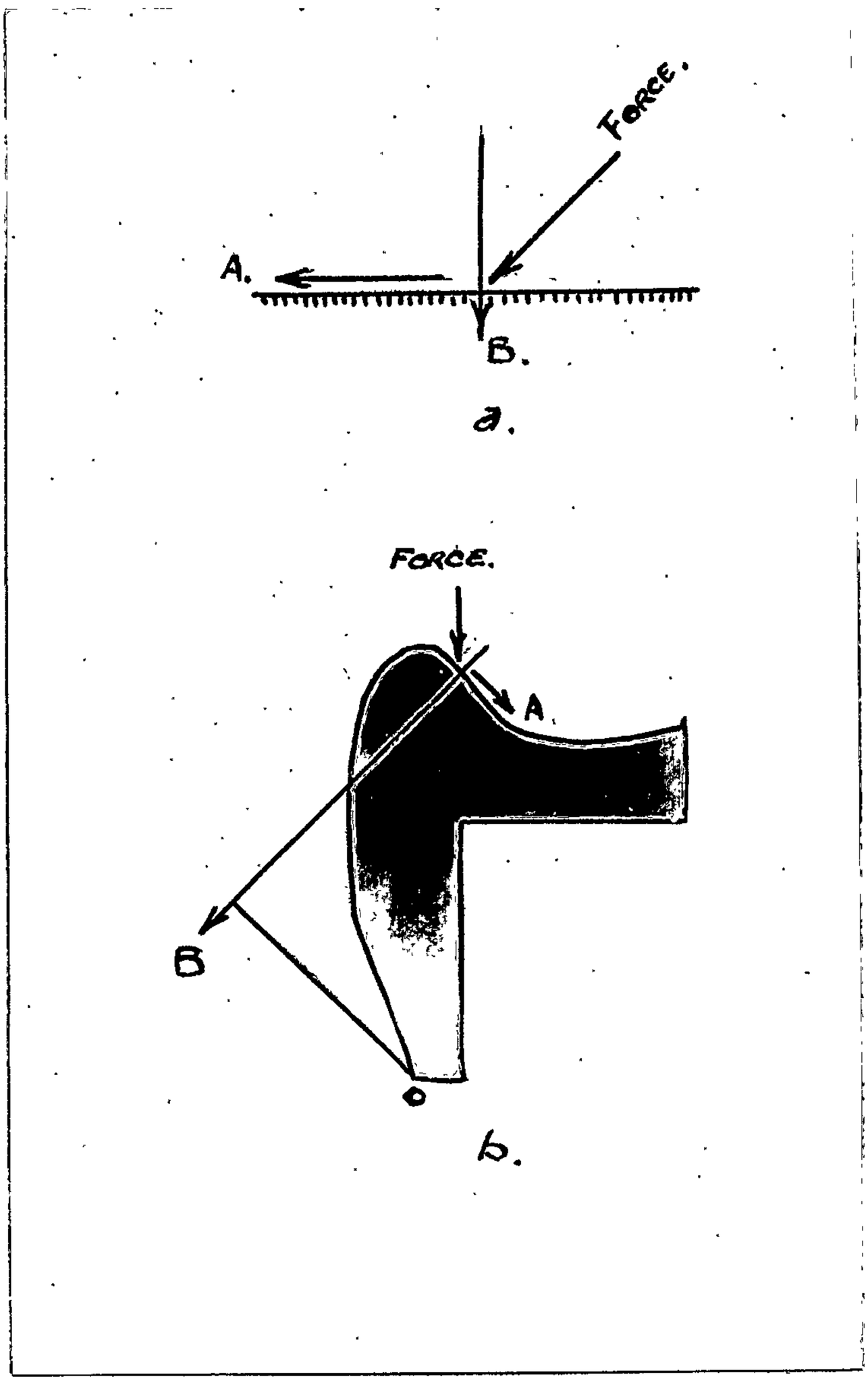


Fig. 18.

Fig. 18 a. illustrates the resolution of a Force applied at an angle to a surface and its resolution into two components A and B.

Fig. 18 b. Diagram showing a mesio-distal cross-section through an inlay, the gingival margin is placed at O.

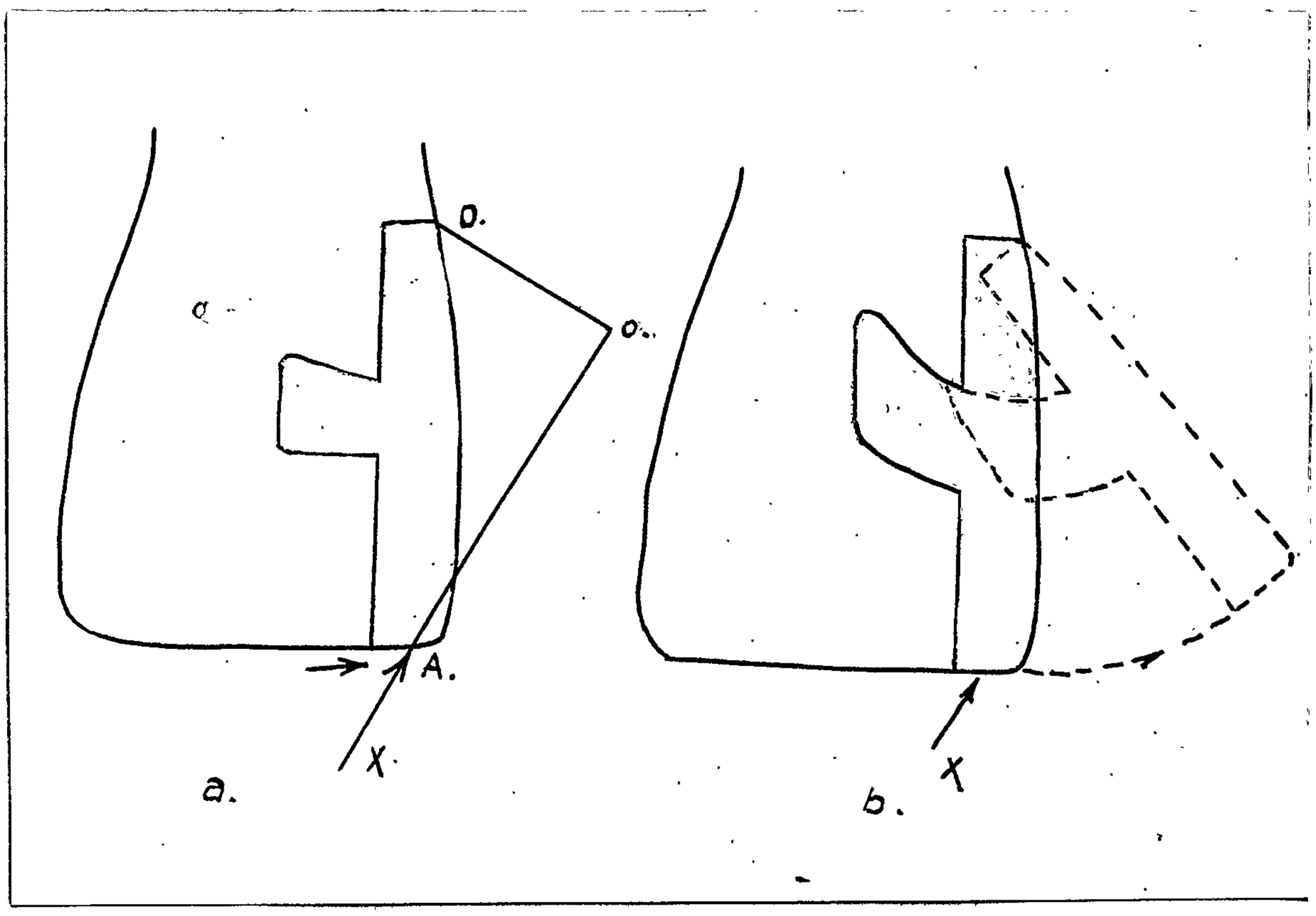


Fig. 19.

is directed in an axial direction and as the mandible slides to rest the force is directed against the lingual marginal ridges of the upper anteriors but in an axial direction. Here is a condition in which a force is acting at an angle with a surface, that force may then be resolved into two components at right angles to one another, one of which is at right angles to the surface (26), see Fig. 18 a. Fig. 18 b. shows the application of a force to a marginal ridge, the force being resolved into two components A and B; B is the important component because this resultant has a 'moment' about the point O.

"The moment of a force about a given point is the product of the force and the perpendicular drawn from the given point upon the line of action of the force" (27). In Fig. 19 a. if a force X is applied at A in the direction AO the moment of the force X about D is X.OD units. The greater the force X, or the greater the length OD the greater the moment of the force X about D. This moment of force may reach sufficient magnitude to cause dislodgement of an inlay in which the retention form is of little value. The action of a force upon a body tending to produce rotation about a certain point is called torque (28); this torque action will depend upon the magnitude of the force and the distance between its line of action and the axis or centre of rotation of the body; the torque action depends, therefore, upon the moment of force about the axis of rotation. An example of torque action may be demonstrated in a restoration having a lingual lock similar in form to that shown in Fig. 19 b.; when force is applied to the incisal edge it tends to rotate the inlay towards the proximal aspect with the gingival margin as the axis of rotation.

To overcome this tendency towards rotation certain types of retention forms may be used, the mechanical feature of which is one of the three systems of levers.

(26) Loney S.L. "Mechanics and Hydrostatics", 1920 Ed., p.12.
(27) Loney S.L. Idem. p.35.
(28) Spinney L.B. "Textbook of Physics", 1927 Ed. p. 36.

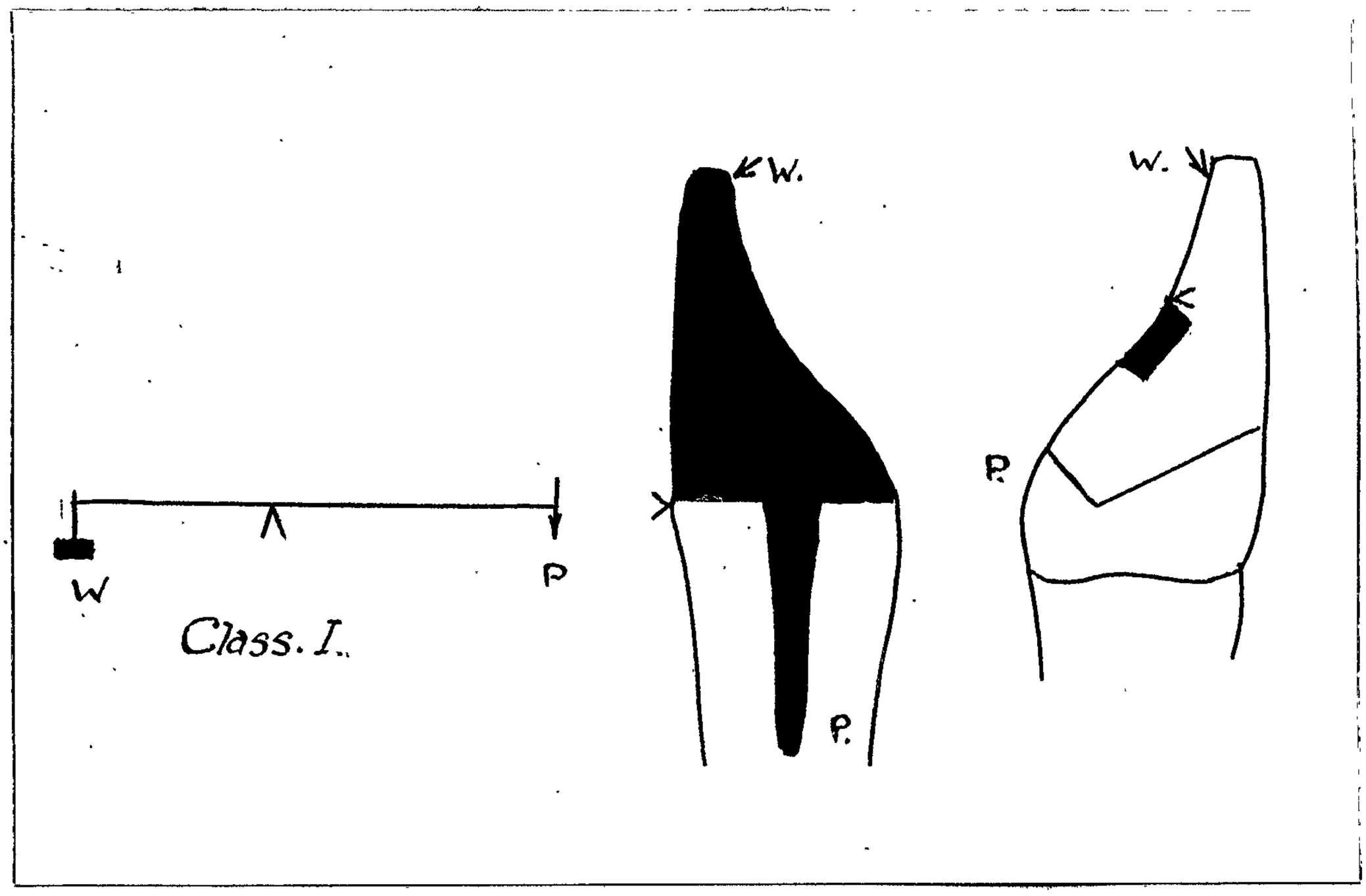


Fig. 20.

Fig. 20. Diagram to illustrate Class 1 lever principle. The inlay preparations are drawn for proximal views of an upper lateral incisor, the fulcrum or axis of rotation is shown by < in both cases.

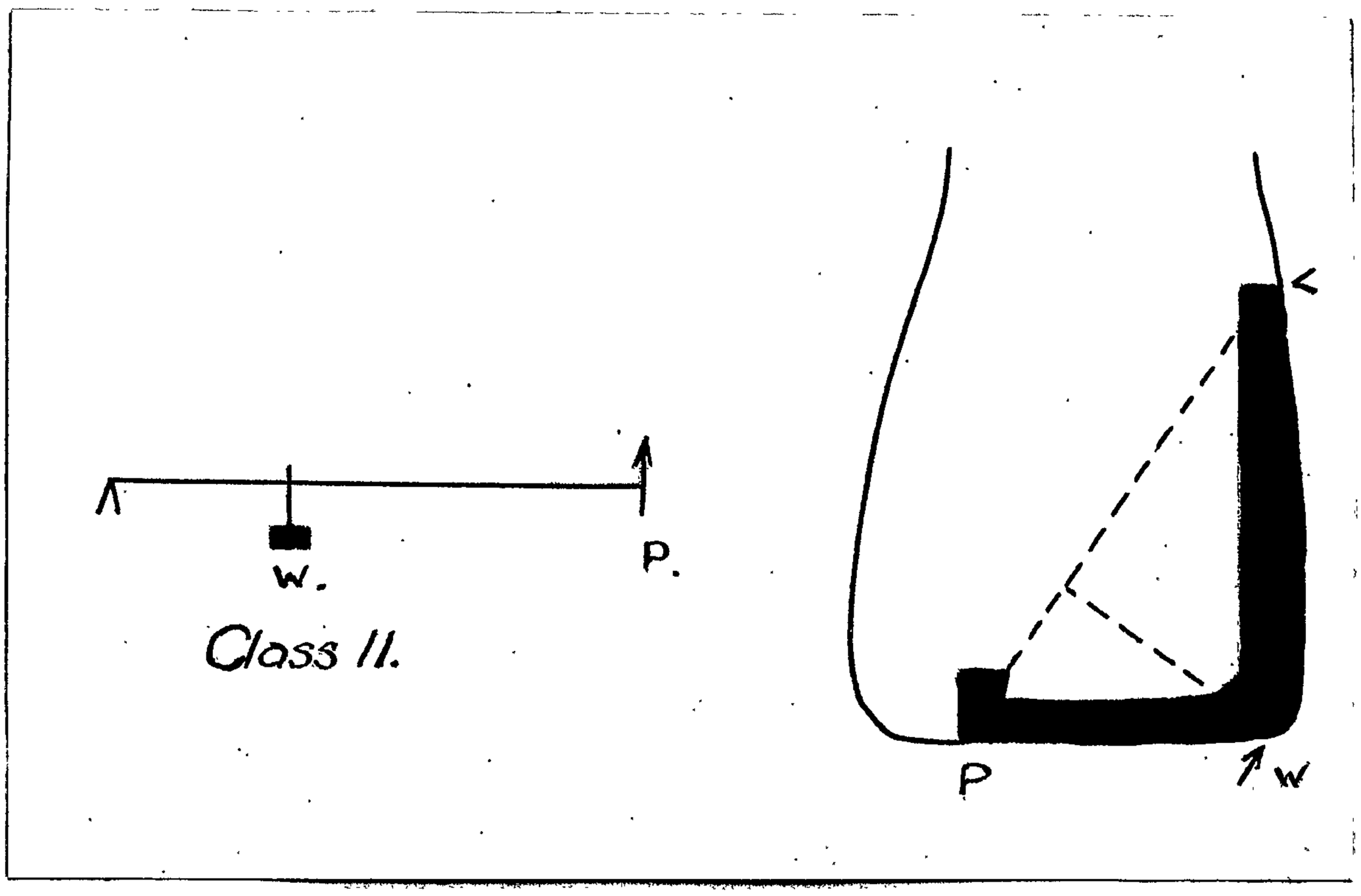


Fig. 21.

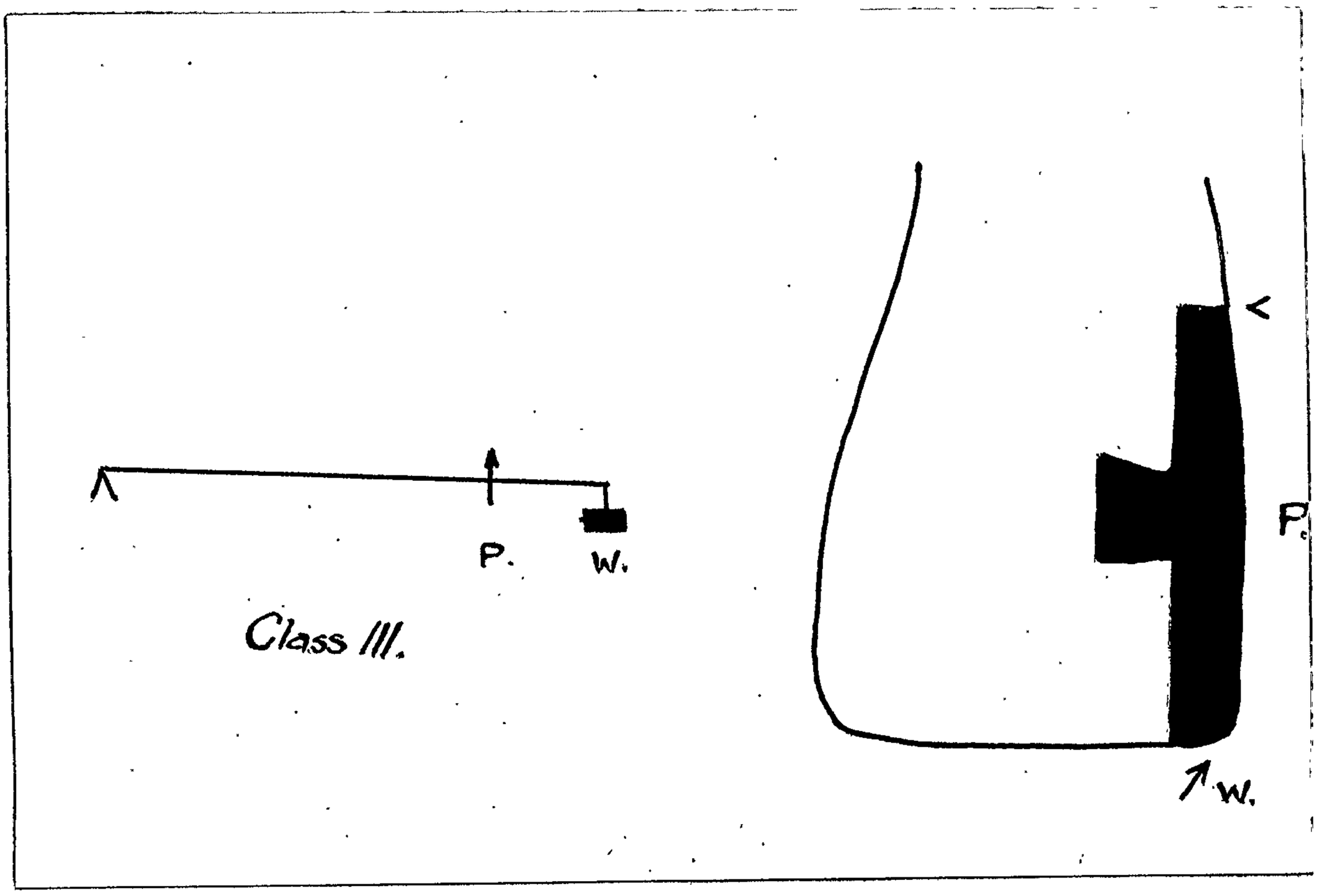


Fig. 22.

There are three types of lever systems (29); the lever consists of a rigid bar which may be straight or bent and has one fixed point about which the rest of the bar may, or tends to, rotate; this fixed point is called the fulcrum. The perpendicular distances between the fulcrum and the line of action of the applied force and the line of action of the resisting force are called the arms of the lever. The ratio between the applied force or Power, as it is called, and the resisting force or Weight is called the mechanical advantage of the system. Where possible an attempt should be made to utilize a system in which the applied force has a mechanical advantage greater than unity.

<u>Levers</u>.

Class 1. This system is arranged so that the power P and the weight W act on opposite sides of the fulcrum. Fig. 20 shows a diagram of the lever principle and two types of inlay restorations using the Class 1 lever principle in their retention forms. The post inlay has a power arm equal to the length of the post, the fulcrum being at the gingival margin; the other type shows a lingual lock inlay preparation without a gingival floor at right angles to the axis of the tooth, the only resistance to movement being by the small wall at P, the fulcrum being on the incisal margin of the lingual step.

Class 11. This system is arranged so that the power P and the weight W act on the same side of the fulcrum but the Power acts at a greater distance from the fulcrum than the weight. Fig. 21 shows a diagram of the lever principle and a proximo-incisal inlay restoration which utilizes its principle.

Class 111. This system is arranged so that the power P and the weight W act on the same side of the fulcrum but the power acts at a shorter distance from the fulcrum than does the weight. Fig. 22 shows a diagram of the lever and a proximo-incisal inlay restoration which utilizes its principles in the lingual lock retention form.

(29) Loney S.L. "Mechanics and Hydrostatics", 1920 Ed., p. 78.

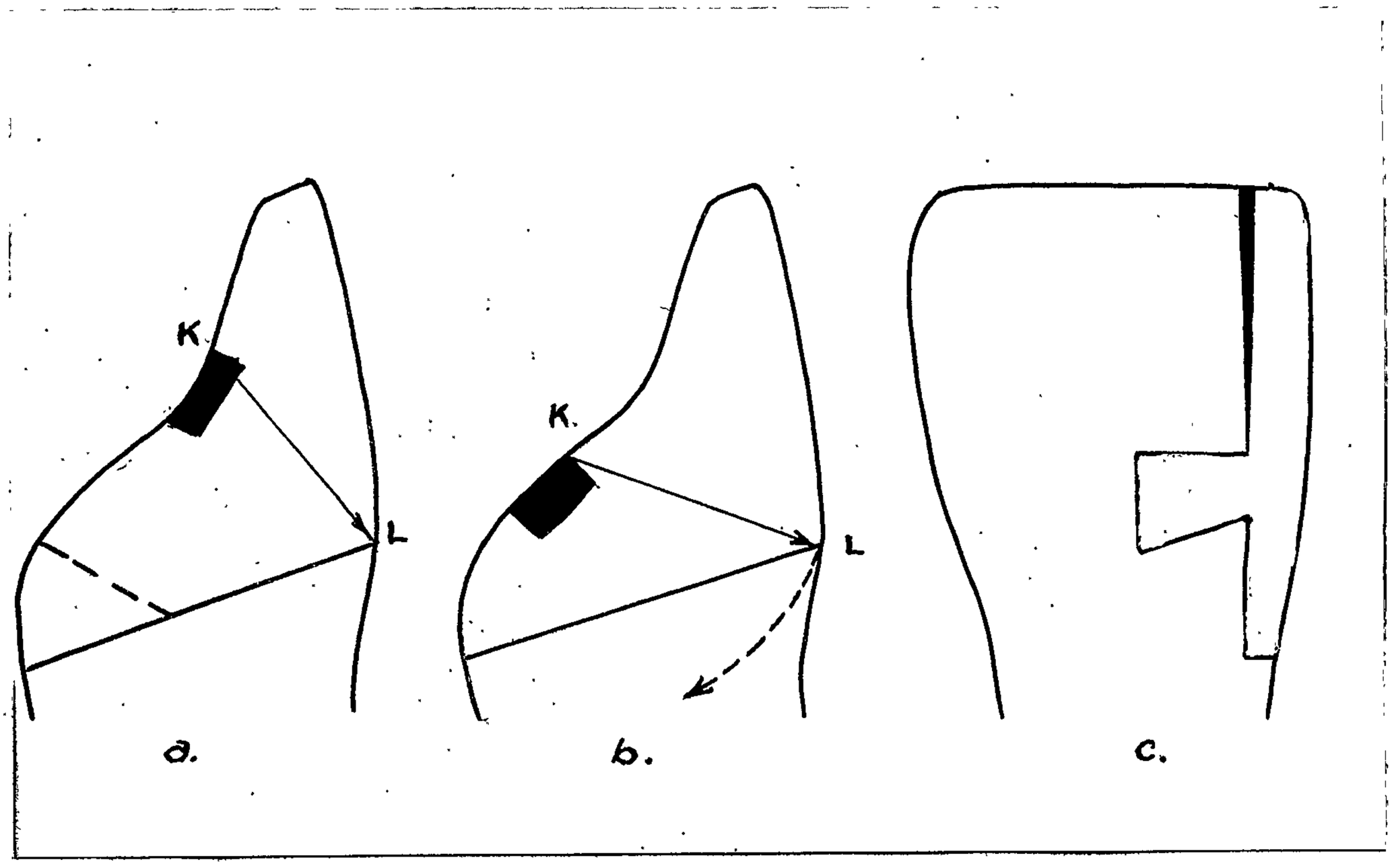


Fig. 23.

Fig. 23 a.b. illustrates a proximal view of a proximo-incisal restoration with lingual retention form, the force causing rotation being considered as applied from the lingual upon the incisal portion of the restoration.
Fig. 23 c. illustrates a lingual view of 23 b.

The arrow in each type of inlay indicates the direction of the masticatory force represented by W.

Class 1 systems are seldom used in inlay restorations, whilst Class 11 occur in the proximo-occlusal and proximo-incisal restorations, i.e. Black's Class 11 and Class 1V cavities, and Class 111 is the system found in proximo-incisal restorations using a lingual lock.

Whenever a lever system is used in which the retention form has a mechanical disadvantage it is important to design carefully and accurately the retention form because dislodgement under those conditions becomes more probable. The following example will illustrate the importance of this.

In Fig. 22 if P< is 2 units, and force W 75 pounds, W< is 4 units, then the power necessary to resist this force at P may be represented by X in the following:

75 : X :: 2 : 4 giving 2X = 300. X = 150 lbs.

By placing the retention closer to the incisal edge so that the power arm is 3 units the equation becomes under similar conditions 75 : X :: 3 : 4 giving 3X = 300. X = 100 lbs. From this example the importance of selecting carefully the position for the lingual lock is apparent.

In the case of an inlay restoration using some retention form such as a lingual lock situated midway between the incisal and gingival limits and having the gingival floor prepared so that it does not oppose tendency to rotation about K the rotation centre, see Fig. 23 a, little resistance to rotation exists other than that afforded by the lingual step and the value of the inlay as a permanent restoration is reduced. Several methods may be used in which the difficulties due to extensive caries in the gingival region may be overcome.

1. Rotation may be prevented by retaining tooth structure and forming a wall along the dotted line shown in Fig. 23 a. thus introducing a Class 1 lever, but if the caries is extensive this

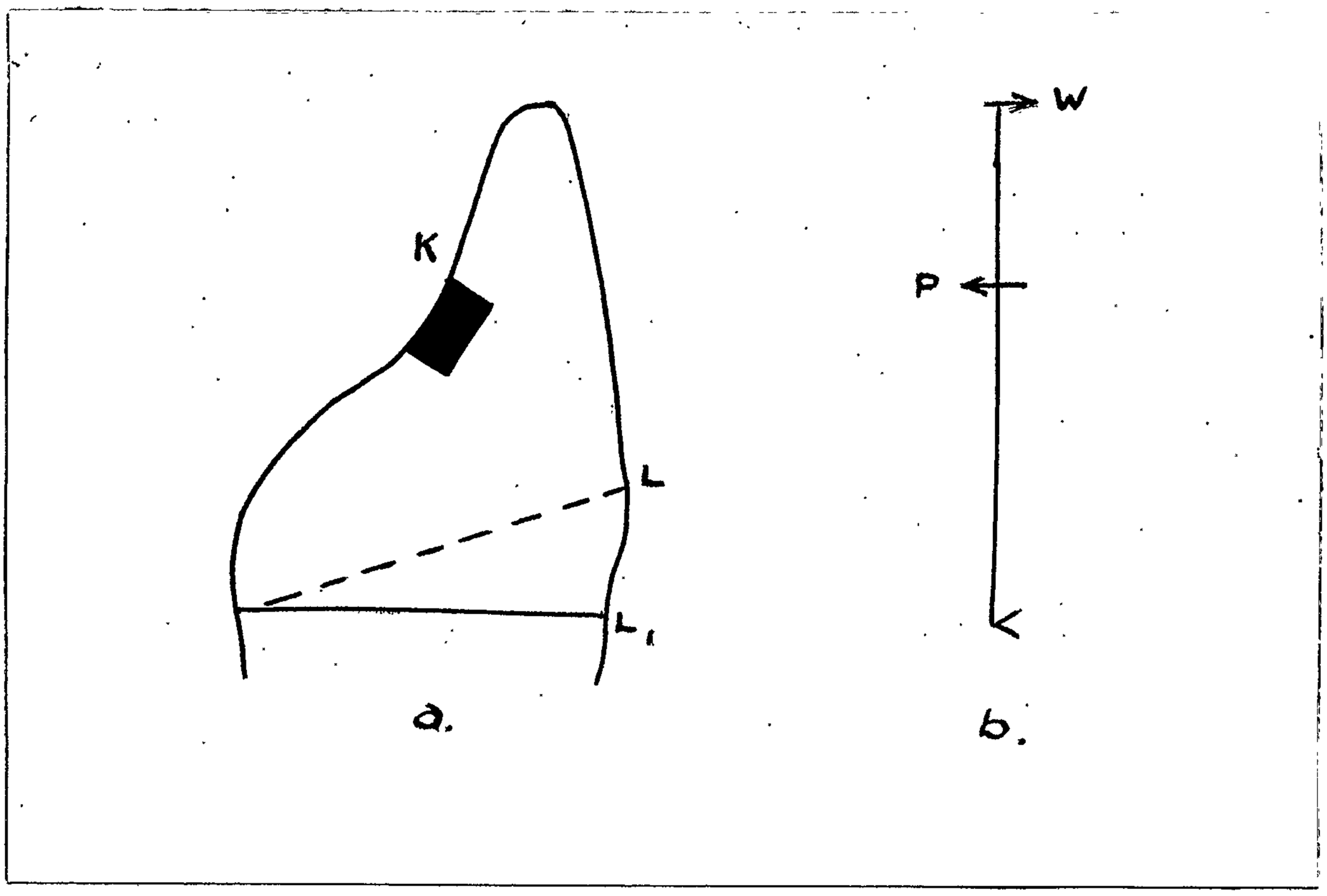


Fig. 24.

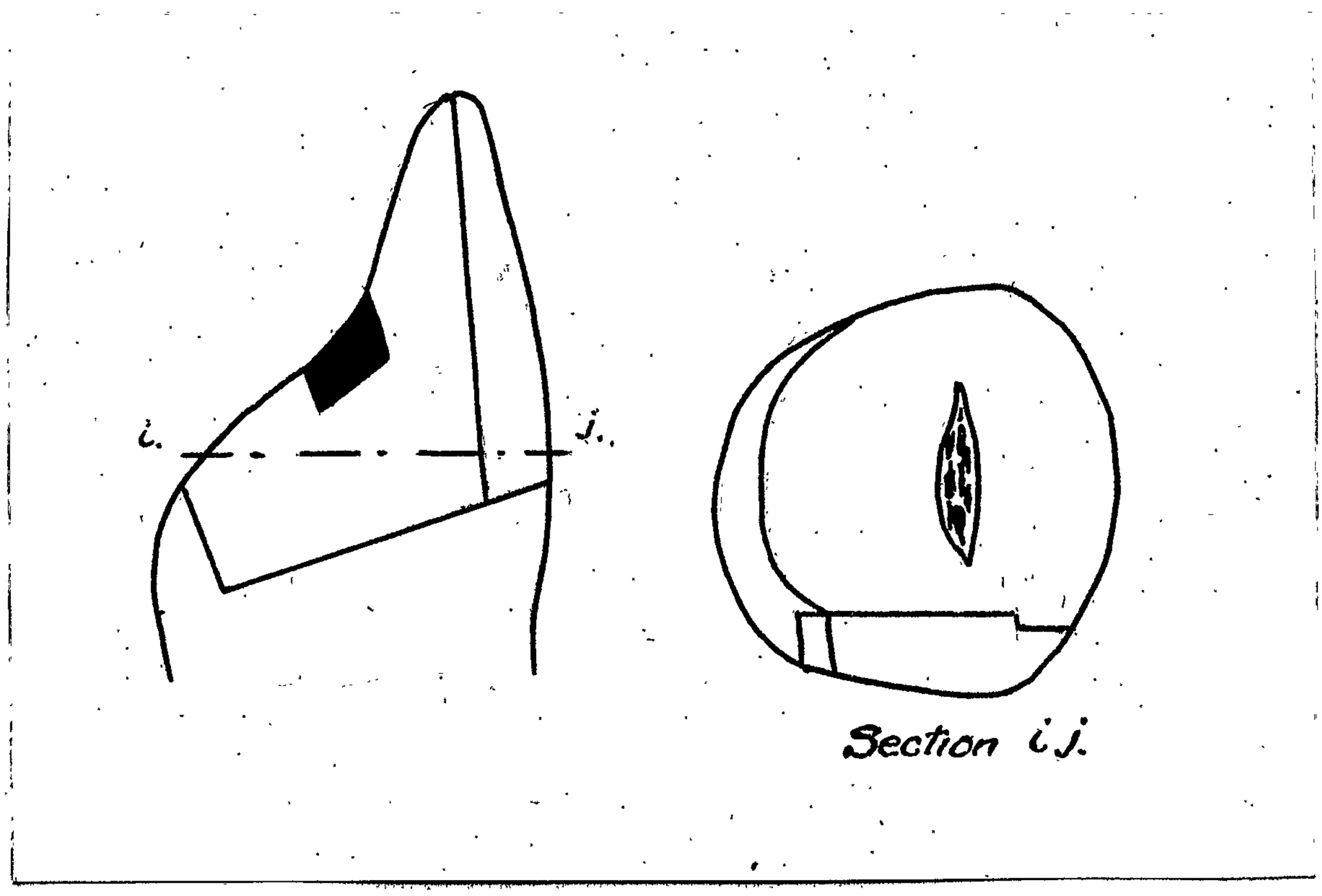


Fig. 25.

may be difficult or even impossible to accomplish.

11. The lingual lock may be placed closer to the gingival margin of the tooth thus increasing the radius K.L. so that its length is greater than the length of a perpendicular from K to the gingival line. Rotation about K from a force applied from a lingual direction would necessitate the passage of L along the arc shown by the dotted line, but because this path is opposed by sound tooth structure rotation is impossible, Fig. 23 b. By using this position retention is improved and the cutting of tooth structure is removed from a close proximity to the pulp, but the incisal region of the gold inlay loses some of its support and may be stretched away from its position due to stress tending to force the inlay in a proximal direction. Fig. 23 c diagrammatically illustrates this defect.

111. If more tooth structure is removed from the labial portion of the gingival wall the radius KL is increased to KL1, Fig. 24, but in extensive caries this may be difficult to accomplish without severe trauma to the gingival and peridental tissues.

1V. Where possible remove some of the axial wall so that a labial wall may be formed as shown in Fig. 25, and in this way overcome the lever principle acting in this direction.

If the method shown in Fig. 24 is used so that the length KL is increased, the centre of rotation changes from K to L, and this point becomes the fulcrum, resistance to stress is given by K and a Class 111 lever principle is introduced. Of the various methods it would seem better to place K as close to the incisal as possible and alter the gingival wall so that the mechanical disadvantage is reduced to a minimum; sometimes a comprise between these methods is necessary.

If the stress which may occur during incision and lateral protrusive movements is considered in relation to the anterior teeth, where this stress is one tending to dislodge the inlay restoration towards the proximal, it will be found to consist

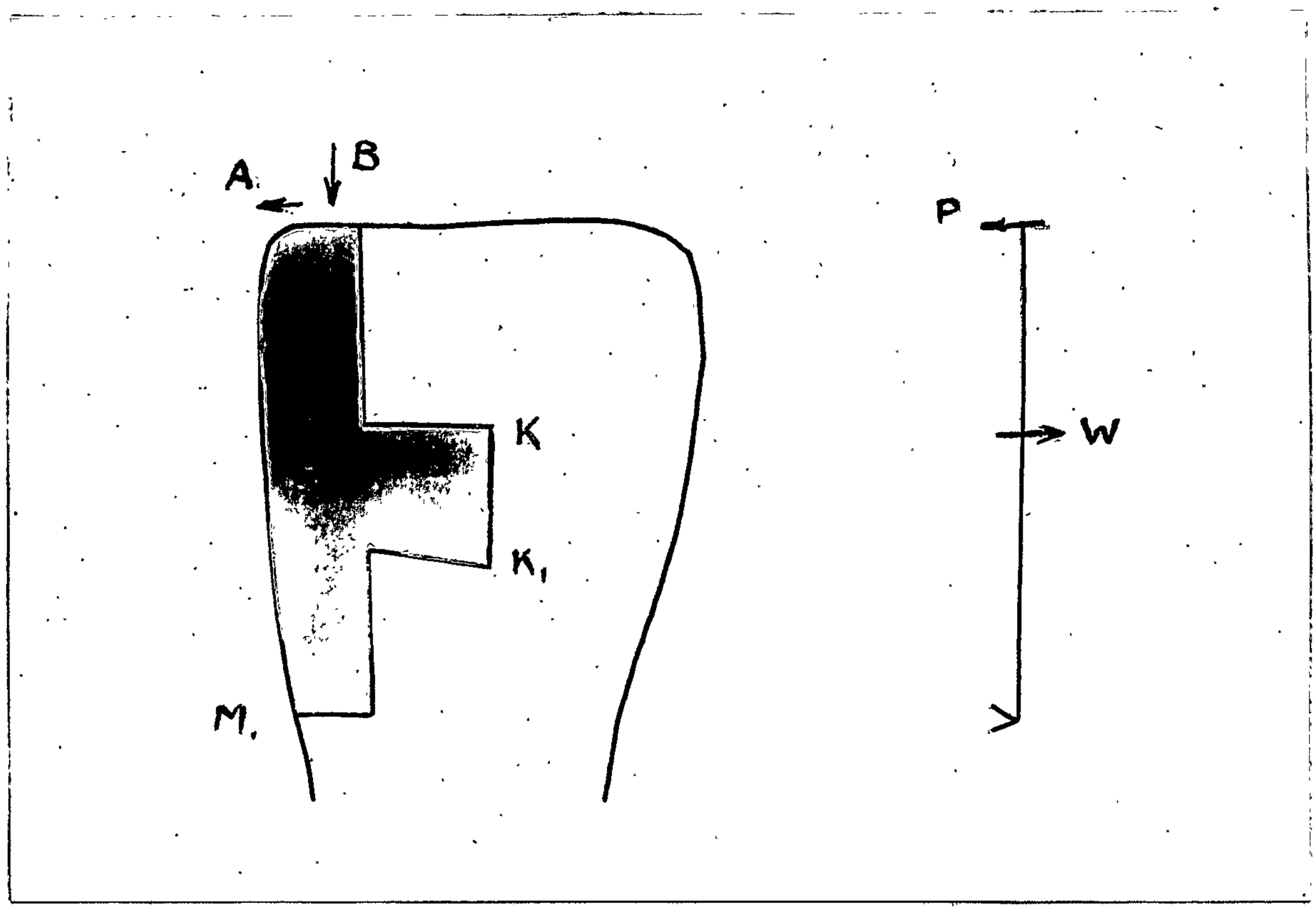


Fig. 26.

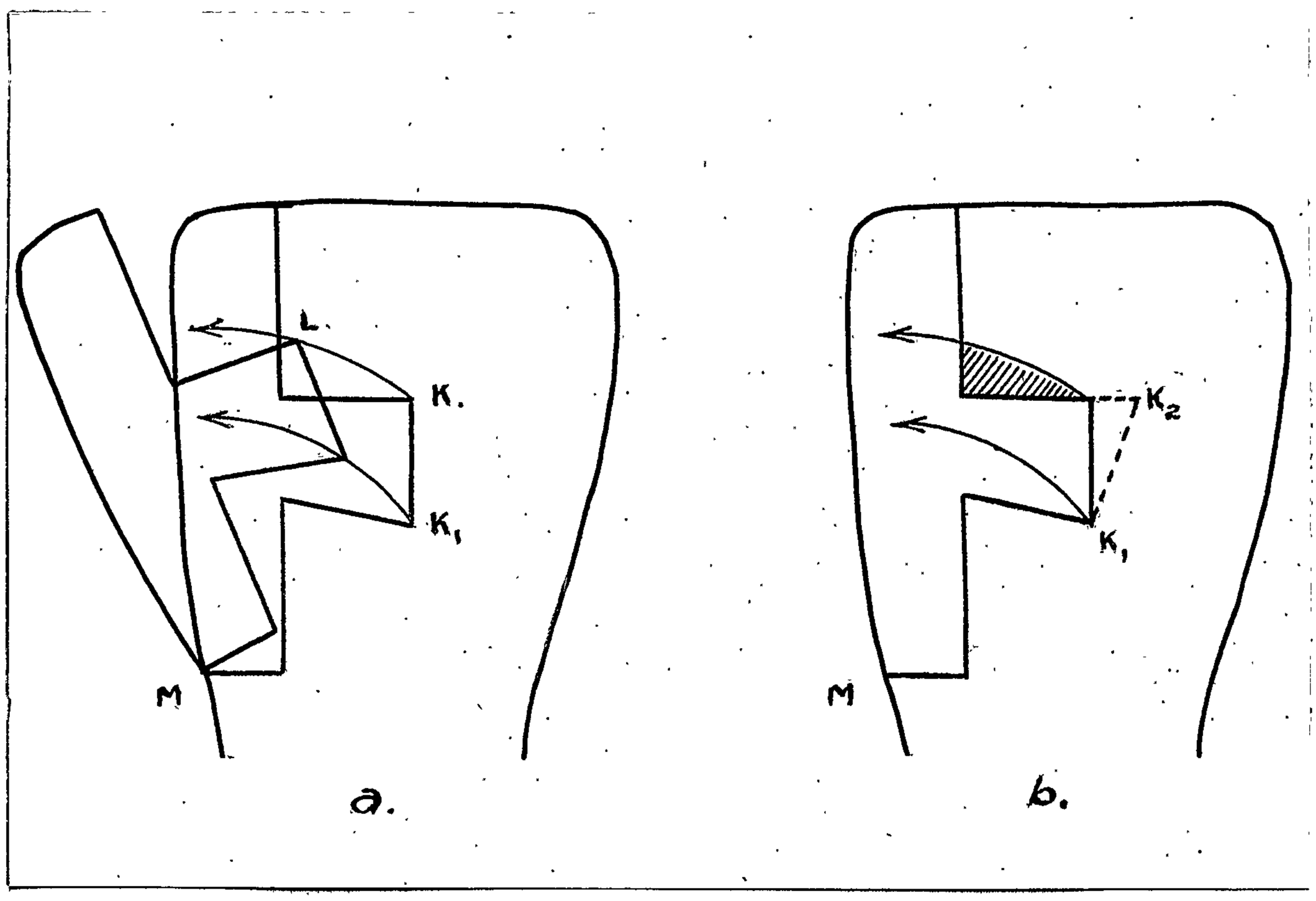


Fig. 27.

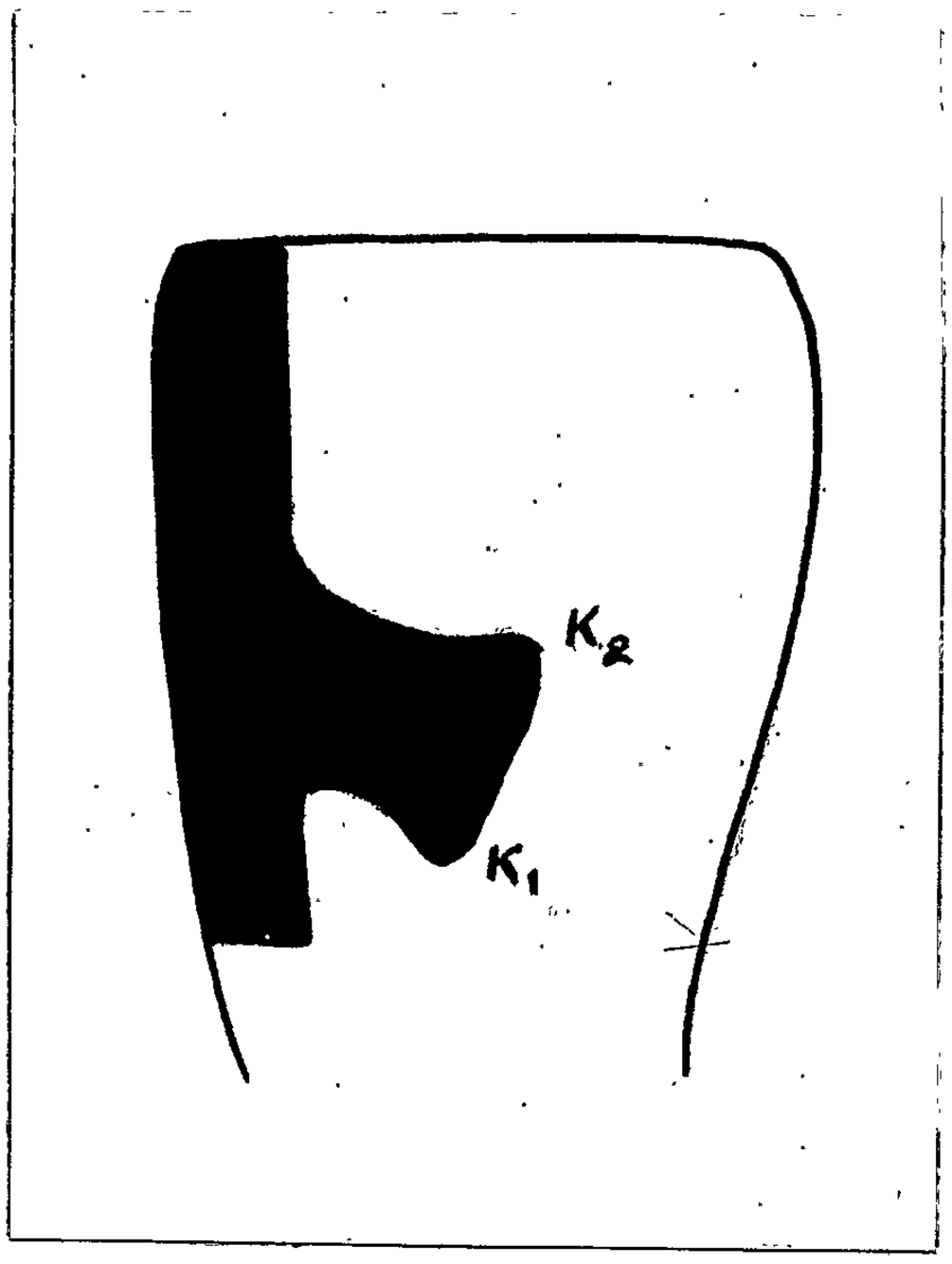


Fig. 28.

Fig. 29.

of two components, in Fig. 26 represented by B acting in the axial direction and A acting in a proximal direction; this latter force will have a tendency to rotate the inlay towards the proximal, M being the centre of rotation. With retention at K a Class 111 lever system prevails.

Supposing rotation about M were possible, then with M as centre, arcs of circles with radii MK and MK1 would indicate the approximate paths followed by the retention form during movement, see Fig. 27 a. The gingival wall of the retention form is within the arc having radius MK1 and therefore K1 passes along a path moving away from the gingival wall which cannot exert any resistance to the movement of K1. In the case of the incisal wall, however, it is within the arc radius MK and since K is further than any other point selected on this wall from M, the retention form cannot move unless the material represented by the shaded portion in Fig. 27 b is removed. If this material is removed by caries or operative procedures resistance to movement is obtained by increasing radius MK so that K2 becomes the new position of this extremity of the incisal wall. MK2 will then form an arc passing through solid tooth structure which will prevent rotation. In this way the objection raised to the retention form shown in Fig. 23 c. may, to some extent, be met and a retention form outlined in Fig. 28 will prevent rotation and at the same time offer some support to the incisal portion of the inlay.

If the tooth is thick the retention form could be cut square in outline and deeper and placed closer to the incisal edge of the tooth thereby reducing the mechanical disadvantage, see Fig. 29. The necessity for outlining this retention form in a 'dovetail' shape is due to stress which may tend to rotate the inlay about the labial margin of the cavity, and methods of overcoming this tendency to rotation are discussed later.

In the case of the thick tooth it is often advantageous to use the Class 11 lever system and prepare an incisal anchorage

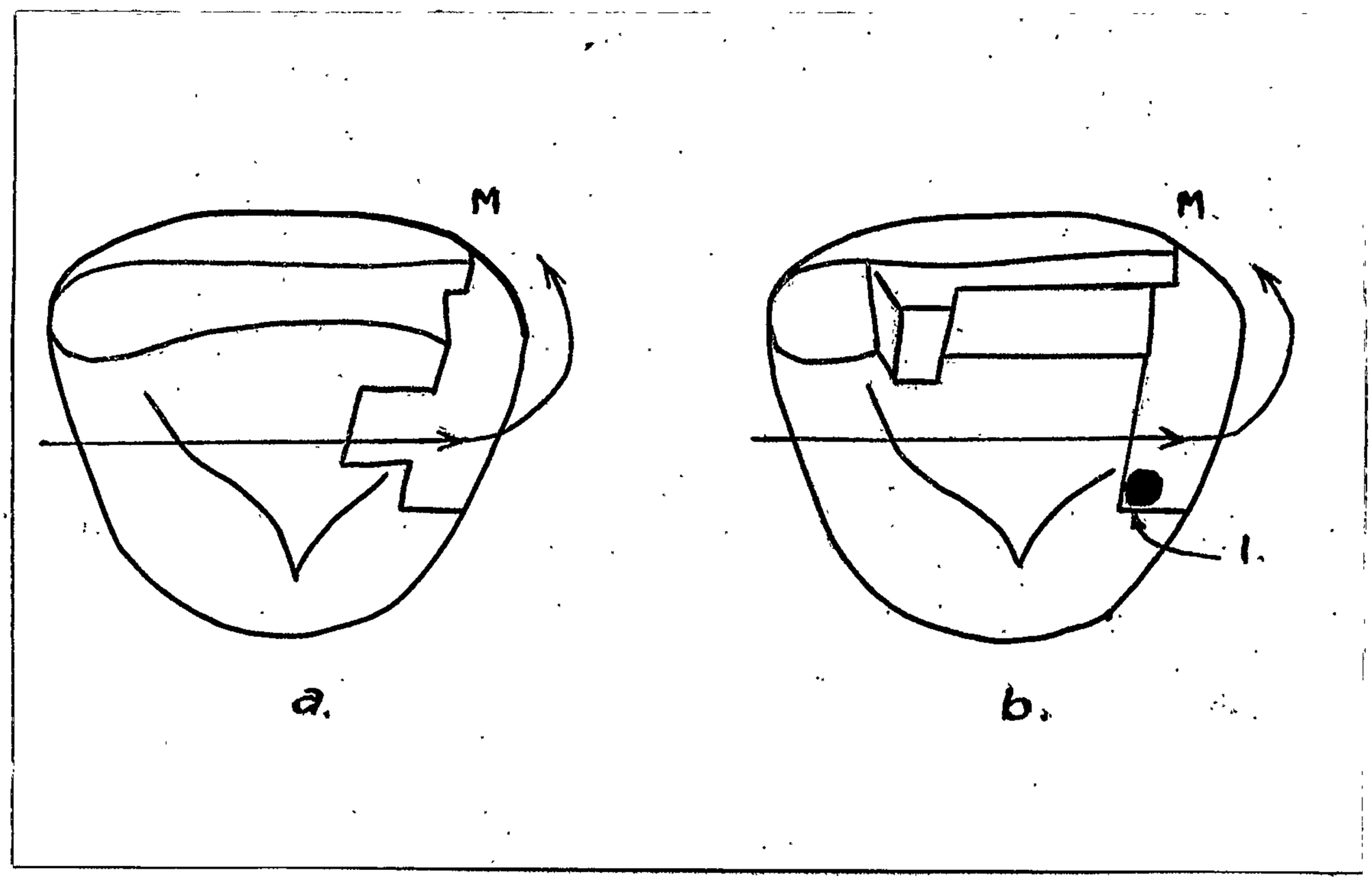


Fig. 30.

Fig. 30 a. shows an incisal view of the lingual lock.
Fig. 30 b. shows an incisal view of the incisal lock.

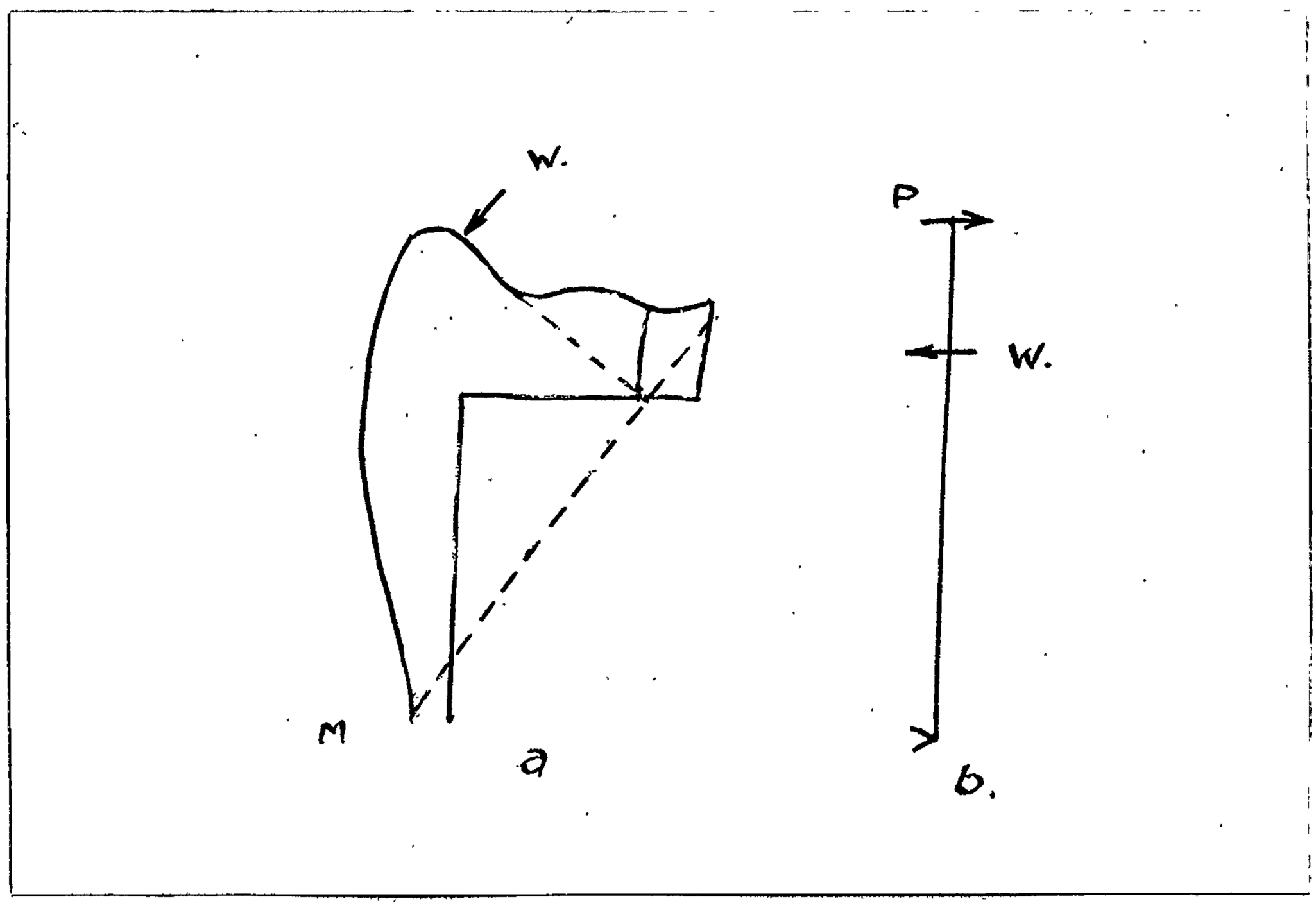


Fig. 31.

as shown in Fig. 21; this type is similar to the occlusal anchorage as used for the posterior teeth. Fig. 21 illustrates the retention form, the dislodgement force acting in the direction W, the fulcrum or rotation centre at < and retention at P. Arm P< is greater than W< so that retention at P has a mechanical advantage over stress at W. Careful designing and cutting of the retention form is needed to overcome any tendency to rotation about the labial margin. Fig. 5 shows the areas where greatest stress appears to occur; the marginal ridges appear to absorb a large amount of this stress which is increased during lateral movements of the mandible; the lower incisors impacting with the ridges tend to induce rotation of any restoration in these areas about the labial margin of the cavity, see Fig. 30. The lingual dovetail, Fig. 30 a, is a satisfactory form but the incisal form is not so satisfactory because of the difficulty of providing the correct shape and at the same time of retaining adequate tooth structure to support the inlay. Pins are used at the extremity of the incisal step with some success when the pulp is favourably situated, but if the pulp is large assistance by this means is not available; the gingival floor in its lingual extremity provides some assistance where a pit may be placed to accommodate a pin in the inlay and at this position it may function as an excellent retentive factor with a working arm I.M. which is greater than the distance of the lingual step to M and therefore I should be effective in overcoming any torque action about M, Fig. 30 b. In addition the incisal step has a supplemental dovetail step cut at its extremity which is of further assistance in preventing rotation.

When a proximo-occlusal inlay is examined a similar retention system is presented although the retention arm is stronger and has more bulk than the incisal form; the use of pins in the occlusal form is seldom indicated. Fig. 31 illustrates the lever system in this type of cavity.

When a decision has to be made in the selection of a type of retention the aesthetic demands of the case will often require the selection of some form possessing a lever principle with a mechanical disadvantage and it is necessary to realise this so that needless cutting may be avoided and its substitution by an accurately designed inlay though possessing inferior mechanical factors will in general give satisfactory service.

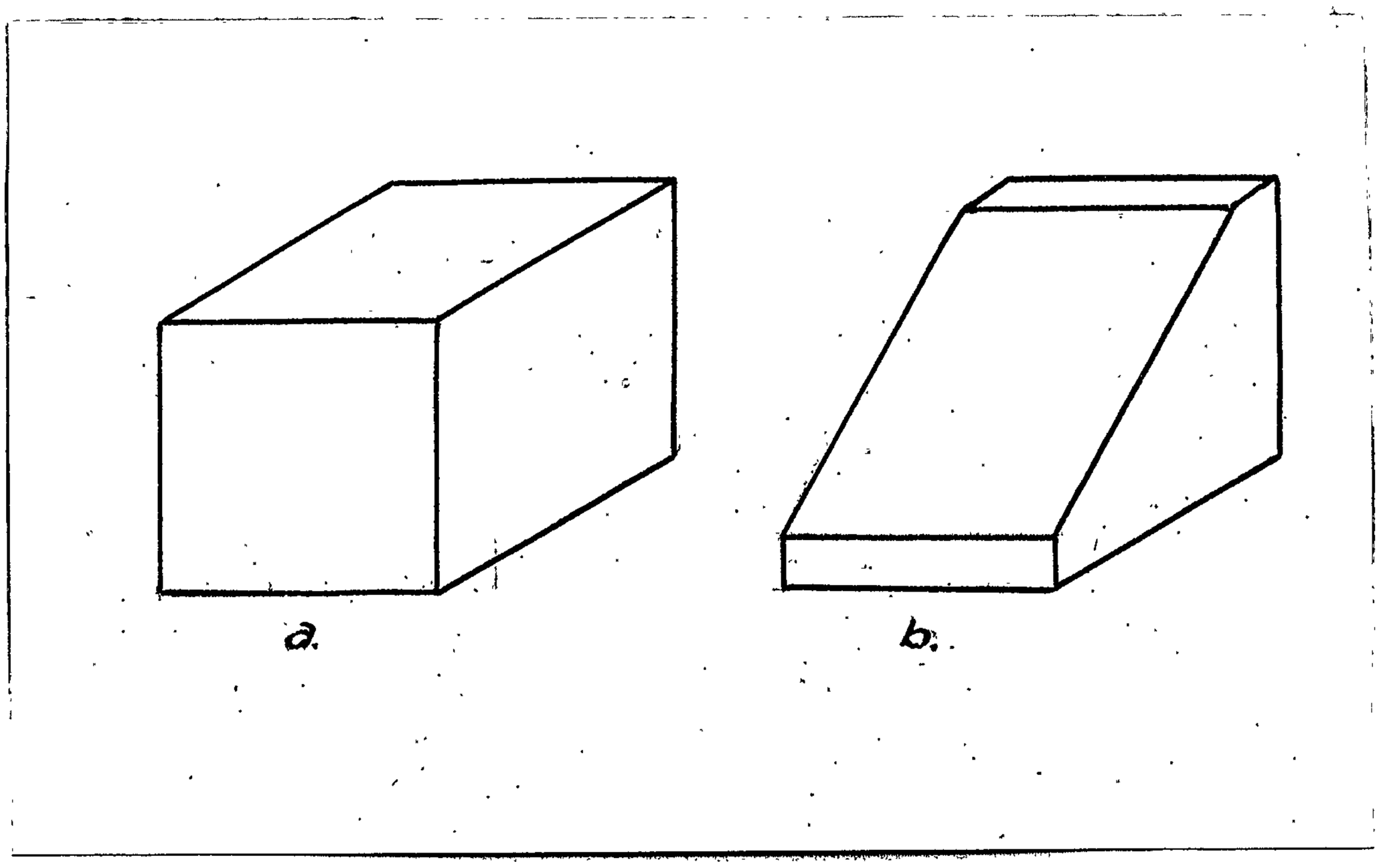


Fig. 32.

Fig. Geometric forms representing a. posterior teeth, b. anterior teeth.

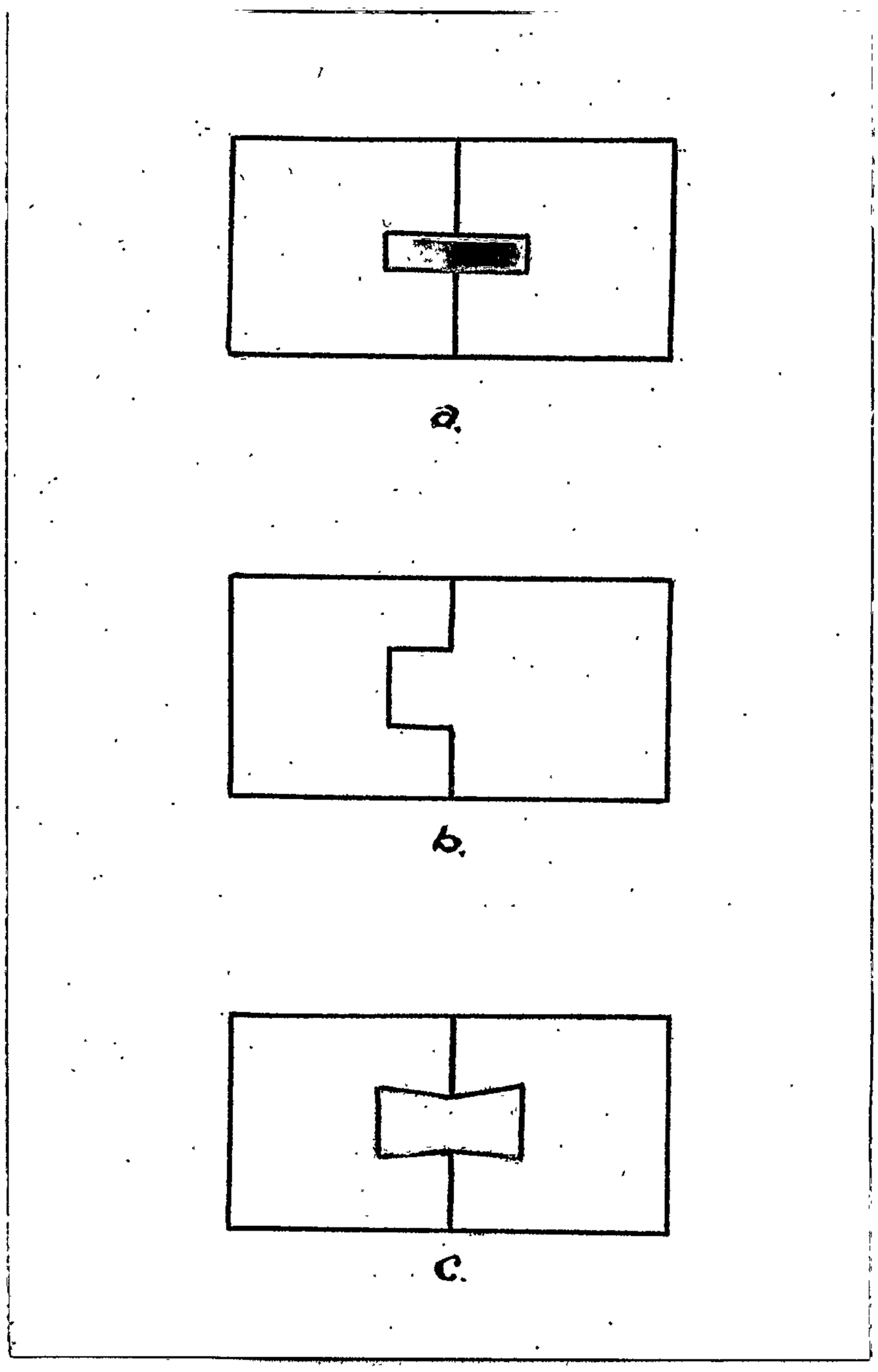


Fig. 33.

Fig. 33. a. Dowelled joint. b. Toggle joint. c. Slate cramp.

SECTION 3.

Geometric forms of retention.

Every class of cavity preparation may be reduced to some simple shape and applied to a simple geometric form such as a cube to represent the tooth. With simplified external contours it becomes possible to study the inlay cavity and compare its characteristics with the methods of joining materials together. A cubical form for the posterior teeth and a pyramidal form for the anterior teeth have been used to illustrate the various types of retention, see Fig. 32.

Passing from the field of operative dentistry to one in which great use is made of cutting special shapes for joining materials together, it may be shown that a marked similarity exists in the various forms used in both fields; by examining the mechanical principles used it is thought that modifications may be selected which may be applicable to inlay cavity design.

In masonry there are a variety of joints used in the construction of walls etc. which have a union effected by means of cutting a form in one piece to receive a counterpart form in the other; but because of the nature of the materials used and the large bulk of the portions the forms are generally restricted to simple ones, e.g. dowelled joint, toggle joint, and slate cramp, see Fig. 33 (30). A plan of the joints only is shown but the forms are of the 'box' type.

In wood-working arts (30) there are available some fifteen or more joints and those whose characteristics may be applied to inlay cavity design are now discussed, and their types applied to the geometric forms.

1. Halving, Fig. 34 a. This is a simple lap joint between two pieces of wood; the replica in the tooth, a single step or two surface preparation, is shown in Fig. 34 b, c. If no anchorage exists other than the close adaptation of the parts, the pieces

(30) Buchanan A., Hudson W.H. "Building Construction" Part 1, pp.15.

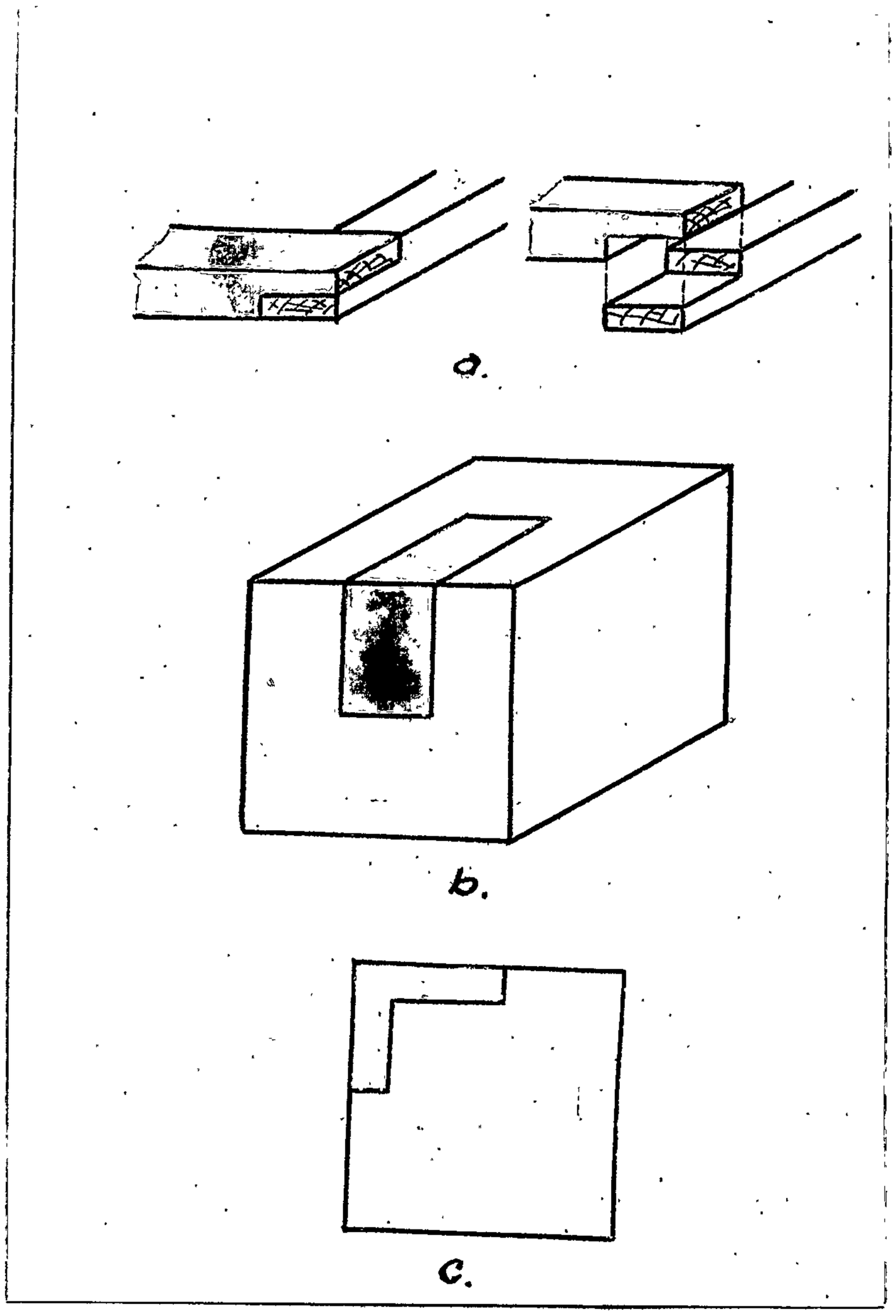


Fig. 34.

Fig. 34 a. Halving. b. Single step preparation. c. vertical section through inlay. Inlay represented by shaded portion.

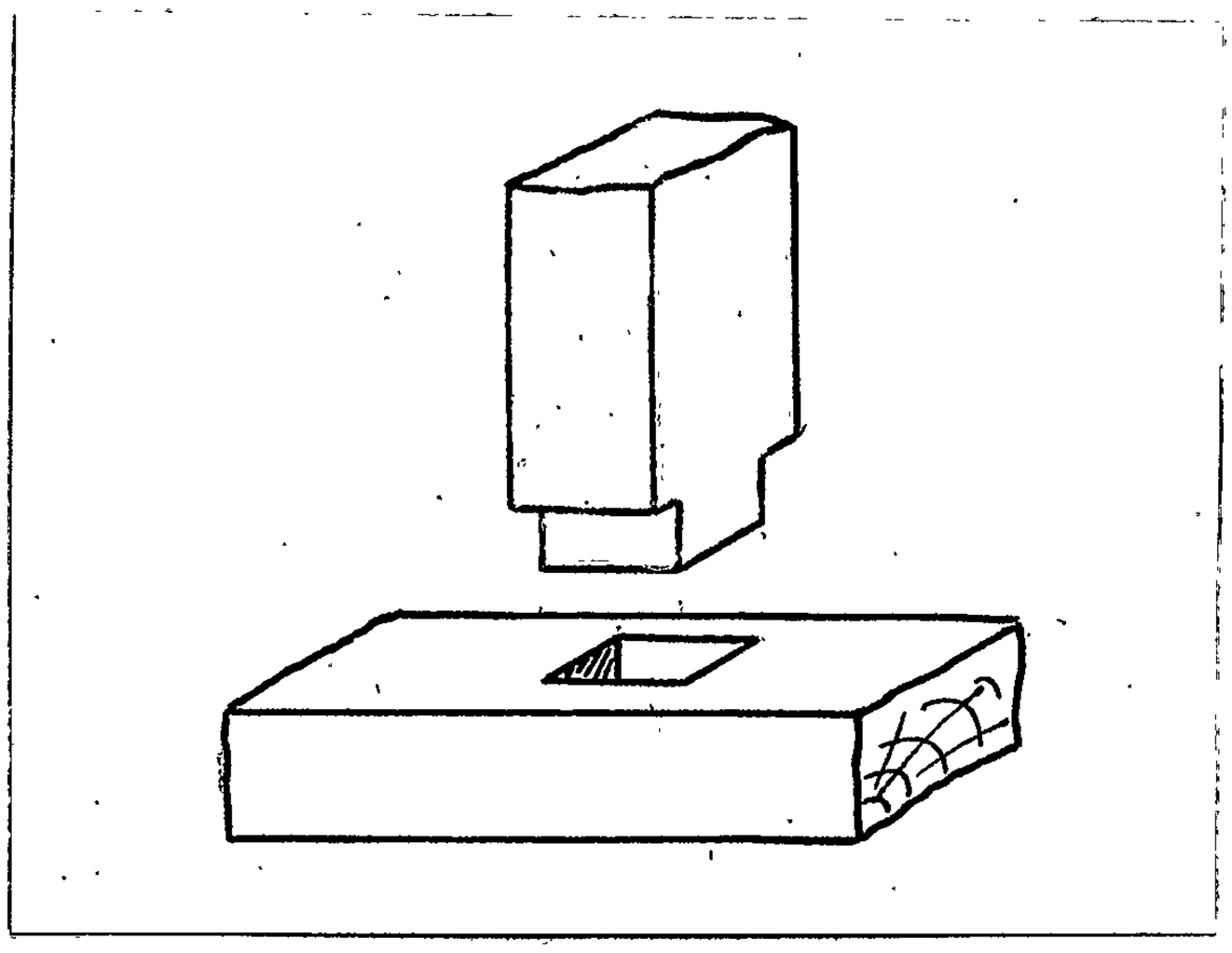


Fig. 36.

are dependent upon the cementing medium to resist stresses which tend to separate them either in a horizontal direction or in a vertical direction, and rotation may occur if force is applied or if the resultant of forces act at a suitable point, the axis of rotation corresponding to the gingival margin, see Fig. 35.

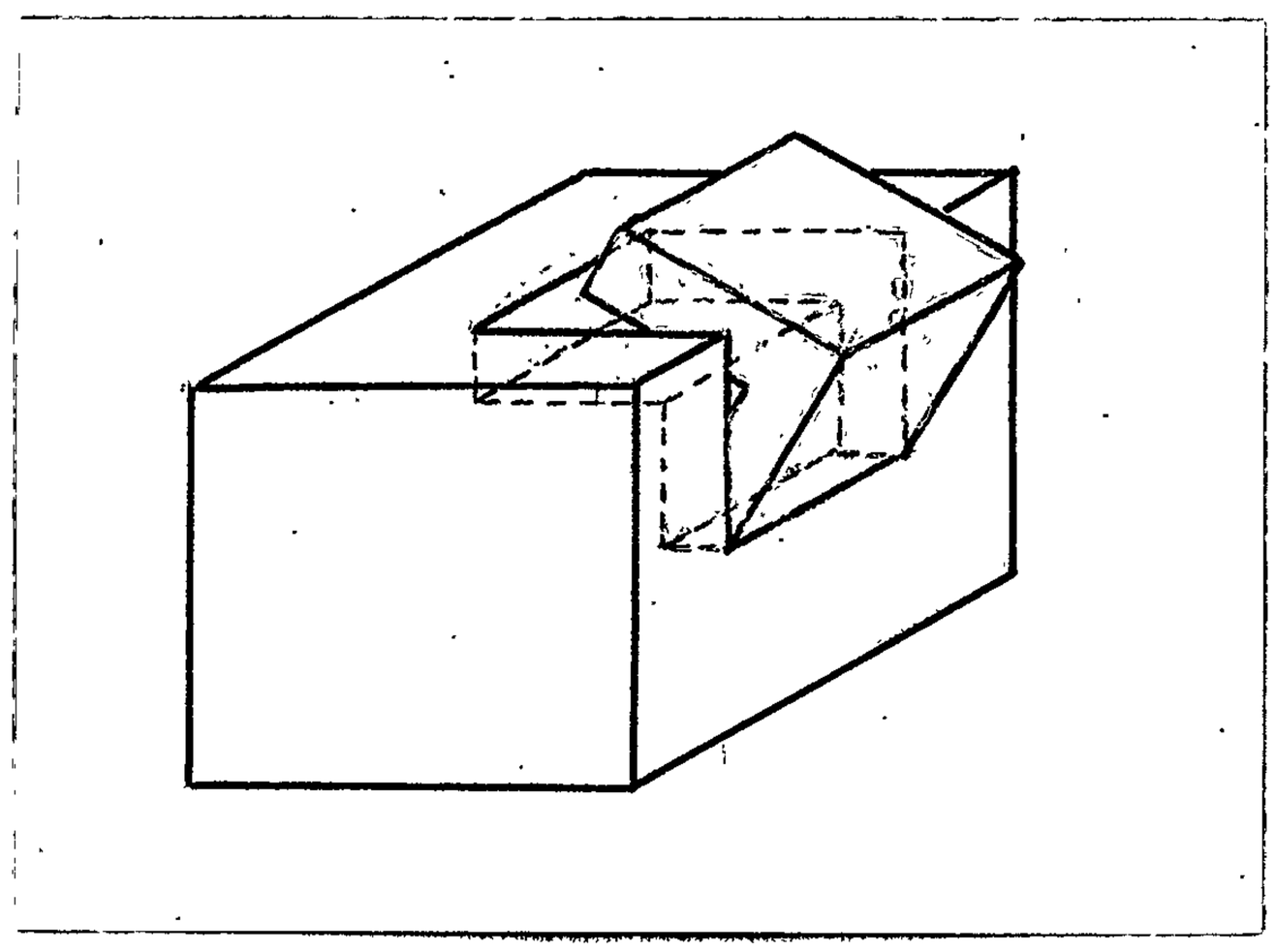


Fig. 35.

Fig. 35. Single step preparation without anchorage showing rotation about the gingival margin.

11. Stump or stub tenon, Fig. 36. In this type a square 'box' is cut in the surface of one member to receive the other member which has been reduced in size to form the 'stump'; the stump is very short in relation to the length of the piece. This form of retention exhibits the characteristics of a Class 1 lever system, and unless the material has sufficient strength to prevent fracture of the stump and the adaptation between the stump and box is perfect this form of retention may not withstand excess stress. In actual practice the retentive value is improved by placing a small wedge in the end of the stump before glueing the parts, the stump is then driven into the box; the function of the wedge is to force the sides of the stump into very close contact with, and maintain pressure against, the walls of the slot.

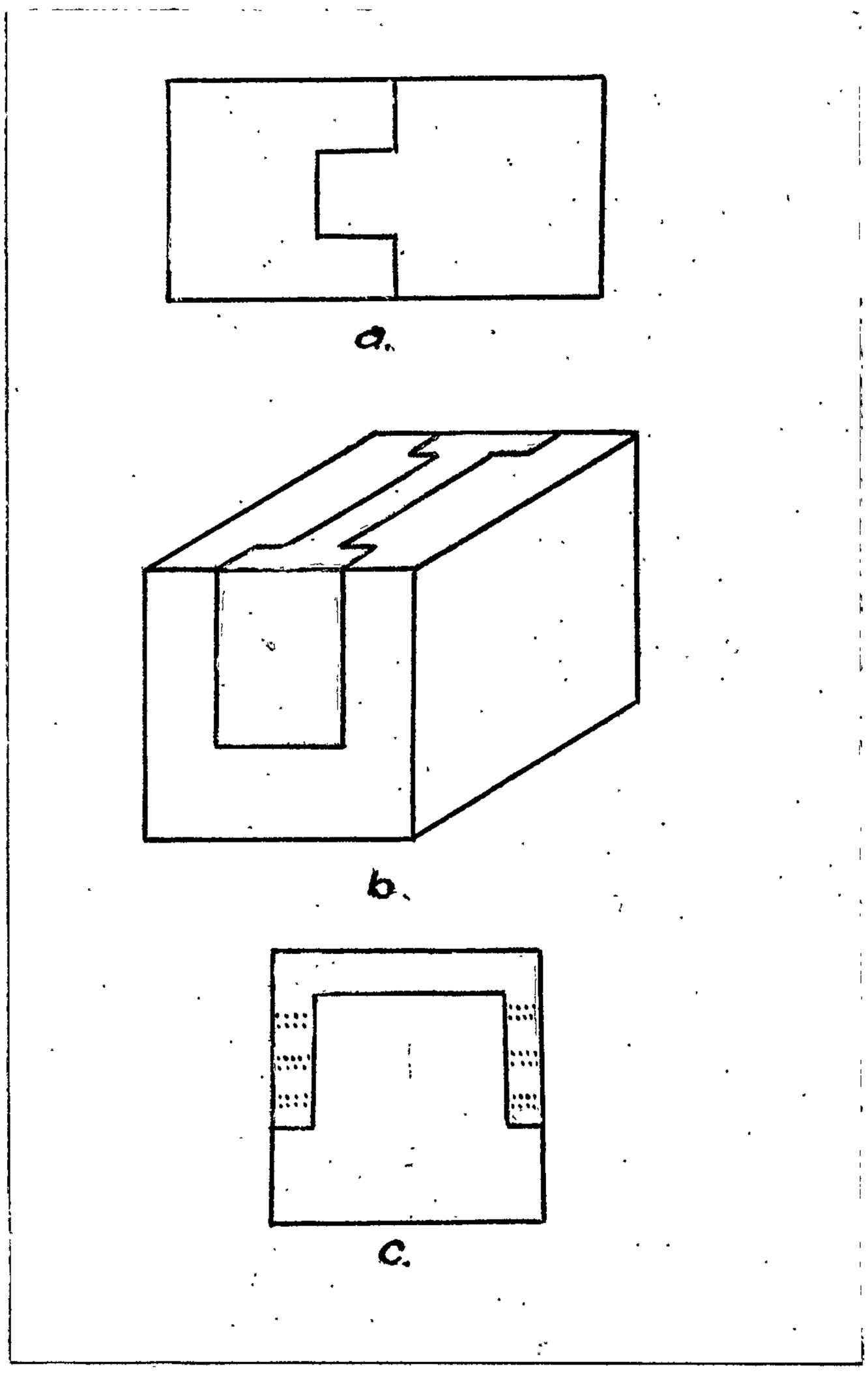


Fig. 38.

Fig. 38 c. represents a section through the M.O.D. inlay. The auxiliary grooves for cement are cut in the mesial and distal portion of the inlay as marked by the dotted lines. The cement in this position acts similarly to a 'key' holding a wheel and shafting fixed.

1V. Open mortise and tenon, Fig. 38 a. In this type of joint, which may be likened to a double lap joint, another development in retention form of a reciprocal nature is seen; this reciprocal resistance is developed by the two parallel arms of the mortise which oppose stress tending to cause rotation about the base lines. The replica in tooth form is shown in Fig. 38 b and is known as an M.O.D. inlay, also termed a saddle inlay. Because of the increased internal surface area and complexity of this type of cavity the cementing medium can be of greater assistance in opposing movement in a vertical direction; when the inlay has been cast and fitted to the cavity, grooves are cut in its sides so that they are placed at right angles to the line of withdrawal of the inlay after the manner of Bodecker (34). These grooves become filled with cement which when crystallised acts in a similar manner to a key used to attach a pulley wheel to a round shafting, the cement with a high crushing strength being an advantage. This advantage is of no inconsiderable amount as shown by Head (35) in a series of experiments conducted in 1905 in which he was able to demonstrate the value of altering the retention form by means of grooving the inlay which had been fitted to the cavity, in addition grooves were cut in a corresponding position in the walls of the cavity and the inlay cemented in position. With a smooth inlay and no grooves in the cavity walls the inlays were dislodged with a pressure equal to 8 ounces weight; with grooves in both the inlay and cavity the pressure necessary was equivalent to 19 pounds weight. It therefore seems probable that the use of this type of grooving is a definite advantage in the retentive value of the inlay, especially when a cement with a high crushing strength is used. Grooves need not be cut in the walls of the cavity because their substitution by the minute irregularities attendant upon instrumentation of the dentine is unavoidable and the value of these irregularities as retention

(34) Gillett A.W. and Irving A.J. "Gold Inlays by the Indirect System", 1932 Ed., p. 65 et seq.
(35) Head J. Dental Cosmos, Vol. 47, 1905, pp. 779.

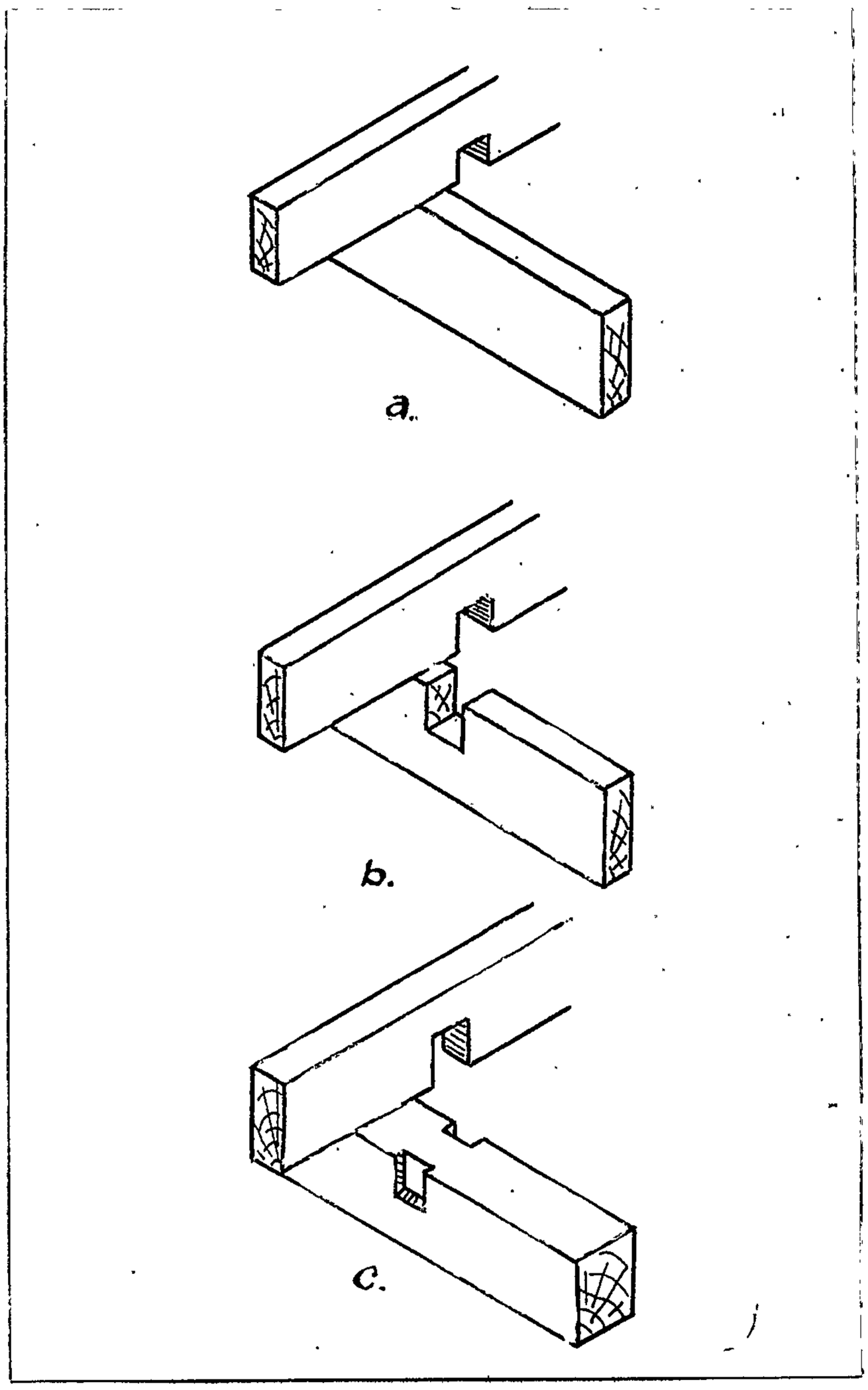


Fig. 39.

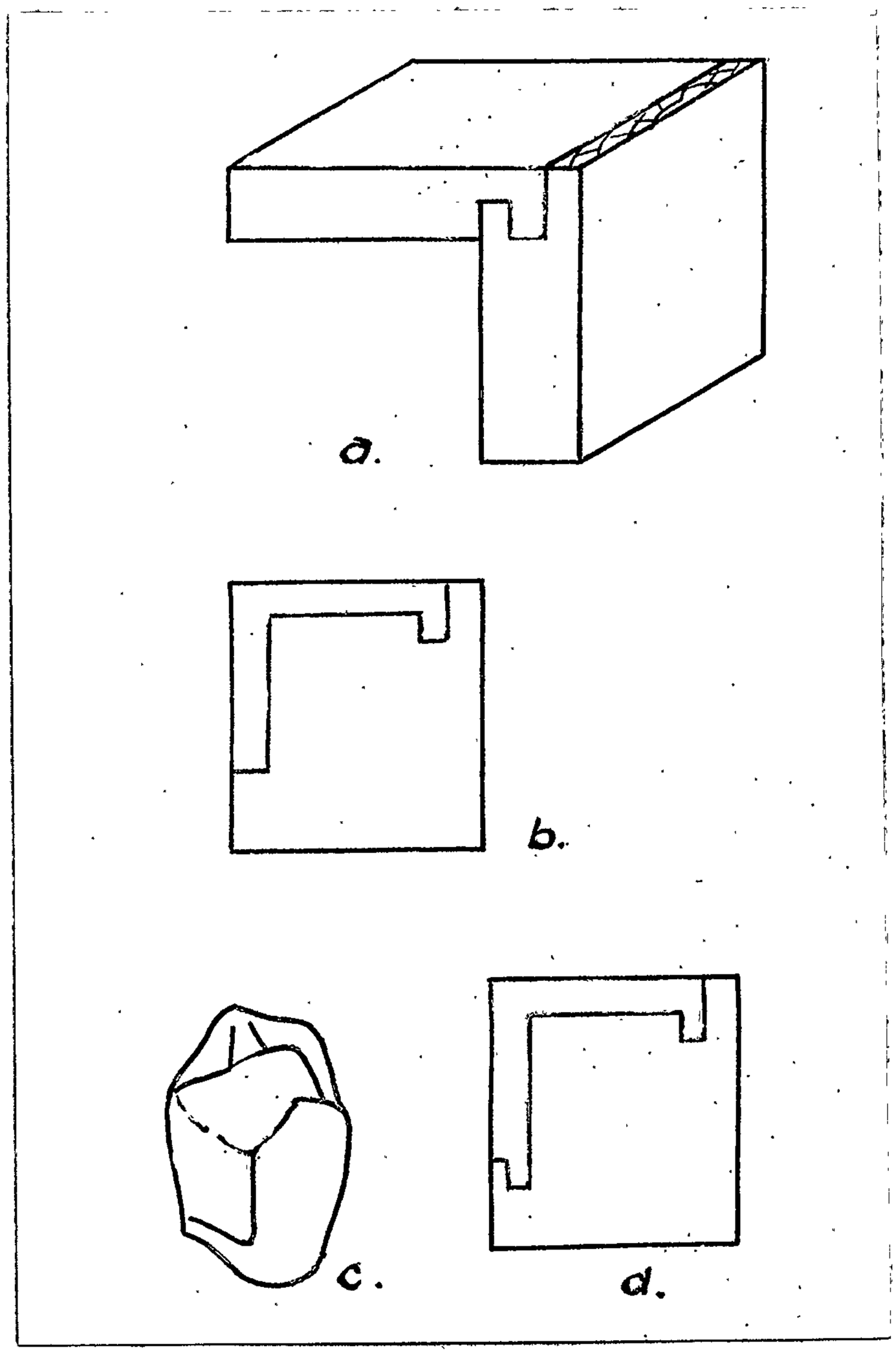


Fig. 40.

Fig. 40 b,d. illustrates a cross-section through the two surface inlay using supplemental grooves for retention.

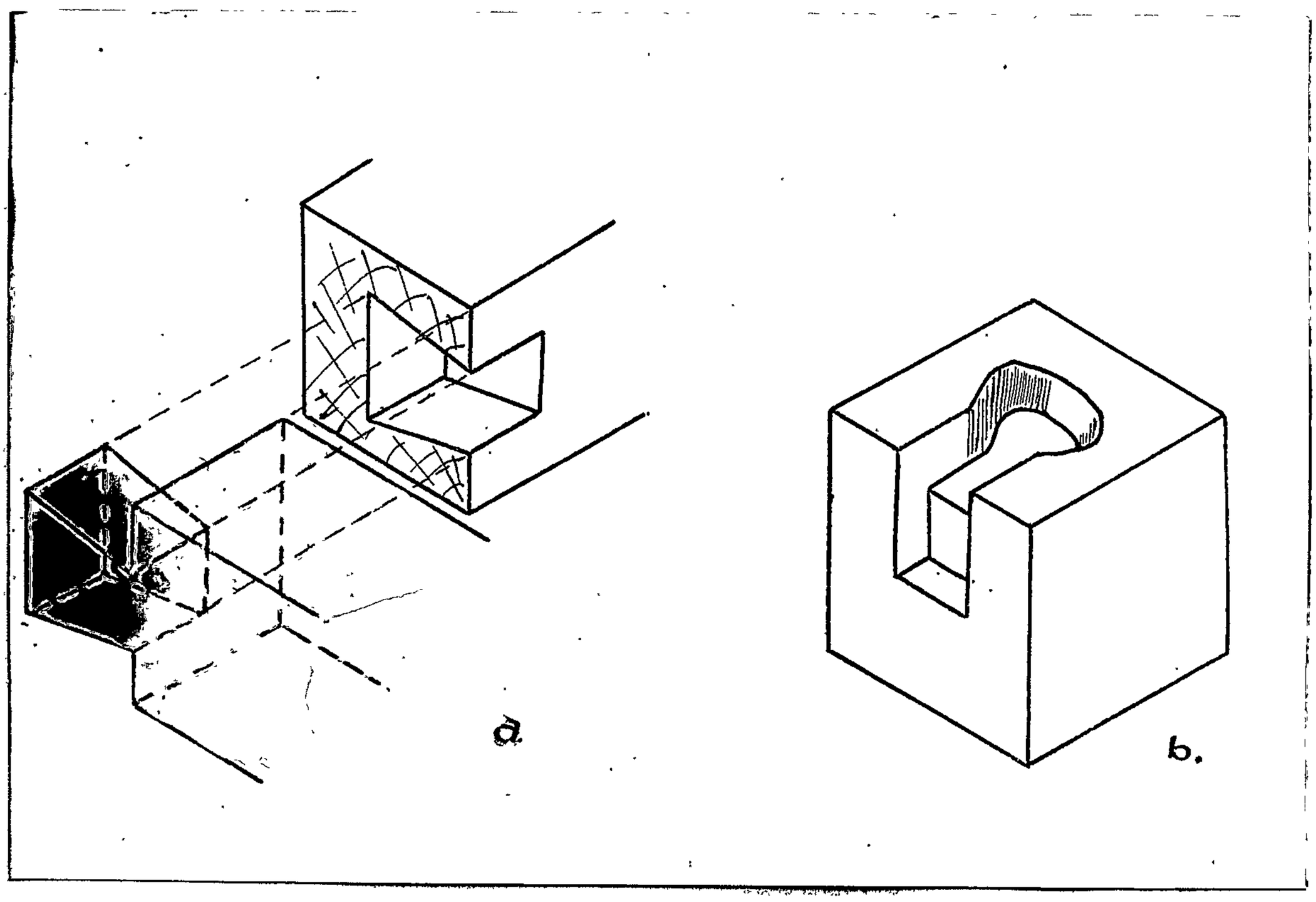


Fig. 41.

plus the adhesion of the cement is probably equal to that of the grooving.

There are numerous other joints used in woodworking which utilize the principle shown in the double lap or mortise and tenon among which may be mentioned notching, Fig. 39 a, double notching, Fig. 39 b, and cogging, Fig. 39 c. Rotation of the cut member in the notching may occur in a horizontal axis and this has been overcome by introducing the box form to both members in double notching and cogging.

V. The groove tongue and mortise, Fig. 40 a. This type of joint is used for end grain joints and uses a supplemental groove in the one member; its replica in cavity preparation exists as a two surface preparation or single step using supplemental grooves in the floor of the occlusal step, Fig. 40 b. This form is an advantage when the retention form of the occlusal step cannot be obtained because of extensive caries of the proximal marginal ridge, Fig. 40 c. A groove, if necessary, can be cut in the gingival floor in addition to the one in the occlusal floor, Fig. 40 d. This gingival groove is advocated by McMath (36) and others. The danger of using this gingival groove alone would seem to be in that the masticatory force has a large mechanical advantage over any resistance supplied by the small gingival wall which may collapse under stress; this gingival groove alone should not be depended upon for any resistance to masticatory stress; it may be helpful in holding the wax used for the inlay 'pattern' in close adaptation with the cavity at this position during chilling of the wax, and so increase the probability of an accurate gingival contour for the inlay.

V1. Lap dovetail. This type is another end grain joint using the form of a dovetail tenon on the one member; the mortise, however, is not cut right through the timber as in the single

(36) McMath J.F. Dental Cosmos, Vol. 67, Dec. 1925, p. 1162.

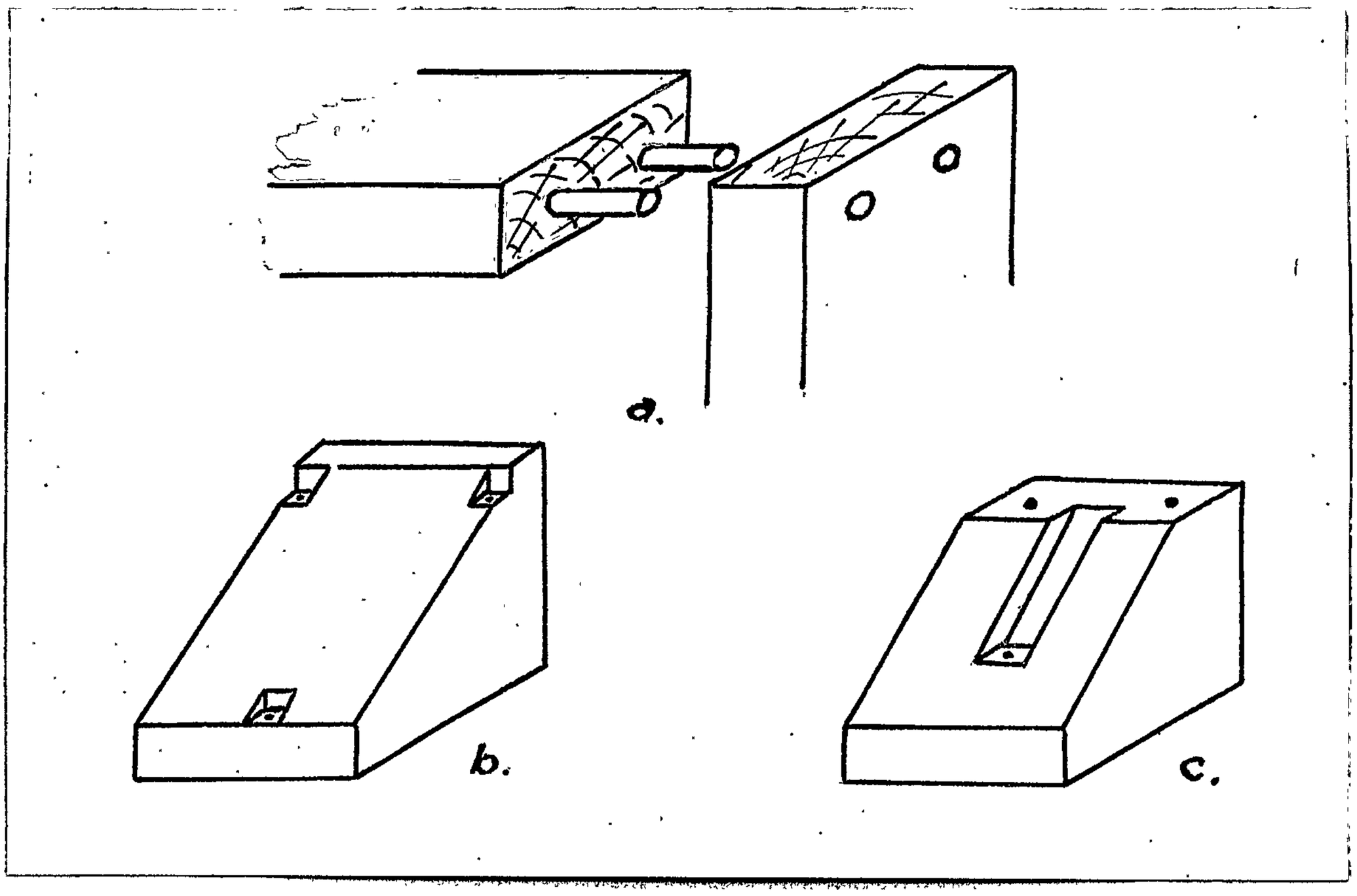


Fig. 42.

Fig. 42. b. Pin-ledge. c. Pinlay.

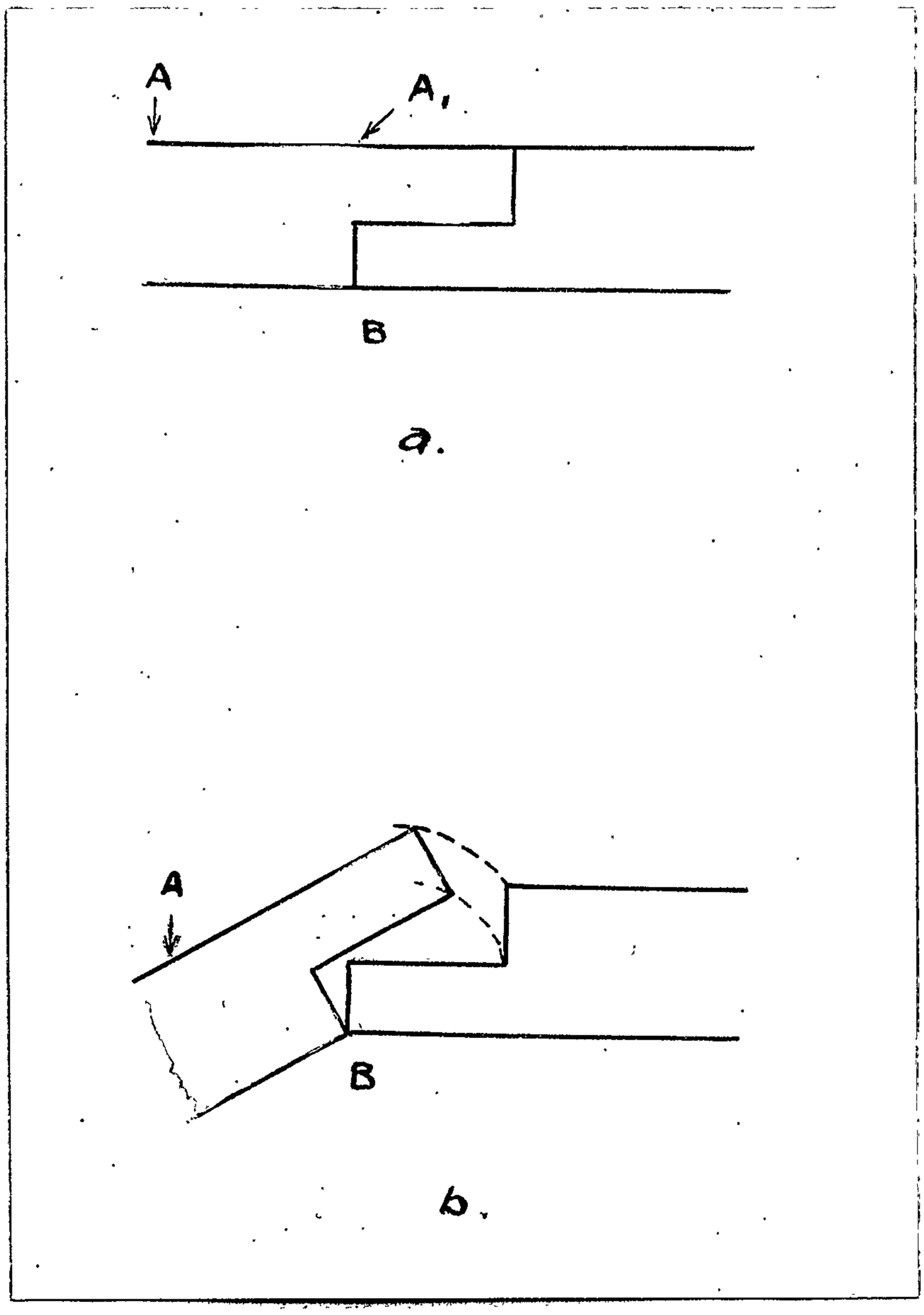


Fig. 43.

dovetail, but is left short of the surface, Fig. 41 a. This form when used with a shoulder has its replica in the single step, orthodox type of two surface preparation or Black Class 11 cavity (37), Fig. 41 b, cf. Fig. 37 b.

V11. Dowelled joint. In this type of joint, union is effected by using dowels or wooden rods glued into one member so that some length is allowed to project, Fig. 42 a, holes are drilled in the other member to correspond with and receive the dowels, the union being effected by glueing the two pieces together; nails and screws have a similar principle for retention. The method has a wide application in inlay restorations and is found in the pinlay methods of Pincus and the pinledge of Burgess (38), the replica in tooth form being shown in Fig. 42. b, c; it seems to have a particular use where large portions of tooth structure have been lost and the presence of the pulp limits the cutting for 'box' type of retention form.

The basic principle of retention in each type of joint, except that of the first type, i.e. the halving, would appear to be as follows. When two pieces are cut so that they may be brought together to form a joint, the one portion or positive, which receives the other portion or negative, is so formed that the negative can enter in one direction only; movement after the negative is actually in position can only follow in a direction opposite to that of insertion, the cementing medium being depended upon to prevent this latter movement.

Fig. 43 a. shows the simple lap joint (in cross section) in which movement may occur in at least horizontal and vertical directions, rotation also follows, as shown in Fig. 35, about the base line or gingival margin. If pressure is applied at A or if some force having a similar effect is applied in the direction A, Fig. 43 a, rotation about B follows and the negative portion

(37) Black G.V. "Textbook of Operative Dentistry", Vol. 2, 6th Ed., p. 117.
(38) Burgess J.K. Dental Cosmos, Dec. 1915, July 1917.

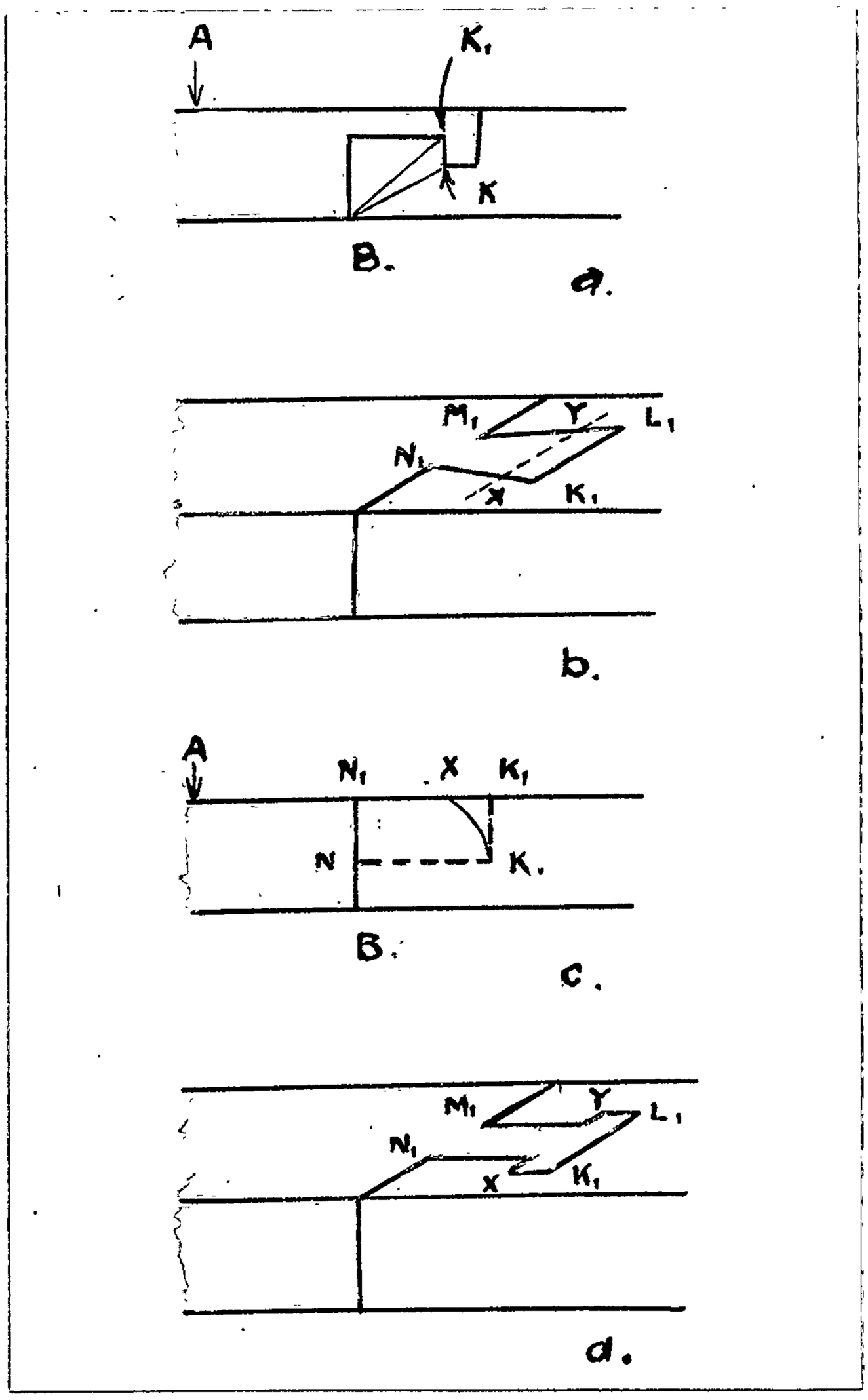


Fig. 44.

takes up a position as shown in Fig. 43 b, until with further application of the force, the negative is completely dislodged. In addition to the use of a cementing medium, this defect in retention form has been overcome by three methods in the other types of joints.

1. By increasing the vertical dimension of the extremity of the negative portion and cutting the positive portion to accommodate this increase.

11. By increasing the horizontal transverse dimension of the extremity of the negative portion and cutting the positive portion to accommodate this increase.

111. By using dowels in the negative portion received by holes in the positive portion, the result being somewhat similar to 1.

In the first method a groove is cut across the positive portion thus placing a wall KK1, Fig. 44 a, on the rotation path and in a position opposed to the direction of rotation. If pressure is applied at A, rotation about B is prevented by the wall KK1 because radius BK is less than BK1 and therefore the arc followed by K would pass through the material forming the wall KK1. Wall KK1 also prevents movement in a horizontal direction, so that this type of joint can be considered as satisfying the demands made upon it.

Instead of the groove, a dowel (method 111) could be used but may require greater depth for efficient resistance to movement. With the second method an increase in transverse width is made at the points K1L1, Fig. 44 b, so that the walls L1M1 and K1N1 of the negative form converge as they approach the main mass. Because the materials have thickness the negative form has a similar outline within the joint and if the walls are at right angles to the surface the same area will be found in the base of the 'box' in the positive form. The base is designated NKLM to correspond with the external outline. Fig. 44 c. shows a side elevation of the joint. If pressure is applied at A so

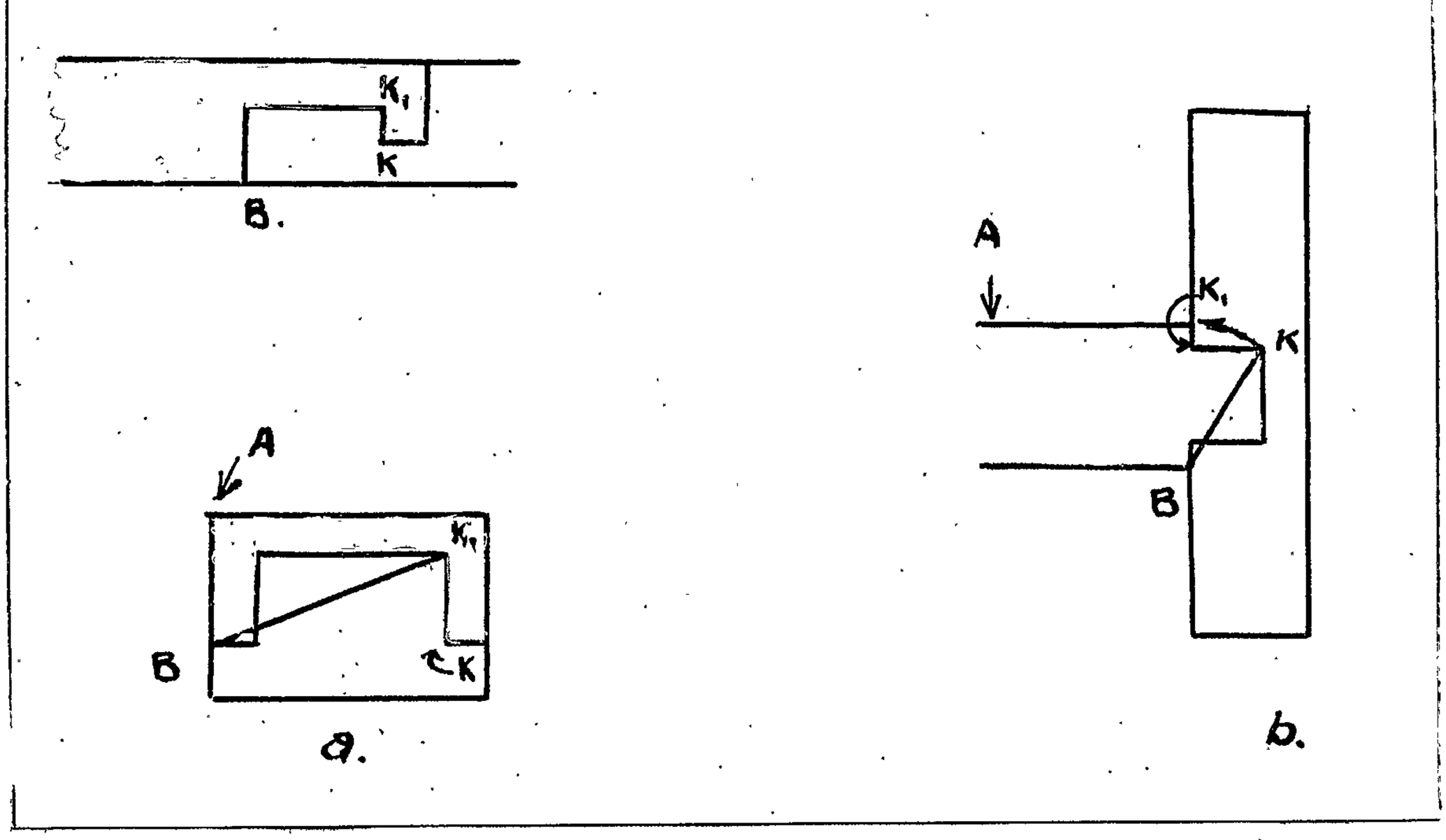


Fig. 45.

that rotation tends to occur about B, K would move to some position X. Since KL =K1L1 the width across the joint at X, Fig. 44 b, must be equal to K1L1 to permit this movement, but the walls L1M1 and K1N1 converge so that the distance M1N1 is less than the distance L1K1, so that K cannot move to X. Similarly L cannot move to Y, therefore rotation about B is impossible. Further, because the walls K1N1, L1M1 converge, movement in a horizontal direction by the negative form is impossible, therefore this type of joint can be considered as satisfying the demands made upon it.

If the walls of the positive form diverge in a vertical direction so that the mortise is a 'hopper' form, then rotation about B might be possible with a very shallow and open mortise form; to overcome this tendency to rotate, the walls L1M1 and K1N1 should be made to converge rapidly so M1N1 is very much reduced; if this cannot be done the modification shown in Fig. 44 d. may be used.

The open mortise and tenon is an extension of the principle outlined in method 1, and is shown in Fig. 45 a.

The stump mortise and tenon and dowels may be considered to be more efficient because less material is removed for their preparation, and if adequate depth of the stump or the dowel is obtained so that the mechanical advantage of the dislodging force is reduced, a further increase in efficiency may be expected. Fig. 45 b. shows the stump tenon, pressure at A tends to cause rotation about B, radius BK is longer than BK1, therefore wall K1K prevents rotation about B. This is true for any length of K1K, but in practice the greater the length of K1K the more efficient the retention. If the length of K1K is very short, then great accuracy of fit must be obtained to have any retention.

From this study of the retention principles it would seem that the box form of adequate depth is a most important feature and modification of the box by means of grooves, dovetails,

pits etc., arranged so that they overcome any tendency to movement by the parts is freely undertaken to improve retention.

These retention aids coupled with the mechanical principles of the levers can be and are used for the retention of gold inlays in the teeth. The complex contours of the teeth do not complicate the problem, other than in certain positions, except to limit the amount of material available to support the inlay. Because of this limitation the form of the cavity, the relationship between the various walls, and the cutting of the angles must be precise. The cutting of tooth structure must be conservatively carried out to minimise trauma to the pulp, both during cutting and in designing the cavity so that the metal will not be placed too close to the pulp. The need for this pulp protection and the aesthetic demands are the most frequent reasons for modifications in the design of the inlay cavity, and sometimes, in the substitution of another type, if a change is contemplated, knowledge of the limitations and capabilities of the various designs is helpful in the selection of the type of design most likely to withstand stresses which come upon it and at the same time efficiently to restore the defective surfaces.

This study of mechanical factors involved in a few joints would appear to support Gowan's (39) contention expressed in this statement "The interior dimensions of a cavity (inlay) may so far as the strength of the filling itself is concerned be smaller for an inlay than for a foil ..... an inlay being a single rigid piece is supported by the whole area covered by it; its hook-like hold in the occlusal portion of the cavity is much stronger than that of a foil filling, so that unless much dentine is lost by caries little gingival wall is needed to support the inlay against occlusal stress".

(39) Gowan W.C. "Science and Practice of Dental Surgery", Bennett, p. 424 et seq.

SECTION 1V.

The good qualities which should be found in an efficient inlay design may be grouped as follows:-

1. Aesthetics demand that the outline of the cavity should be pleasing in form so that there will be displayed neither too much nor too little gold on those surfaces which can readily be seen.

11. The outlines of the cavity should be so arranged that they will occur in areas readily cleansed by the passage of food across the junction between gold and enamel, and also that this junction will be readily reached by the bristles of the toothbrush.

111. The design should be one that will make possible the permanent retention of the inlay in its position.

1V. The design should also be one which is arranged to give support to the tooth structure from which it derives its retention, so that its resistance form is a maximum.

V. The design should be one in which are found the above necessary good qualities and at the same time, the vitality of the pulp should not be endangered by operative and post-operative trauma so that longevity of the tooth as an efficient organ may be assured. This important demand necessitates economy in cutting and removal of tooth structure.

This last requirement may be more easily satisfied by the use of an inlay than by other methods; because of the strength of the casting, the retention form and resistance form can be kept well within the required outline and cut to an accurate shape. The extension of the inlay to the 'relatively immune areas' of the teeth is obtained by thin wedge-shaped projections from the main bulk. The inlay permits the use of a much longer bevel which favours the use of 'slice' preparations where possible.

In the preparation of cavities for inlays the general steps of procedure viz: outline form, resistance form, retention form and the preparation of walls and margins should be followed, although quite often retention form will be linked up with

resistance form, and the attention bestowed upon the preparation of the margins of the cavities for other types of restorations should in no way be diminished but rather increased in order to permit the easy withdrawal of the thin wax extensions of the inlay model. The particular process of inlaying, whether applied to dentistry or not, demands that the cavity shall be shaped so that the inlay can be readily and accurately placed in position. In the case of the cast gold inlay, the process also demands that the shape of the cavity be such that a wax pattern or model of the finished inlay can be withdrawn from it without the possibility of distortion. To permit this, the walls of the cavity must be designed so that they are parallel to or slightly divergent from the common plane of direction of withdrawal of the wax. The more nearly the walls approach a parallel with this plane the greater the mechanical value of the design; but the diverging walls ensure greater safety in the removal of the wax and may permit of greater adaptation of the finished inlay to the cavity walls. The degree of divergence of the walls is most satisfactory when the angle they form with the seat of the cavity is just slightly greater than a right angle (40). The contour of the tooth, presence or absence of defects in the enamel, the strength of the enamel walls, the line of cleavage of the enamel, the proximity of adjoining teeth may require a greater inclination of a wall or part of a wall in order to meet the above conditions in various cases. Black (41) says "resistance form is that shape given to a cavity intended to afford such a seat for the filling as will best enable it to withstand the stress brought upon it in mastication", it follows then that the greater the number of functional demands made upon a tooth the greater the efficiency required in the resistance form of the cavity prepared to receive a restoration to its defective surfaces. The greatest

(40) Volland R.H. "Cavity preparation for Cast Gold Inlays". Journ. of the A.D.A., March 1927, pp. 472.
(41) Black G.V. "Operative Dentistry", Vol. 11, p. 112.

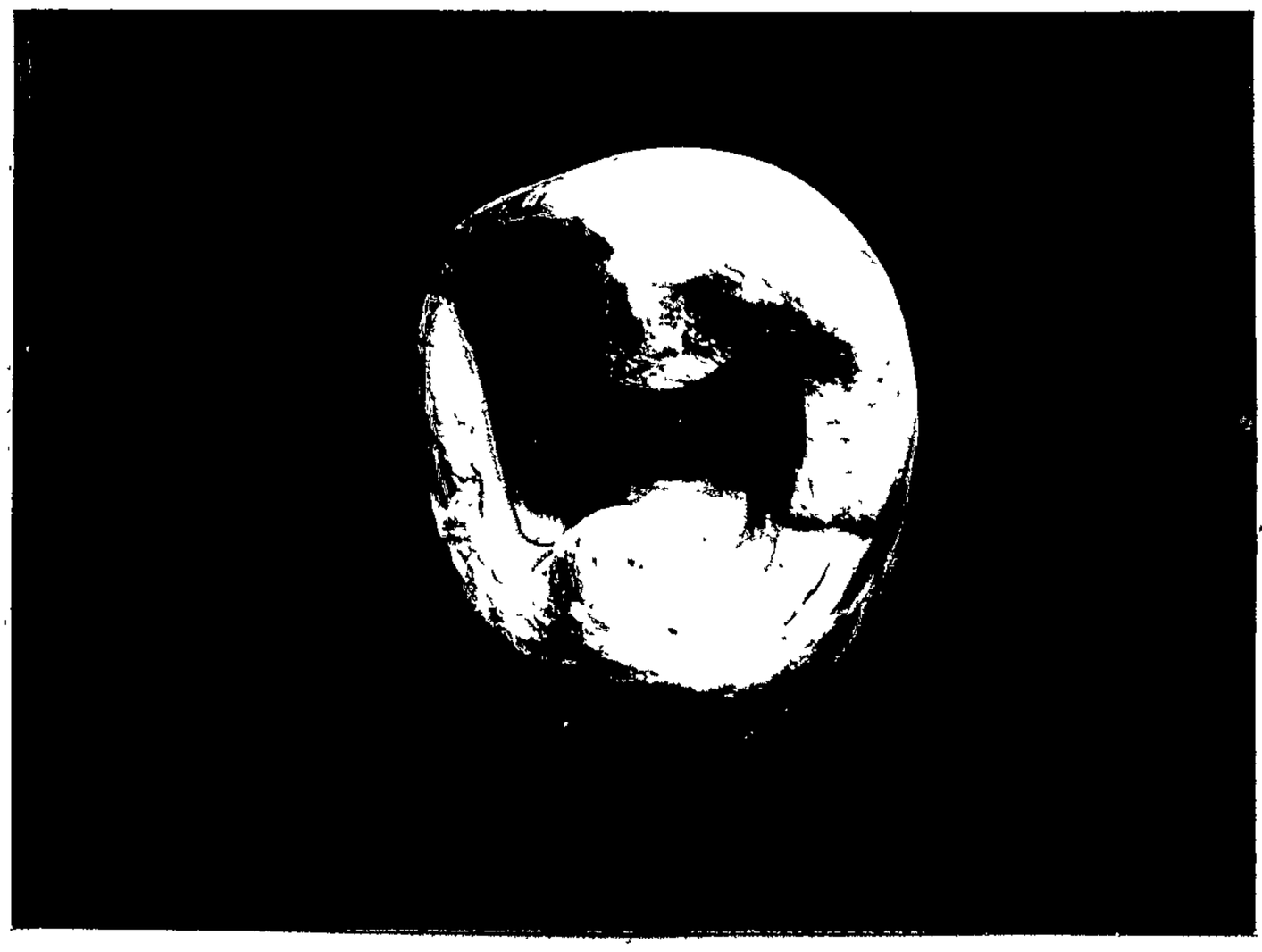


Fig. 46.

Fig. 46. Photograph of a simple box cavity in the occlusal surface of an upper bicuspid.

a.

b.

Fig. 47.

resistance to a thrust is gained by directly opposing it with a flat wall. Where the thrust tends to promote a tipping of the restoration, the use of a flat wall opposed to the direction of movement and placed on the 'tipping path' will neutralize these undesirable movements. The use of this wall is not possible in all inlay cavities and occasionally other forms such as dowels, dovetails, grooves and posts assume the main or supplementary retention form. These forms used in conjunction with certain mechanical factors which have been discussed, will satisfy most of the demands which occur.

The following designs have incorporated in them the mechanical characteristics which have been discussed in the previous sections.

1. Simple box cavities which are prepared to restore defects on smooth surfaces and in developmental pits and fissures, see Fig.46.

These types are best cut so that the 'hopper' form is reduced to a minimum; the outlines should be simple and the floor cut flat, although Chayes (42) advocates the use of floors which slope from the centre to the line angles of the cavity; either the pulpal or axial wall is then higher in its centre than at its periphery. Increased retention may be obtained by the use of grooves on the walls of the inlay, as is done with proximo-occlusal and other forms of inlay, cf. Fig. 38.

11. Posted inlays, Fig. 47 a. and b.

In these types of inlays generally little structure remains in the tooth which has lost its vitality, and therefore little help is likely to be obtained from the coronal remnants to retain the restorations. Two methods have yielded favourable results with this type of work and they have been designed to overcome the tendency of the inlay to rotate about an axial plane. Fig. 47 a. shows the use of a recessed supplemental wall cut around the root canal and the outline of the recess formed by this

(42) Chayes H.E.S. "Technic & Scope of Cast Gold Inlay", p. 76.

a.

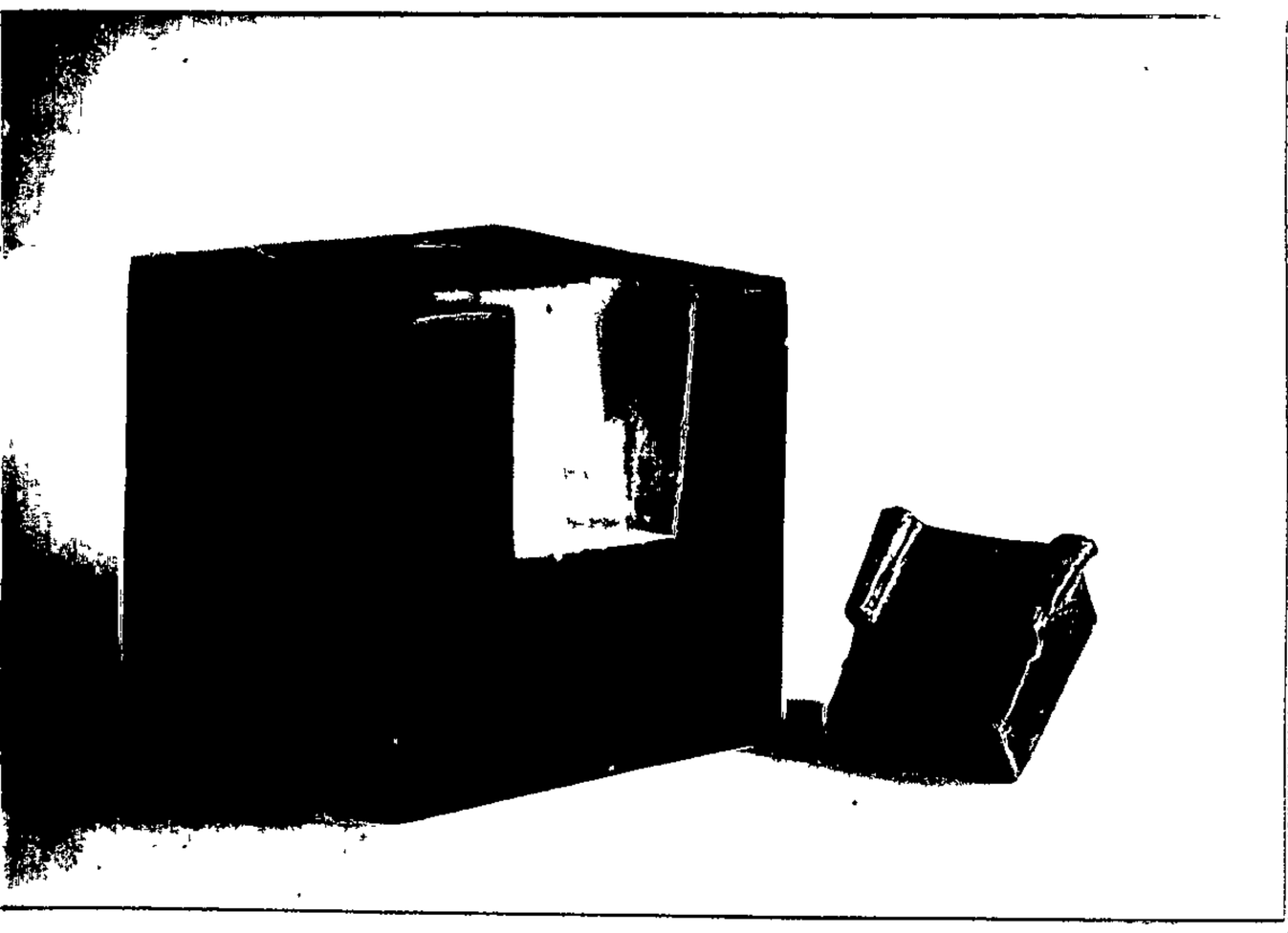
b.

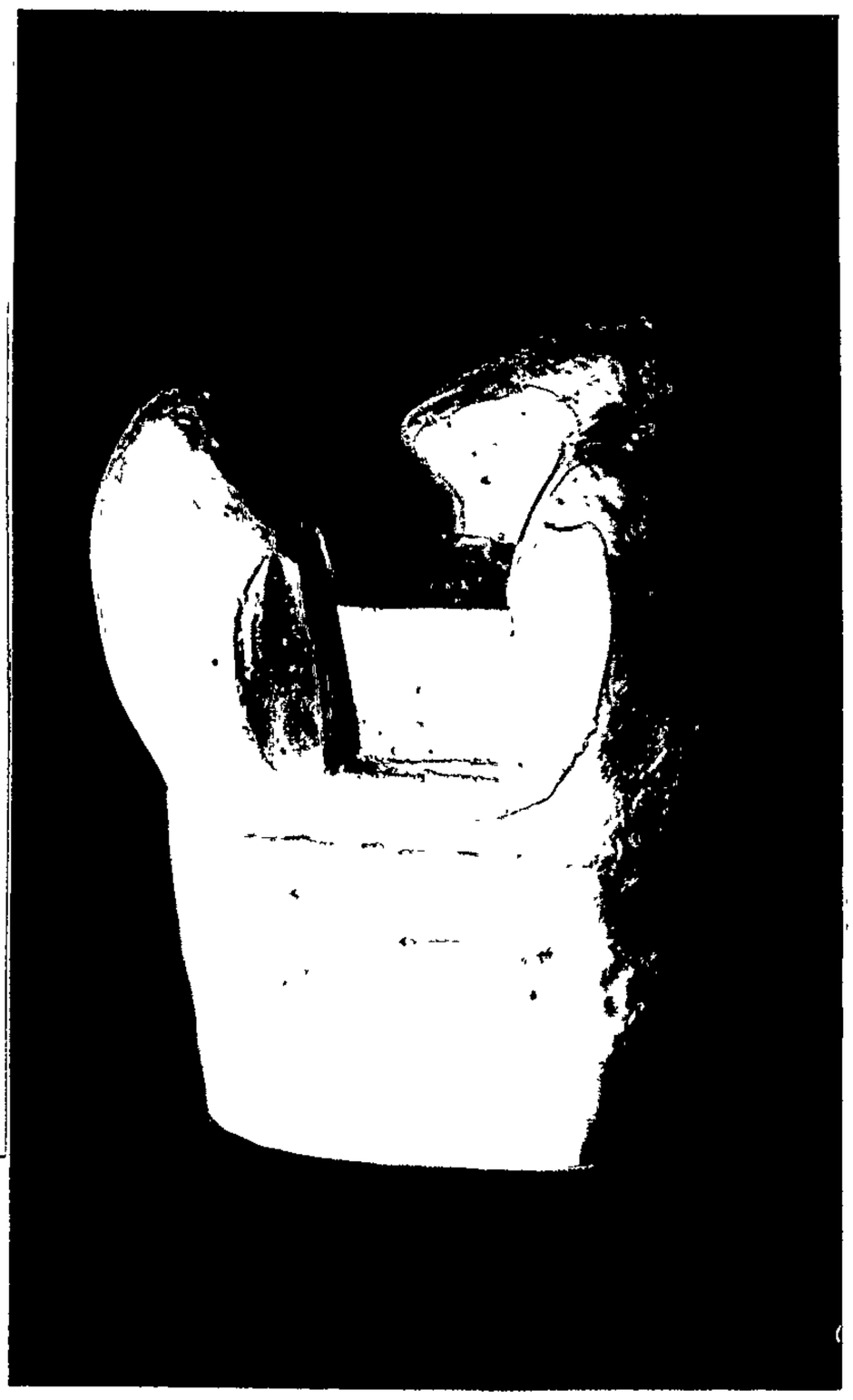
Fig. 48.

wall should be approximately rectangular. Fig. 47 b. shows the use of a slice cut diagonally from labial to lingual so that the post may be arranged to enter the canal directly from the incisal aspect, a small portion of the cingulum and marginal ridge being retained to form the supplemental wall to prevent rotation. The large bulk found in the posterior teeth readily permits of the adaptation of these two methods to similar conditions in those regions. An examination of the mechanical principles involved in retention will show that a Class 1 lever system is incorporated; the gingival margin is the fulcrum with a work and power arm arranged on either side, cf. Fig. 20. Additional retention may be obtained by serrating the post, but if the post fits the root canal closely this is an unnecessary complication.

111. Pinlays and Onlays. Fig. 48 a. and b.

These types are used to advantage where incisal edges or cusps are being restored. The preparation on the tooth surface is very simple and requires a minimum of cutting, the surface being made a plain surface and holes or pits are sunk at convenient points to receive projecting pins from the casting. The pits should be wider at the surface than at the base, thus permitting more accurate insertion of the wax for the pattern and also of the finished casting. The principle is the dowel principle and has a greater efficiency when the pits are cut as deeply as the pulp will permit. The depth improves the retention as far as lateral rotation is concerned and also helps to overcome the possibility of dislodgment when traction force is applied to the occlusal surface; this traction force may at times be very real, especially when some glutinous material has been crushed between the teeth and the jaws have been rapidly separated, then the possibility of dislodgment of the onlay or pinlay is not remote. Fig. 48 a. shows the restoration of an incisal edge and angle of an upper anterior in which much of the labial tooth structure is kept for retention as well as for aesthetic purposes.





a. b.

Fig. 49.

Fig. 50.

Where heavy stresses occur, such as on the upper canine, the importance of the use of a wall to oppose stress is very necessary. Fig. 48 b. shows this type of cavity. The closer the pits are made to the gingival area the greater the increase in the mechanical advantage of the pins of the casting.

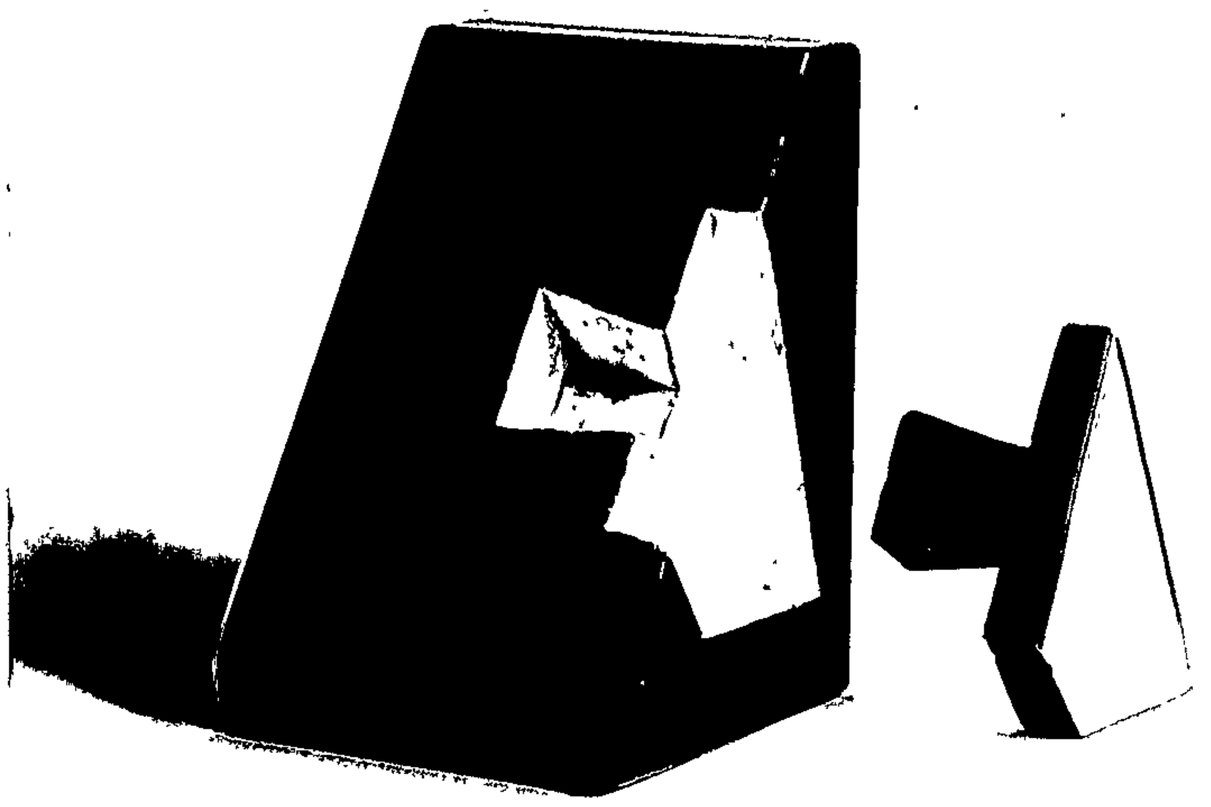
This type is readily adapted to posterior regions where broad flat surfaces can be prepared and pits widely spaced.

1V. Dovetails.

These types of cavities are developed for small restorations and are limited in their application; they are used for small proximal cavities on the anterior teeth and on the lower bicuspids, and occasionally, when developmental pits and fissures are not extensive, other teeth may be suitable for these cavities, otherwise full extension to 'immune areas' is essential.

Fig. 49 a. shows the geometric form for these dovetail inlays; an open cut is made from the occlusal with sufficient extension buccally and lingually, the retention is then developed by means of grooves cut along the junction of the buccal and lingual walls with the axial wall. The 'inlay' is shown at the side of the model and the extent of the grooving of the line angles is seen. Instead of the grooving the axial wall may be extended buccally and lingually. Fig. 49 b. shows this type applied to a bicuspid tooth, the extension in the proximal portion having been obtained by 'slicing' the tooth; a modification is shown in this form which has introduced a 'step', thus reducing the bulk of the metal close to the pulp, and the retention has been gained by a minimum of cutting at the expense of the buccal and lingual marginal ridges. The type and its modification is generally useful for lower bicuspids.

Fig. 50 shows the dovetail form used for the proximal surface of upper anterior teeth, the line of insertion being from the lingual with the incisal and gingival walls converging as they approach the labial aspect. The inciso-axial and gingivo-axial



a. b.

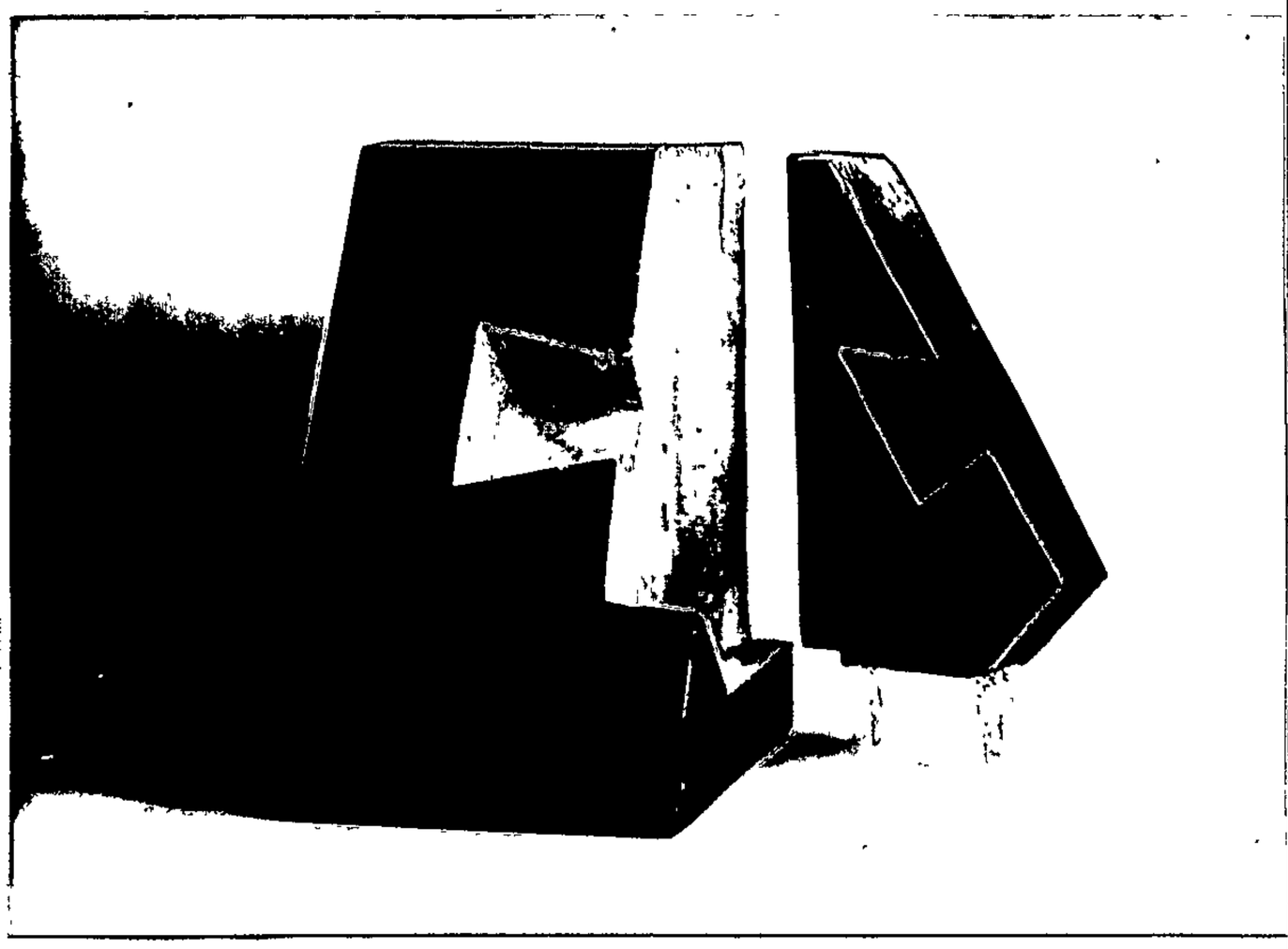
Fig. 51.

line angles are grooved, the grooving being deeper in its lingual region and the extension being obtained by a long sweeping bevel towards the incisal and gingival regions. The direction of stress on this restoration is upon the marginal ridge, and rotation of the restoration would tend to occur about the gingivo-labial angle; in Fig. 49 b. the axis of rotation is about the gingival margin. Rotation has been prevented in both cases by the placing of grooves on the 'tipping path'.

The advantage of this type of cavity is in the reduction of the internal area and angles, the formation of a shape with a compact bulk in the wax and hence in the casting; an improved result in casting may be expected with a minimum of distortion between the wax and finished inlay stages. A further advantage is the reduction in the bulk of metal close to the pulp, cf. Fig. 51; this latter form possesses the orthodox type of step retention form and is in more general use because of the necessity to relieve any stress bearing unduly upon the incisal portion of the tooth.

V. Lingual lock. A.

This form shows the fundamental principles of retention as applied to all anterior restorations for proximal defects in which for aesthetic reasons it is desirable to display a minimum amount of gold. The axis of rotation of this inlay is in the gingivo-labial region and the lever system belongs to the Class 11 type, rotation under stress being prevented by the dovetail step; so that really this type of inlay form comes under the step group which is discussed later. A comparison of the geometric forms of this type and the step group, see Fig. 57 a, will confirm this and the principles of retention are those discussed on pages 59 and 61 and illustrated by Fig. 44. The discussion of this type here is introductory to the larger lingual lock form which exhibits a more complicated mechanical system. As in the



a. b.

Fig. 52.

Fig. 53.

specifications set out for inlays, q.v., the retention and resistance form is kept as small as possible and extension is obtained by means of a broad bevel, Fig. 51 b; the geometric form shown in Fig. 51 a. has opposing labial and lingual walls with a gingival wall joining, and where possible this form improves the retention.

V1. Lingual lock. B.

This form shows the extension of the inlay to involve the restoration of the incisal angle; this extension introduces the problem of the Class 111 lever. With masticatory stress applied to the incisal portion, the axis of rotation is found at the gingival margin (Fig. 22), the power arm is relatively short and therefore the mechanical advantage of the masticatory force is correspondingly increased, and the cutting of the retention form must be accurate so that movement under the influence of this force is neutralized. As in the previous type, an attempt has been made to preserve as much material as possible to form labial and lingual walls, Fig. 52 b; the geometric form with the inlay rotated out of the cavity, Fig. 52 a, shows this more clearly, and where possible, this labial wall should be retained so that tendency for the inlay to move under a force from the lingual is neutralized, and the strain that would otherwise be taken by the step is removed. This is a disadvantage which is found in the form shown in Fig. 53. Where a plain slice is made on the proximal surface, any gross defects are filled in with cement and the slice is made straight through from lingual to labial. In this form, there is no gingival wall and no factor to prevent rotation by a force exerted from the lingual, other than the walls of the lingual step which are, of necessity, very small compared with the long arm over which the force of mastication acts. The result may be that the torque action is sufficient to dislodge the inlay from its seat, but the advantage of this form is the protection afforded to the pulp from thermal

Fig. 54.

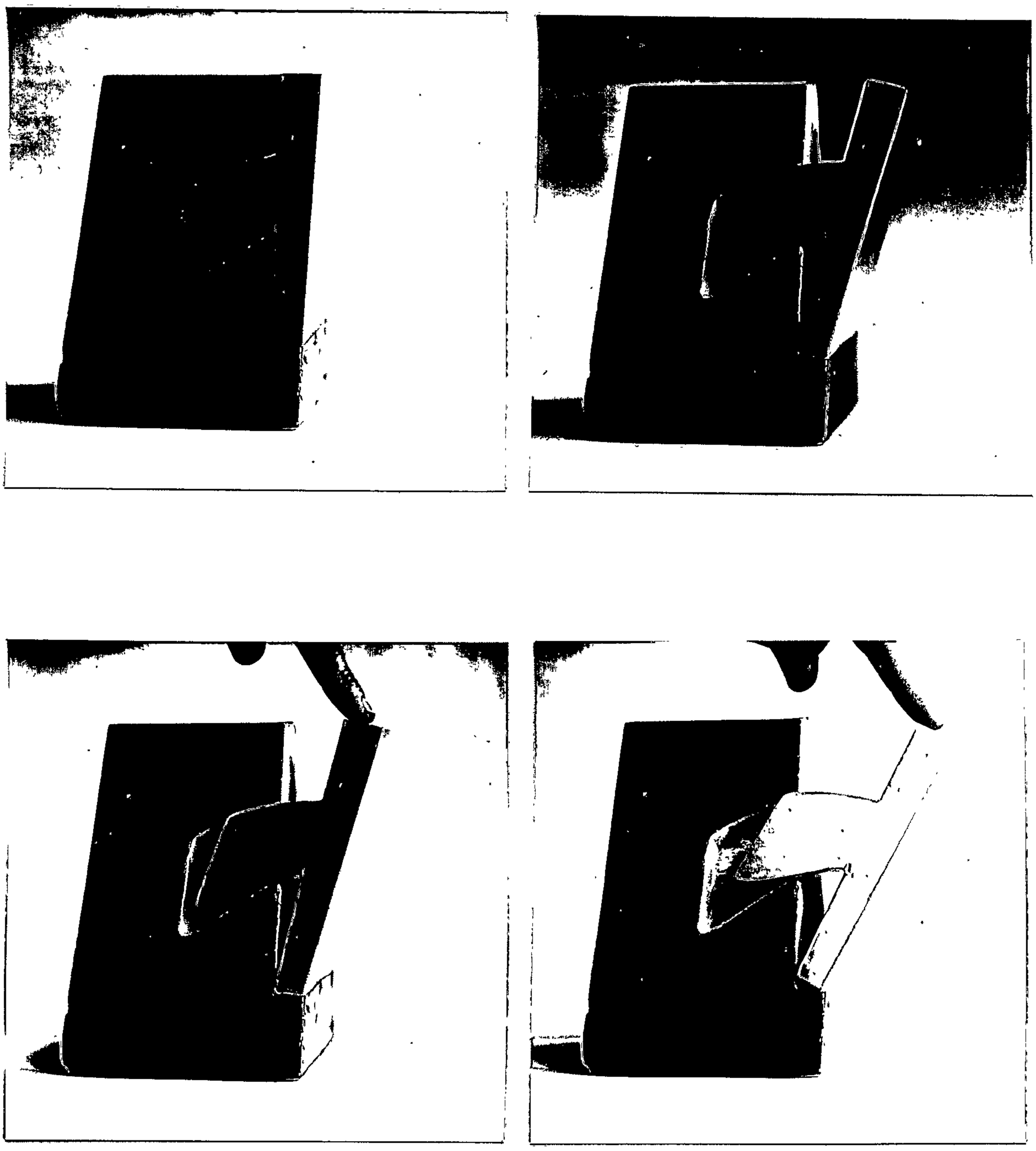


Fig. 55.

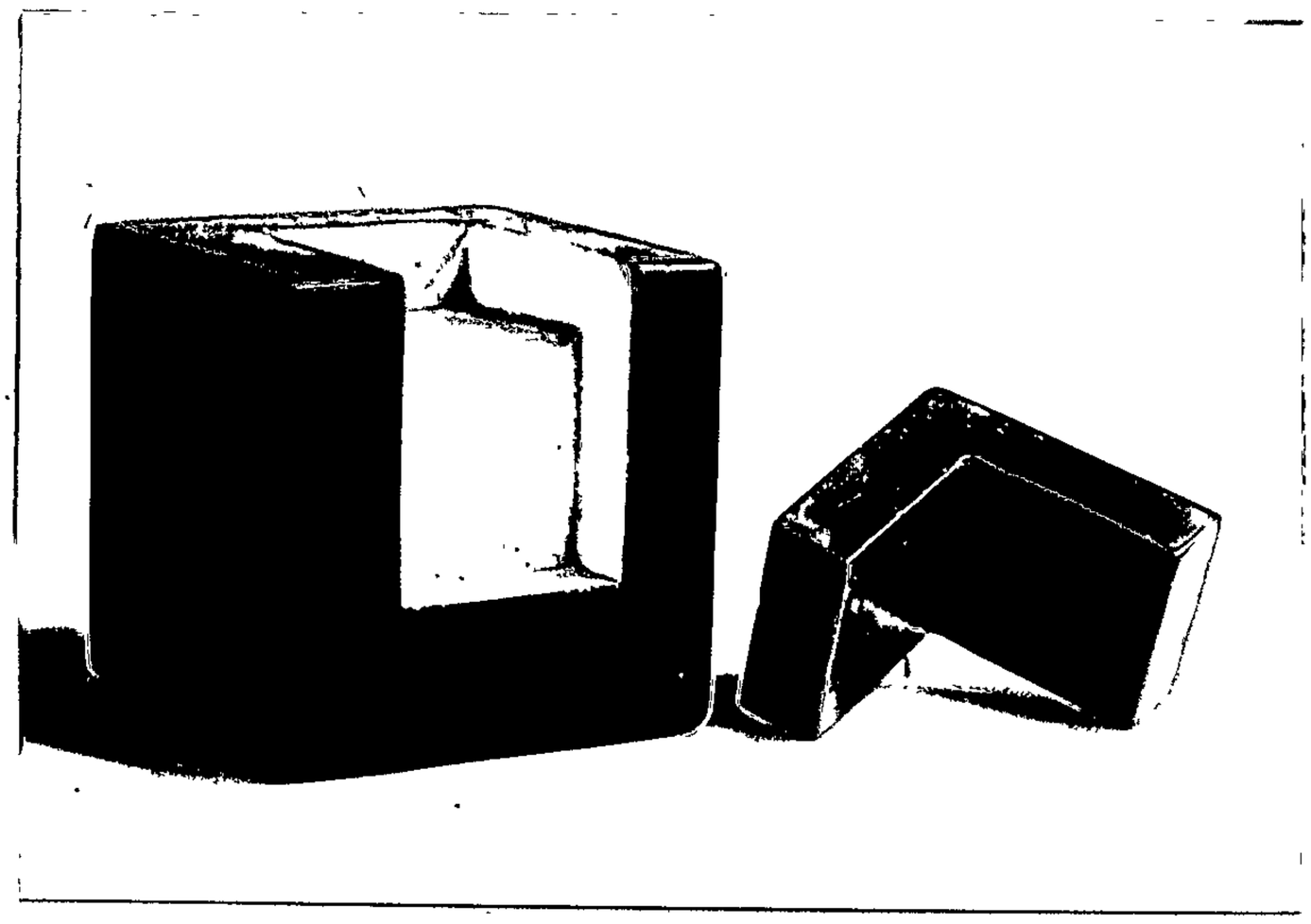
shock, the ease and speed of preparation in the tooth and the probability of a more accurate casting result because of the simpler contours. A secondary feature in this form and in the preceding one is the development of a bevel on the incisal edge, so that the enamel in this region may have some protection.

Fig. 54 shows a modification which may be resorted to when extensive caries has caused loss of important areas of the tooth structure. An extension of the step is made into the cingulum, a short dowel is placed at the base of the cingulum and cutting of the cavity is arranged to permit withdrawal of the wax more towards the incisal aspect. There is a danger in this modification due to the proximity of the pulp and care must therefore be exercised during cavity preparation.

Fig. 55 illustrates a very important feature of the lingual lock preparations and the value of a correctly prepared incisal wall of the lock. The length of the proximal opening to the lock is about three-fourths of its distal width but when a suitable force is applied to the incisal edge, rotation of the restoration about the gingival margin readily follows. The position of the gingival wall of the lock and of the inlay clearly demonstrate that these parts play no part in resisting movement of this nature. Fig. 27 demonstrated this point by geometric methods.

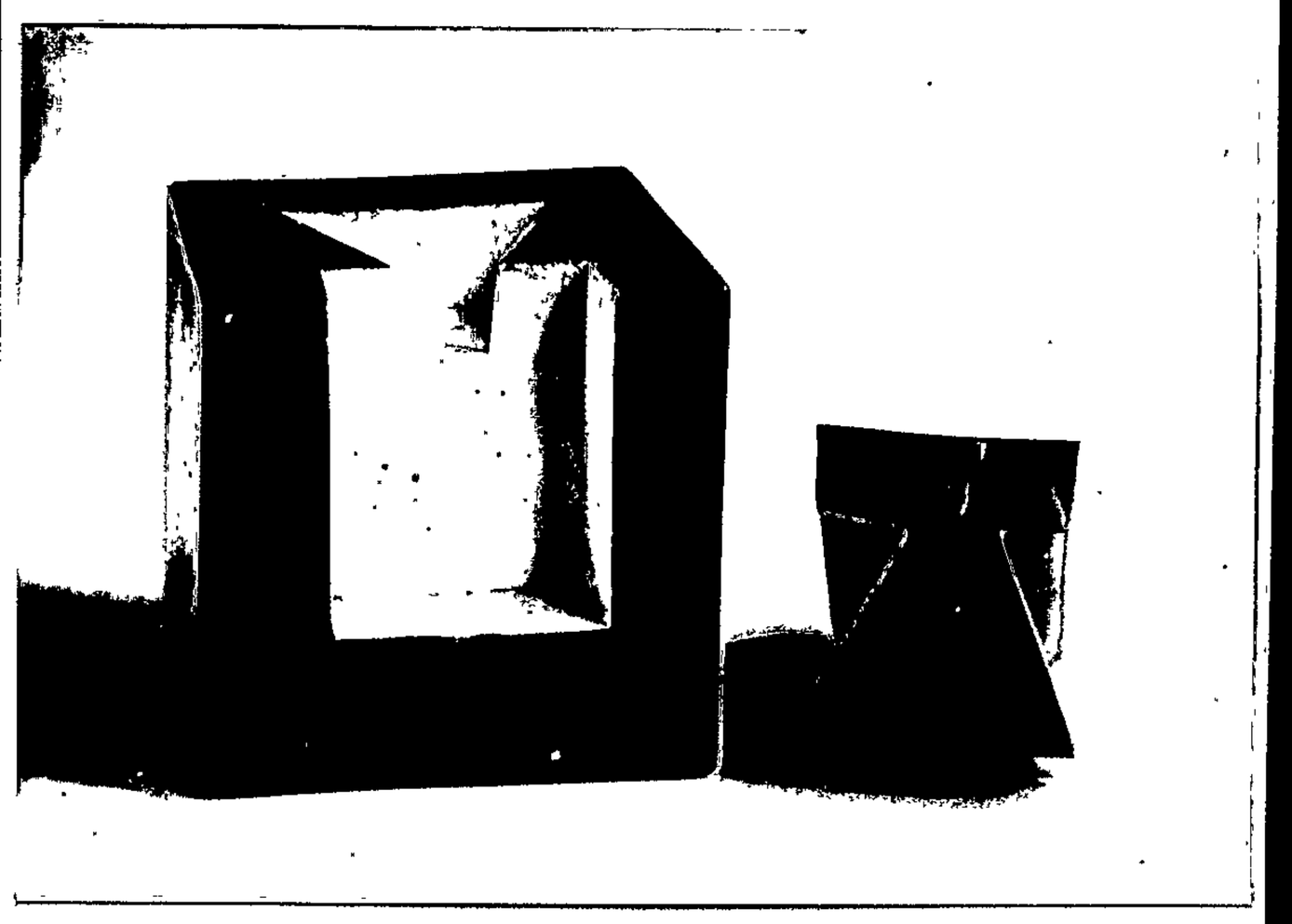
The position for the step so that adequate bulk can be given to it and at the same time protect the pulp by leaving sufficient dentine between it and the inlay, seems to be in the middle third inciso-gingivally (43). In cutting the cavities in practice it is better to restrict somewhat the degree of convergence of the incisal and gingival walls of the lock so that compensation for the distortion of the casting during shrinkage and solidification may be possible (44), (45).

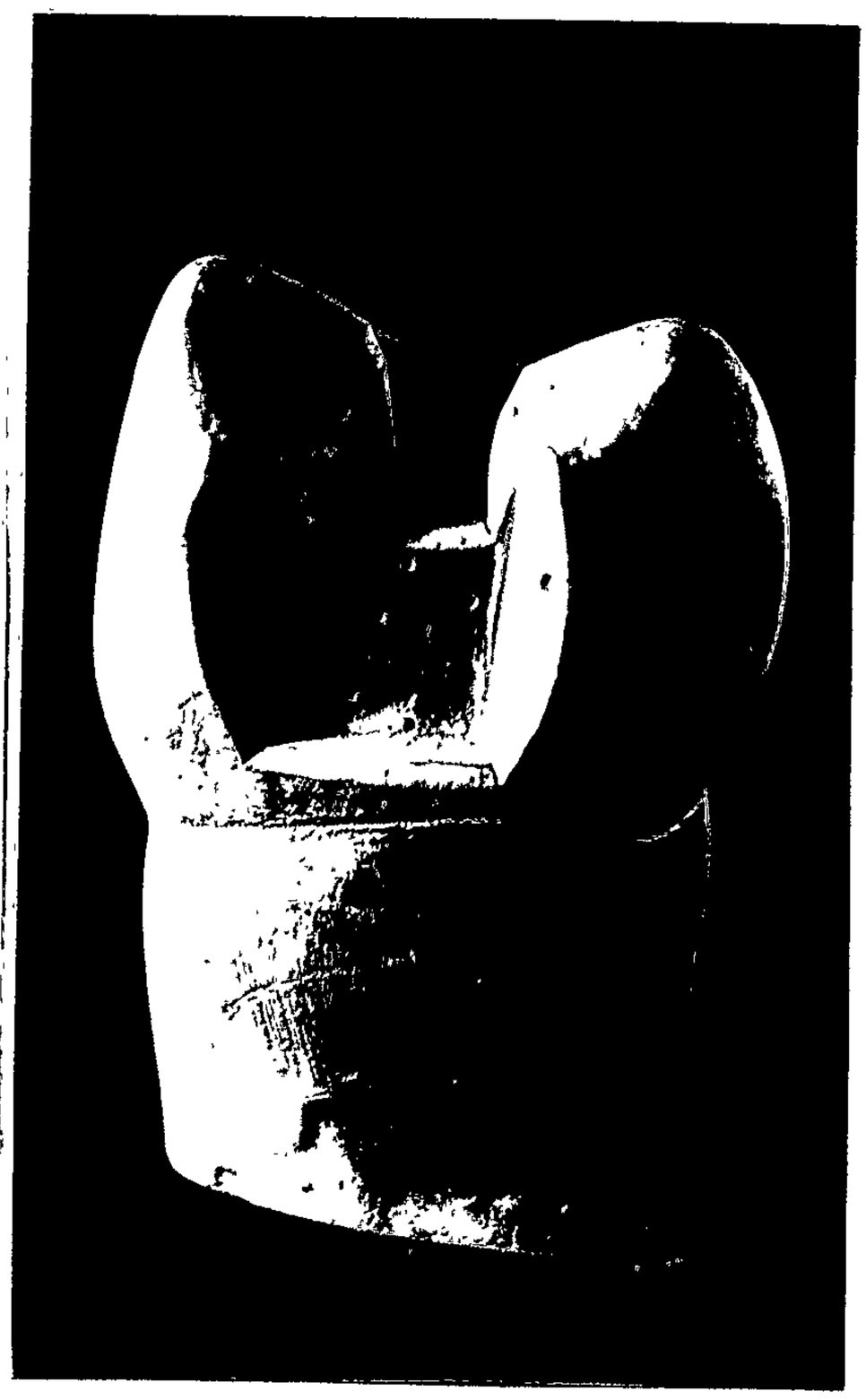
(43) Volland R.H. Journ. A.D.A., March 1927, p. 482.
(44) Campbell J. Dental Cosmos, Vol. 75, p. 553.
(45) Smith E.A. "Working in precious metals", N.A.G. Press, pp. 90.



a. b.

Fig. 56.





a. b.

Fig. 57.

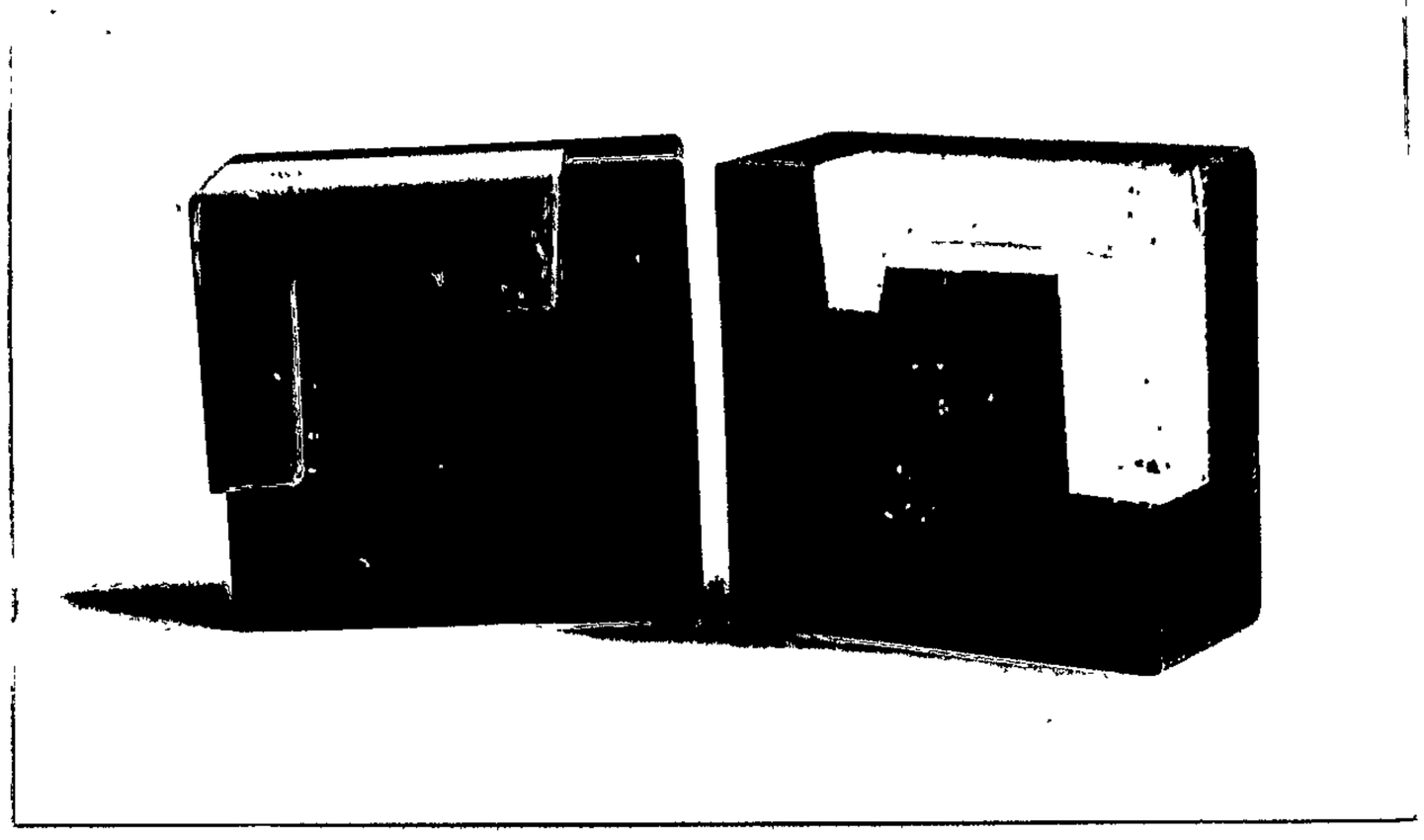
V11. Steps.

Grouped under this section are those inlay forms which consist of a step; they exist in proximo-occlusal, proximo-incisal, linguo-occlusal, and bucco-occlusal situations; the group is subdivided into Group 1 posterior and Group 11 anterior.

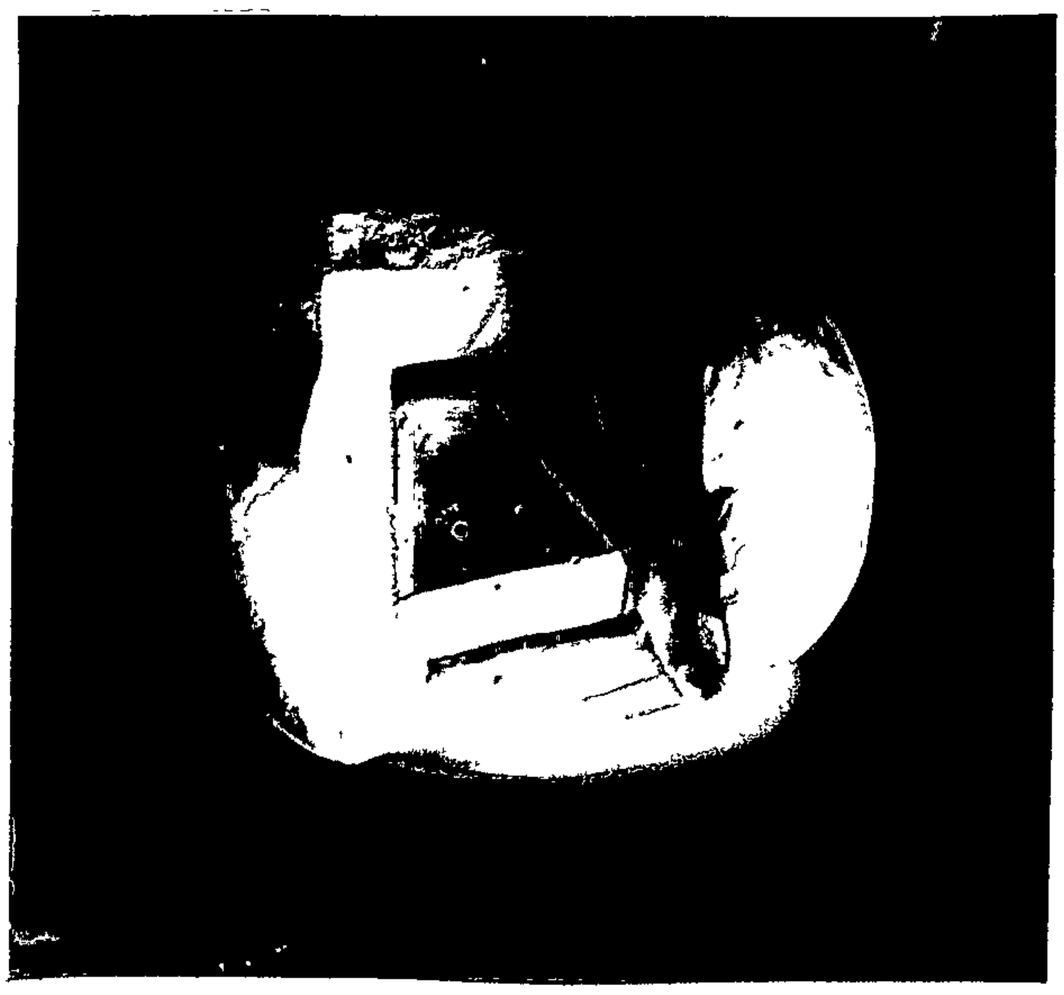
Group 1. Fig. 56 a. shows that the fundamental design of the lap-joint retention is gained by various modifications such as dovetails, supplemental grooves, and dowels. The axis of rotation is the gingival margin in this as in all other cases of the two groups, where retention is obtained by some form in the extremity of the occlusal or incisal step. Fig. 56 shows two examples of this step restoring occlusal defects and involving lingual and buccal surfaces; resistance to rotation is simple and is obtained from the angle at which the step meets the vertical portion and from sufficient depth in the occlusal portion.

Fig. 57 a. shows the use of the lap dovetail (q.v.) and is the fundamental principle underlying the retention form used for all proximo-occlusal restorations. Fig. 57 b. shows the use of the form applied to a bicuspid tooth where retention is obtained from the triangular ridges of the buccal and lingual cusps, extension of the proximal parts being obtained by the use of broad bevels. Where the proximal caries is more extensive and greater loss of the marginal ridges has occurred, the dovetail step is not always possible and the use of a transverse supplemental groove is of excellent assistance in improving retention in the occlusal step. McMath (46) has also advocated the use of a groove in the gingival wall which seems an advantage, especially if a soft alloy is used for the casting, the groove then preventing a spread of the gingival gold towards the proximal, but this is not of as great mechanical assistance as a groove in the occlusal step.

(46) McMath J.F. Dental Cosmos, Vol. 67, 1925, p. 1162.



a.



b. c.

Fig. 58.

Fig. 58 a. illustrates the geometric form for a step cavity using the supplemental groove in the occlusal step.
Fig. 58 b. An occlusal view of the cavity prepared in a tooth.
Fig. 58 c. A proximal view of the cavity seen in b.

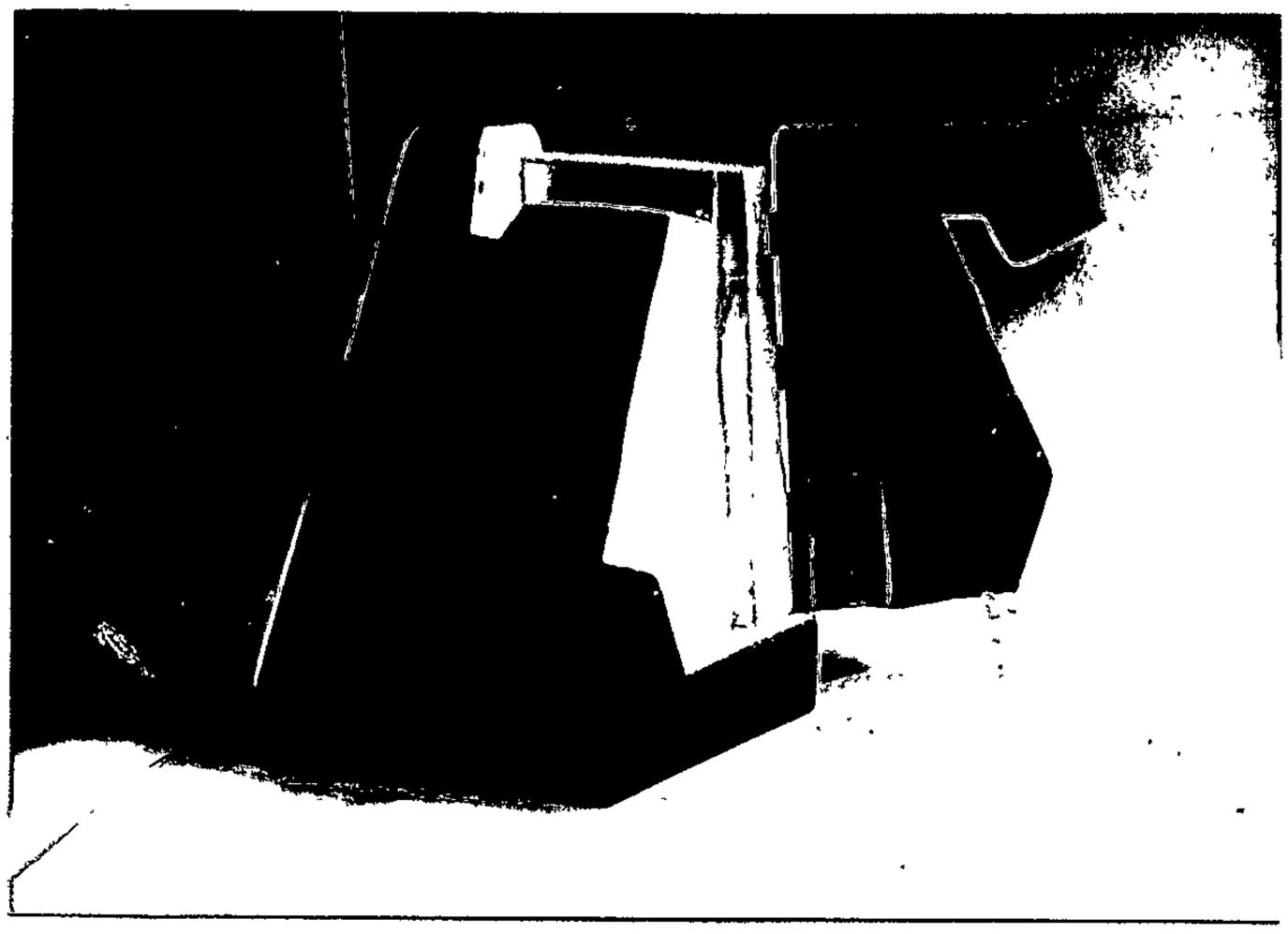
Fig. 58 a. shows a geometric form in which the supplemental groove is used in the occlusal step and is compared with the groove tongue and mortise, see Fig. 40. Figs. 58 b. and c. show two views of the application of the supplemental groove to a proximo-occlusal cavity in a bicuspid.

Instead of the grooves the use of a pin or dowel is advocated in the occlusal, see Fig. 59. To obtain retention equal in efficiency to the groove, the hole is generally cut much deeper than the depth of the groove, and this introduces a danger to the pulp.

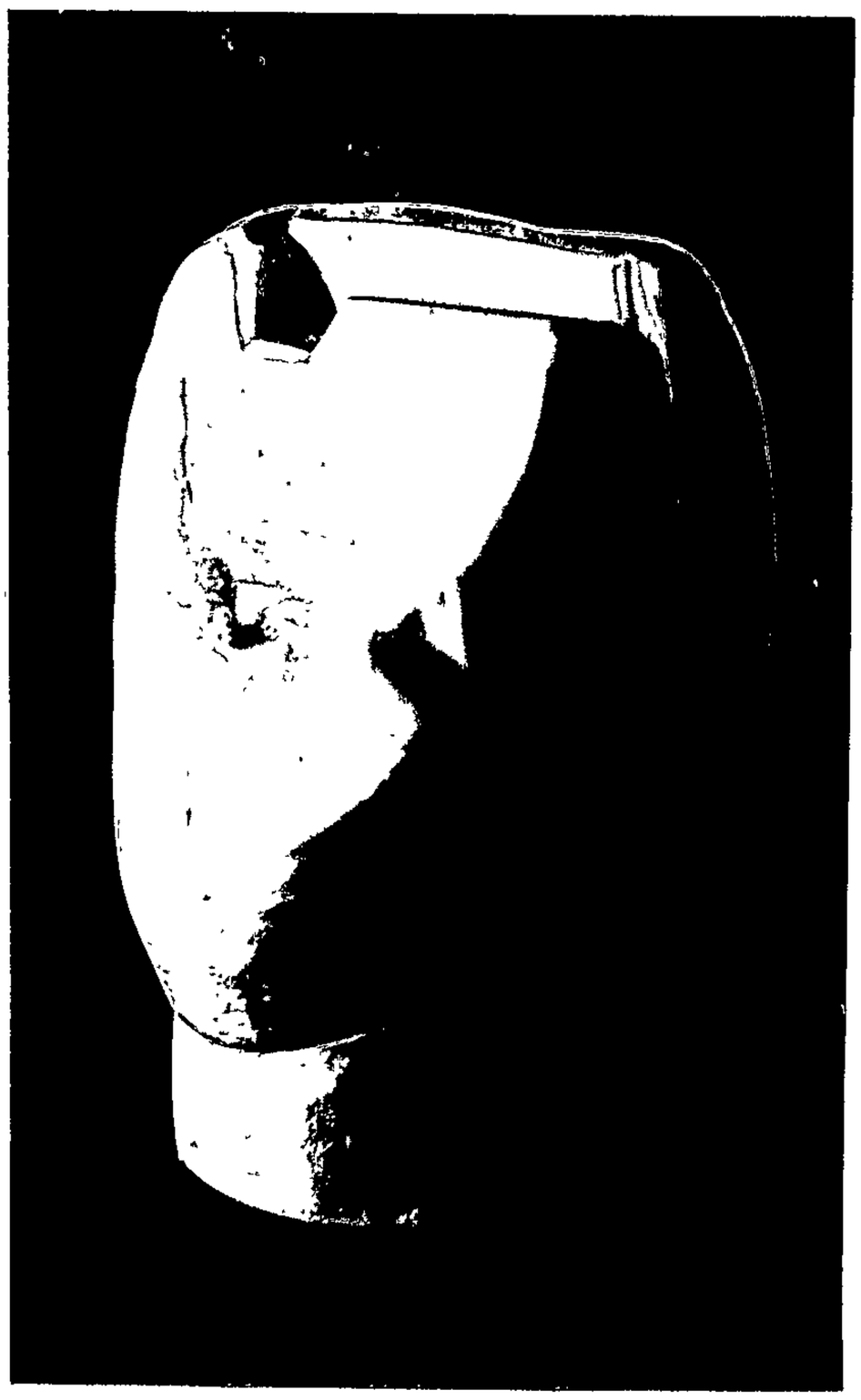
Fig. 59.

Fig. 60.

Fig. 60 is a model of a proximo-occlusal cavity using a slice preparation instead of the mortise form for the proximal portion, the retention being augmented by the use of a channel on the axial wall. This modification is generally applied to non-carious vital teeth used as abutments in fixed bridge-work.



a.



b.

Fig. 61.

Fig. 62.

Group 11. This group uses identical mechanical factors in their retention forms but differs somewhat as the retention form itself is necessarily slighter in bulk owing to the reduced anatomical form of that portion of the tooth used to accommodate it. The axis of rotation to masticatory force on the incisal edge is the gingival margin, resistance to rotation about the labial and labio-gingival margins is not so effective as that offered in the lingual lock form, and its use is restricted to thick teeth.

Fig. 61 a. shows a geometric form of this type of cavity, the proximal form being similar to that of the lingual lock form; labial and lingual walls are formed where sufficient tooth structure remains. The main retentive factor is supplied by the short supplemental groove at the end of the step and the floor of the step is inclined towards the labial wall. The greatest difficulty experienced with this type of cavity is to obtain adequate resistance form in the incisal step if a lingual wall is retained; even if this wall is retained, it is generally too thin for adequate strength and also increases the difficulty of obtaining an accurate wax pattern in this region. The type of cavity applied to an upper anterior tooth is shown in Fig.61 b, in which may be seen a groove placed at the junction of the axial and lingual walls, the groove being extended into the gingival wall forming a pit which receives a pin in the casting. This pin is placed in an advantageous position to prevent rotation of the inlay about the labial margin; Fig. 30 b. illustrates this position. The mechanical factor in this type of cavity is found to consist of a Class 11 lever. Fig. 21 illustrates the lever system.

In lower anterior teeth this type of preparation is limited in its application, their reduced bulk preventing anything but the smallest incisal retention form; the use of a pit at the extremity of the incisal step is successful in many cases, Fig. 62, but a danger resulting from its use is the fracture of

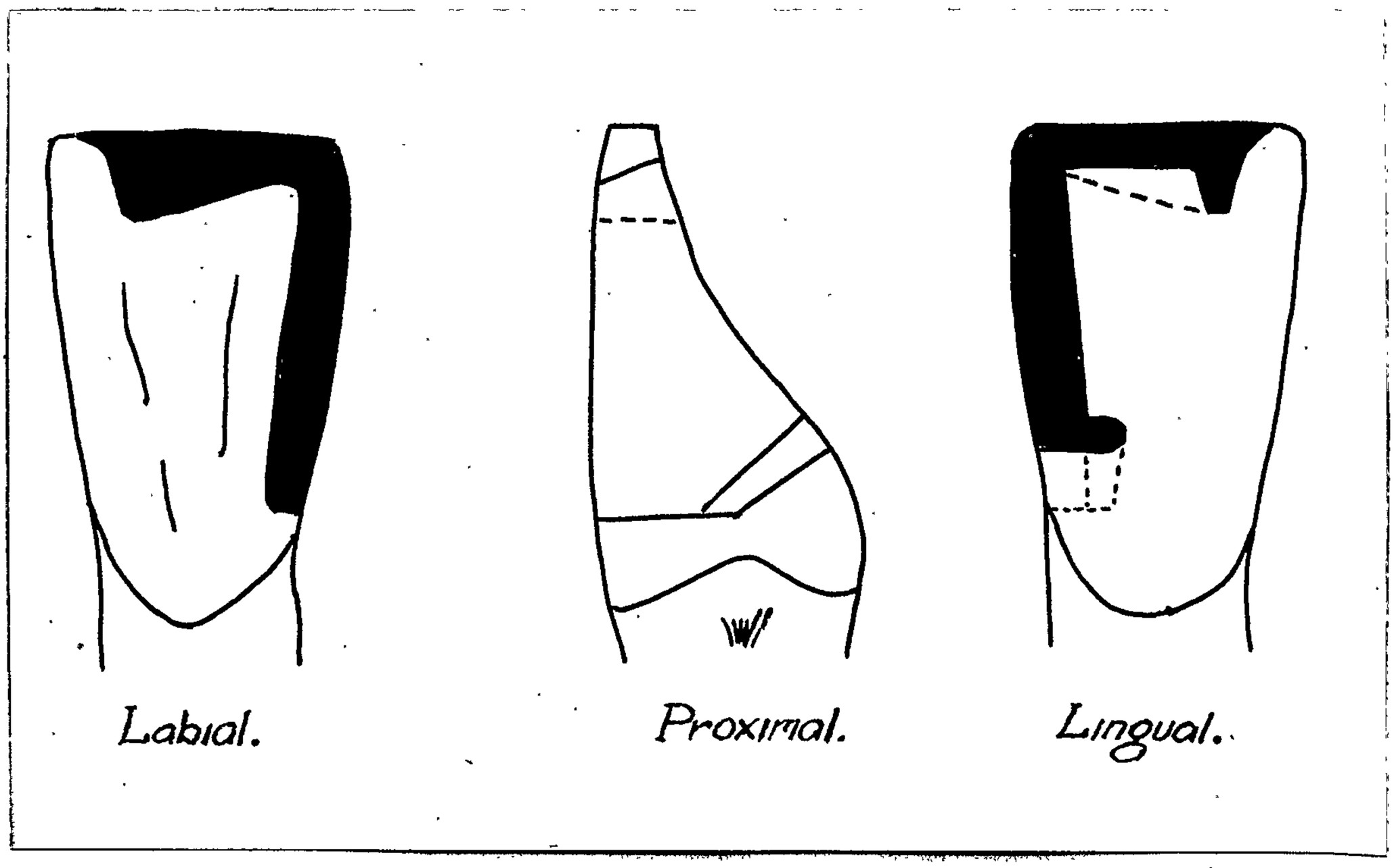
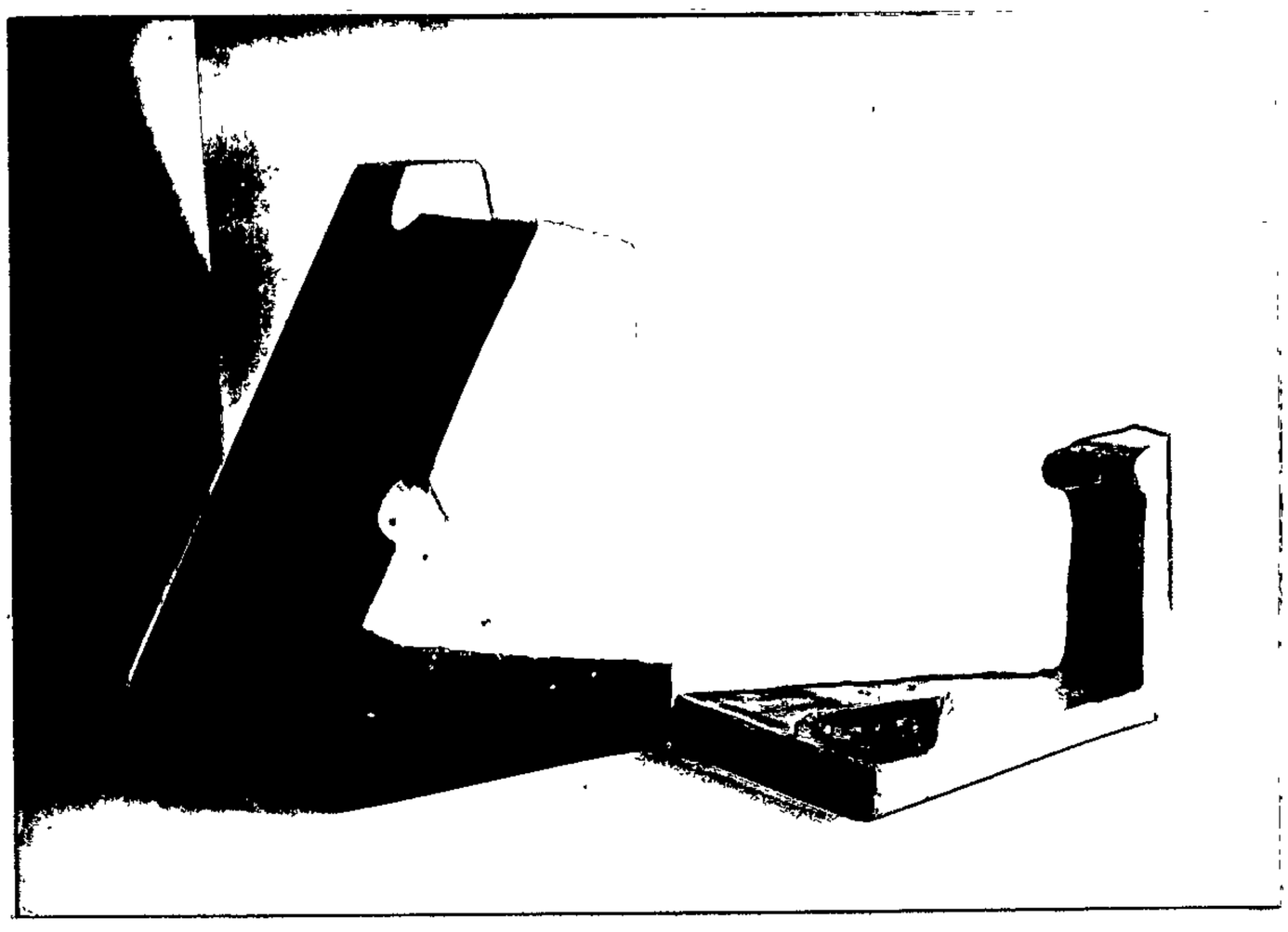


Fig. 63.



a.

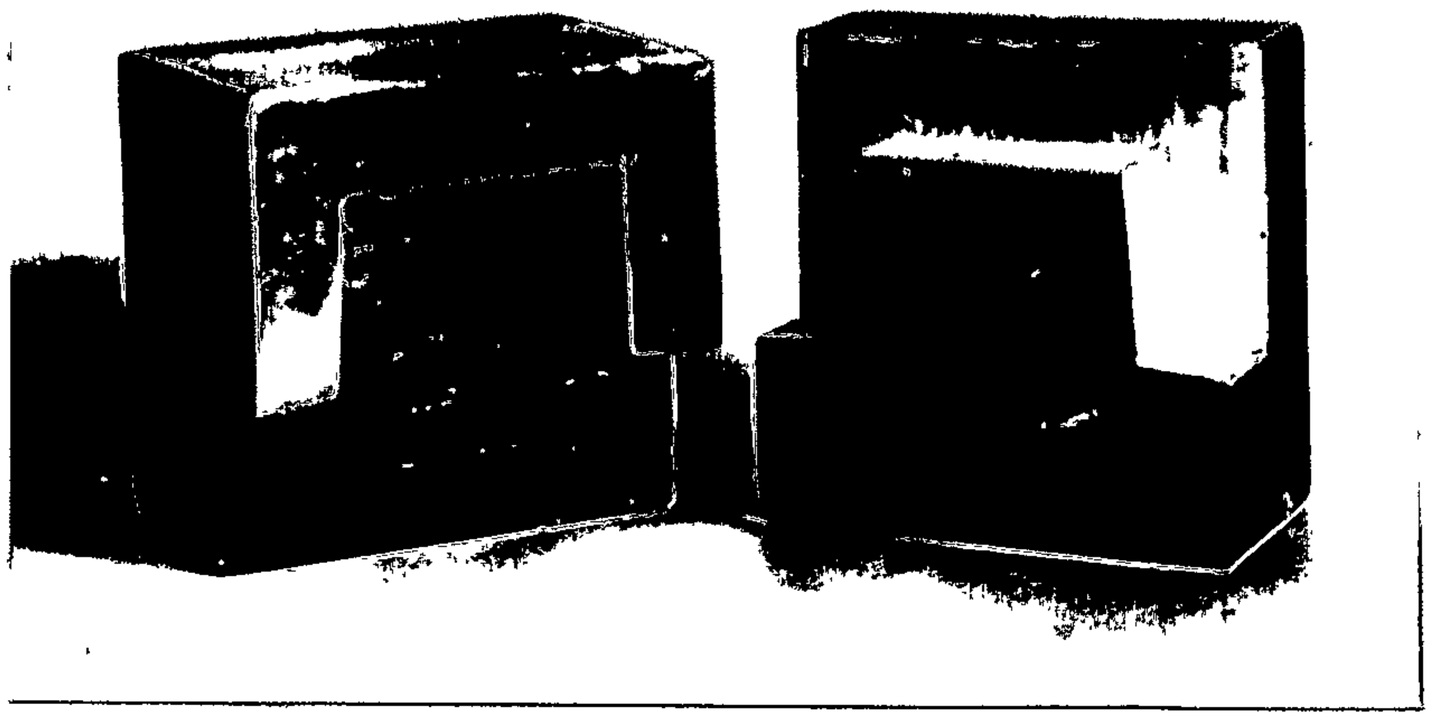
b. c.

Fig. 64.

Fig. 64 c. is a print from a radiograph of a patient's lower anteriors. The lower right central requiring an incisal restoration. Patient's age 31 years. (Note pulp chamber).

the enamel at this position when the casting is seated in position. The use of the mesio-inciso-distal form exposes a large area of the tooth to external irritation, increases the possibility of trauma to the pulp and mars the aesthetic result, cf. Fig. 65 c. The use of a lingual lock in these teeth is contra-indicated when the direction of stress occurring in these regions is remembered, see Fig. 17.

Because the axis of rotation is found in the linguo-gingival region and the direction of stress is shown by the arrow in Fig. 17, resistance to this stress is best developed by opposing it directly with some wall, groove or dowel, and because of the smallness of the teeth, there is seldom sufficient material to do this in a cavity similar to the one described for the upper anteriors. The diagram shown in Fig. 63 illustrates the use of a groove cut in the axial wall and towards the gingival region; this groove is cut at approximately 45° to the axial plane, and deeper at its lingual region. The axis of rotation to stress from the labial becomes the linguo-gingival margin of this groove, the incisal wall of this groove is then directly opposed to any rotation about the linguo-gingival margin. Radiographs of lower anteriors reveal the marked constriction of the pulp chamber at this region which permits the use of the groove, Fig. 64 c. To prevent rotation about the gingival margin, a groove is cut through the incisal edge from labial to lingual, enamel and dentine is then removed from the labial surface as shown in Fig. 63, so that the incisal step has no walls, but a flat surface opposed to the direction of stress, which augments the value of the groove in the axial wall. The direction of insertion and withdrawal of the inlay corresponds to the line of the axial groove which is an inciso-palatal direction and although it does not correspond to the direction of greatest thrust it is a compromise which has had some success in practice.



a.

b.

c.

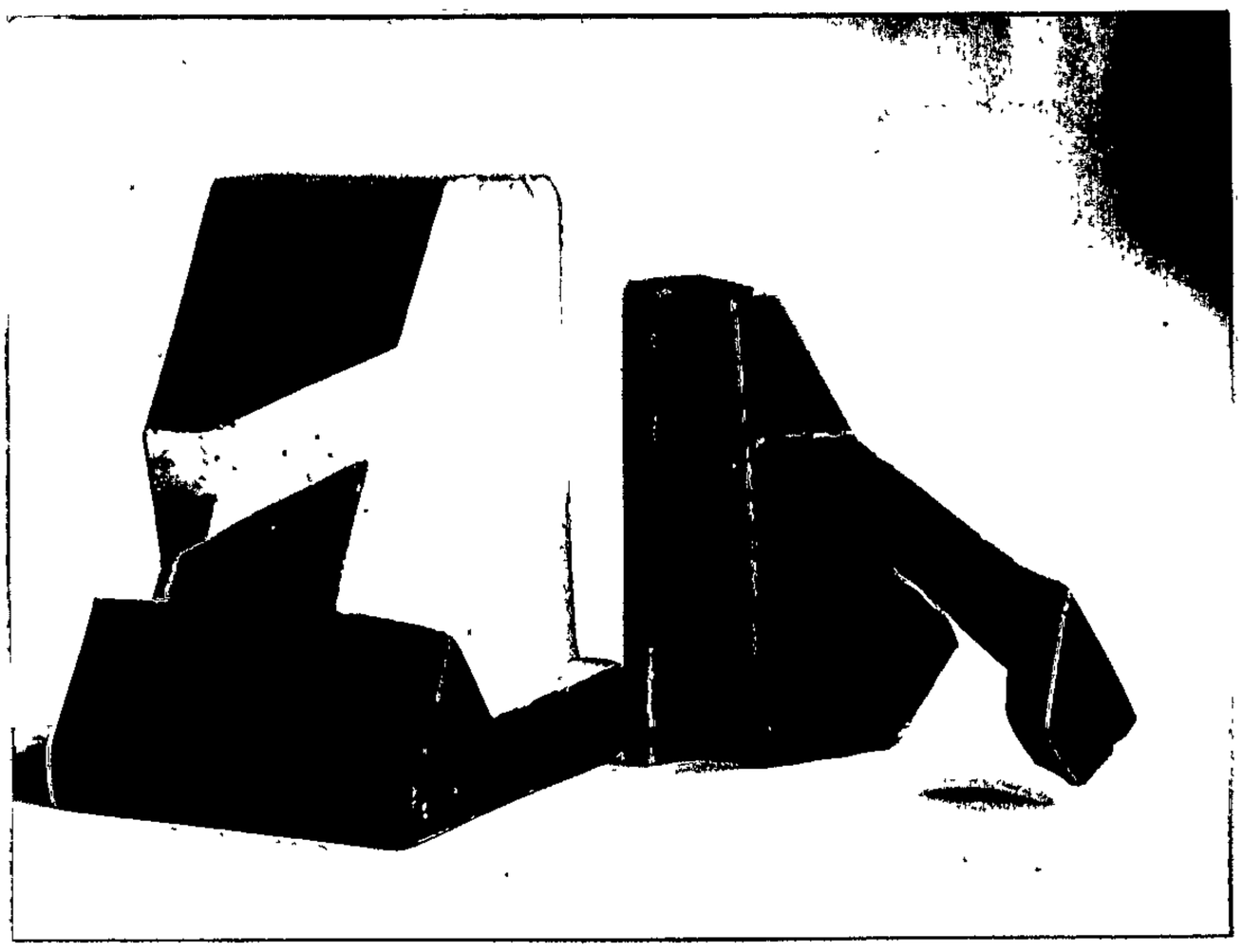
Fig. 65.

Fig. 64 a. shows the geometric form of this modification for a lower anterior proximo-incisal restoration; the inlay lying at the side of the model illustrates the axial and incisal grooves. Fig. 64 b. illustrates the cavity design on a model of a lower incisor; because of the direction of withdrawal of the wax, the retention of any lingual tooth structure is impossible and most of the features of the box or mortise disappear in this form.

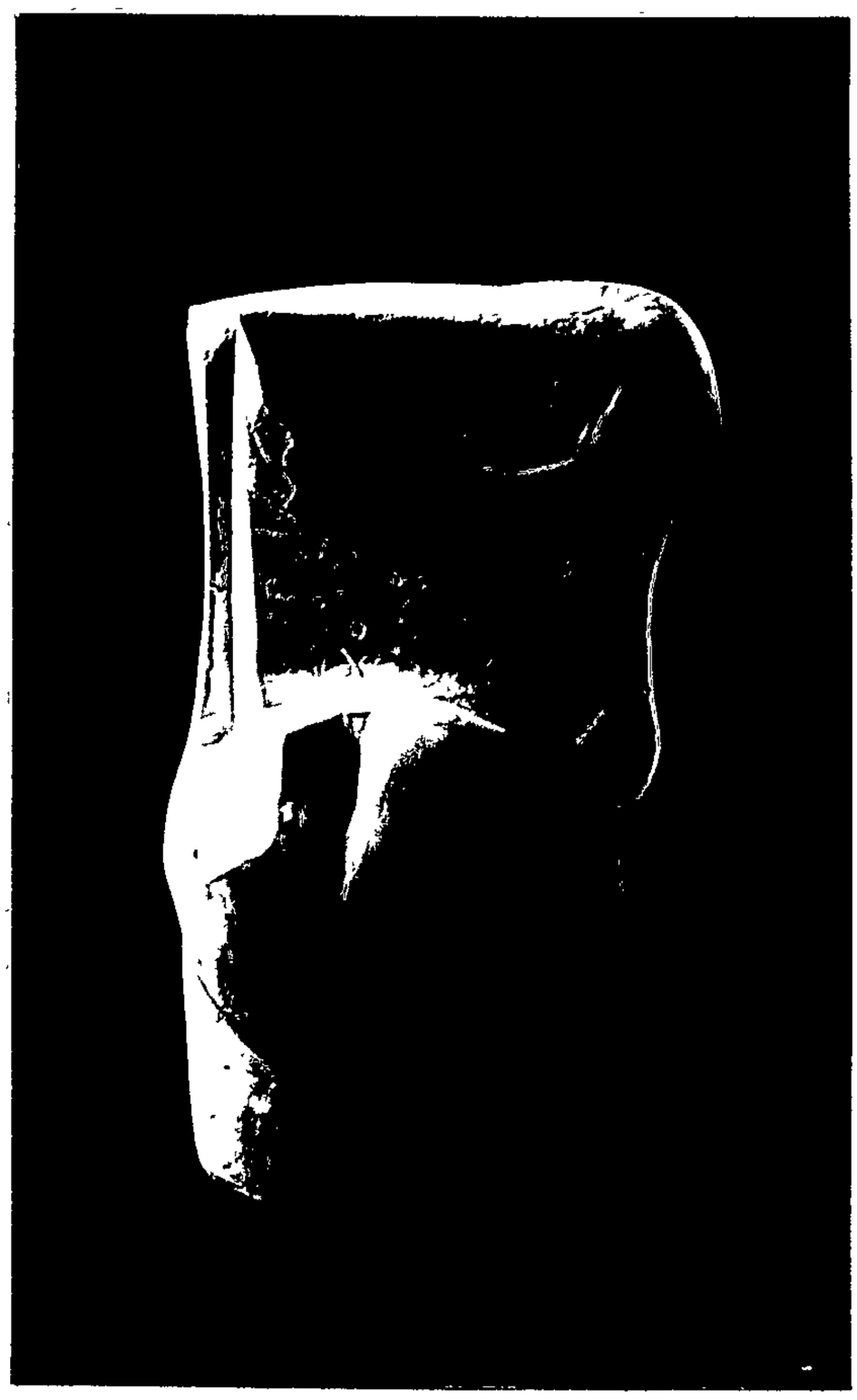
V111. Saddle inlays.

1. Mesio-occluso-distal, 11. Mesio-inciso-distal, 111. Mesio-linguo-distal. These are the three main types found in this group, the characteristic feature of which is the saddle-shape; the finished casting is composed of two larger masses joined by a portion of less bulk. The geometric form is shown in Fig. 65 and compared with Fig. 38 is seen to exist as the open mortise and tenon; the lever system in 1. and 11. is a double Class 11 and there exists what might be termed reciprocal retention, the axial walls resisting alternate thrusts tending to cause rotation about the gingival margins; in addition to the axial walls the buccal and lingual or labial and lingual, where present, also assist in retention and prevent movement in their direction.

Because of this excellent retention form, it is possible to approach the 'hopper' form of the cavity, especially in these two types, which minimises the possibility of distortion of the wax model of the inlay; the objection to the type 11 form is on aesthetic grounds and where possible its use should be avoided. Figs. 65 b. and c. show the two types applied to the tooth form. Occasion sometimes arises where a linguo-occluso-buccal preparation is required, the principle being the same for this form as for the preceding two.



a.



b.

c.

Fig. 66.

The third type, mesio-linguo-distal, belongs to the Class 111 lever system, the lingual step of the lingual lock being extended until union is effected with the other proximal cavity; as with the other types in this group, the more the 'hopper' form can be approached the greater is the possibility of successfully obtaining accurate wax patterns, but the proximity of the pulp at the junction of the axial and pulpal walls in the central and lateral incisors introduces the need for great care in the cutting of tooth structure in this form. Fig. 66 a. shows the geometric form of this type and Figs. 66 b. and c. show two examples applied to the teeth. The section joining the two proximal portions should be as broad as possible, as in Fig. 66 b.

SECTION 5.

As shown by Schwartz (47) there are possible some three hundred and seventy six preparations for inlay cavities to restore defective tooth surfaces. The grouping of these cavity preparations into various classes has been based on (a) the site of the carious lesion (48), (b) the number of surfaces involved (49), (c) the number of steps taking part in the preparation (47), (d) the shape of the retention form (50). A classification based upon the mechanical factors involved in the retention forms, as discussed in this work, is herewith given.

Class 1. Posted inlays, Fig. 47.

This form of inlay is generally used for restoring large cavities on anterior and posterior teeth in which the main support is derived from a post placed in the root canal, the mechanical factor involved being a lever of the Class 1 type, see Fig. 20.

Class 11. Step inlays, (a) anterior, (b) posterior.

This form involves a Class 11 lever, Fig. 21, and both types use a step on the surface which is subjected to the stress which they resist.

Type (a) restores the anterior teeth, in which a proximo-incisal restoration is made, Figs. 61, 62, 64.

Type (b) restores the posterior teeth, in which proximo-occlusal or bucco-occlusal or linguo-occlusal restoration is made, Figs. 56, 57.

Class 111. Lingual lock inlays, Fig. 52.

This form involves a Class 111 lever, Fig. 22, and is used to restore the proximo-incisal defects in upper anterior

(47) Schwartz J.R. "Cavity Preparation and Abutment Construction", 1936 Ed., p. 30, p. 76.
(48) Black G.V. "Operative Dentistry", Vol. 2, 6th Ed., p. 105.
(49) Chayes H.E.S. "Technic and Scope of Cast Gold Inlays", p.74.
(50) Campbell J. Dental Cosmos, May 1933, Vol. 75, pp. 434.

teeth and the retention form is placed on the lingual surface of the tooth. It should never be used on lower anterior teeth, see Fig. 17.

Class 1V. Saddle-shaped inlays, Figs. 65, 66.

In these cavity preparations, there is found a double lever system of the Class 11 type opposed to the main stresses. The M.O.D. and M.I.D., Fig. 65, restorations belong to this class; the M.L.D. restorations though using a double Class 111 lever, may still be placed in this group, see Fig. 66. As well as the M.O.D. restorations, more complex forms involving the buccal and lingual surfaces are found, but these types are extensions of the saddle shape with opposed axial walls.

Class V. Dovetail inlays, Figs. 49, 50.

This class has been used to group these types of inlay which are used to restore the proximal surfaces of anterior and posterior teeth; under favourable conditions only are these types used and then only when the margins of the finished inlays may be laid in 'immune areas'. The lever system actually involved belongs to the Class 11 order but no 'arm' exists as in the other types. In place of the dovetail on anterior teeth, a form using a lingual lock, Fig. 51, is generally employed and is a precursor of the lingual lock restoring the incisal angle, Fig. 52.

Class V1. Pinlays, Fig. 48.

These restorations use pins for retention and are found in vital teeth in which restorations are made, restoring relatively large surface areas with practically no cavity preparation. Generally two pins are used and in pinledge preparations for fixed bridge abutments, sometimes more than two.

Class V11. Box cavities, Fig. 46.

These are simple cavities occurring on any one surface, such as occlusal, lingual, buccal, labial, occasionally the proximal and incisal surfaces. Their main feature is simplicity of contour, having four walls and a flat seat.

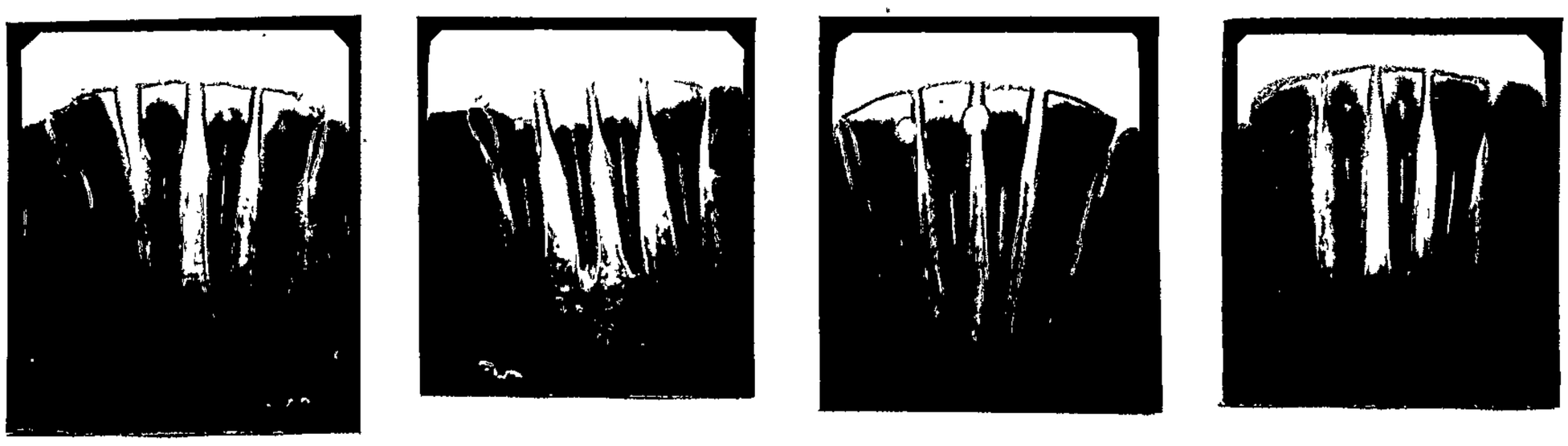
a.

b.

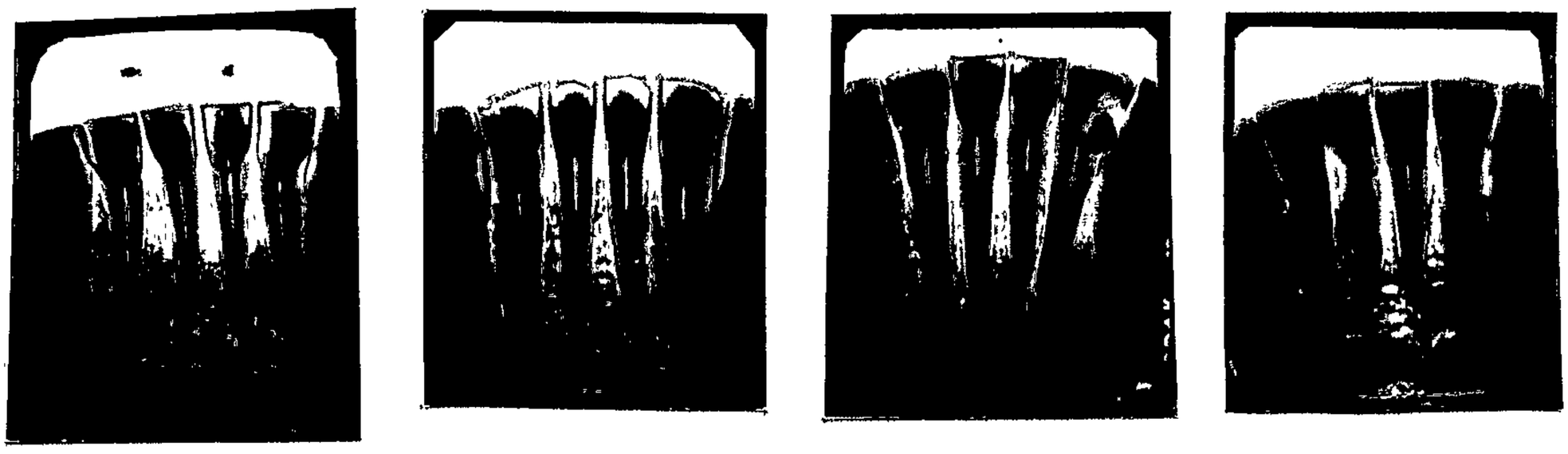
c.

Fig. 67.

Fig. 67. Three examples of the assistance rendered by the use of 'bite-wing' films in the radiographic examination of the mouth. (The above are prints made directly from radiographs.)



Group a.



Group b.

Fig. 68.

Fig. 68. Group a. shows wide pulp chambers, or pulp chambers close to the incisal edge. Group b. shows pulp chambers more favourably situated for the lower incisor restorations.

SECTION 6.

Before commencing any operative procedures it is important that an examination of the teeth in which the restorations are contemplated should be made. Although a clinical examination yields a reasonable amount of information the use of the radiograph is a necessary adjunct.

The extent of the carious lesions will modify to a certain degree the final design of the cavity preparation; if the carious lesion is superficial, i.e. involving the enamel only, a slice type of preparation may be selected; if the carious lesion is medial, a mortise form of preparation may be used; if the carious lesion is profound and the pulp tissue is involved, suitable treatment of this organ can be commenced and a design gaining retention from the pulp chamber and root canal prepared. If the conditions are known, suitable treatment may be planned and all operations may then be directed towards the preparation of the restorations with a minimum of tooth wastage.

The use of the 'bite-wing' film, Fig. 67, would seem a desirable means of carrying out this examination, and is best used as a routine in the preliminary examination of the teeth, because these films present a picture of the crowns of the teeth, the size, shape and position of the pulp chamber, the relation of the carious lesions to the dentine and the pulp, and its relation in the proximal regions, to the 'contact point' and gingival tissues. In those individual cases where pulp involvement appears to be likely, a further and more extensive radiographic examination may then be made. The use of the radiograph for the careful designing of the restoration of the lower incisor is a necessity, and Fig. 68 is a collection of prints of radiographs of lower incisors in which the variations of the pulpal outlines are demonstrated.

To a degree, the radiograph may be said to define the diseased and healthy tissues quantitatively, so that all operative efforts may be directed from the commencement with the most suitable design in mind; in this way a reduction of the cutting of tooth structures can be achieved.

S U M M A R Y.

1. An examination of the important characteristics of the various groups of teeth and of the part played by those groups in the masticatory apparatus during functional movements in the act of mastication, reveals certain mechanical factors and reveals also during the act of mastication, certain movements some of which give rise to an altered occlusal relationship.

The movements are as follows:-

a. The hinge movement.

b. The protrusive movement.

c. A right and left lateral movement in which the condyles alternate as pivotal members.

In the hinge movement the mandible functions as a lever of the Third Class, and in the lateral movements as a lever of the Second Class.

2. These lateral movements produce the masticatory groove into which food is packed, by the tongue and cheeks, for the crushing process. This groove is the site of definite stresses during the various mandibular excursions, and because of the complexity of its surface, it produces alterations in the dispersion of the forces of mastication; these alterations to the direction of the forces give rise to stresses which tend to cause movement of two kinds in any restorative work.

(1) A rotation about the proximal gingival margins.

(2) A rocking movement in a bucco-lingual direction and in larger restorations this rocking movement may become a rotation about the lingual or buccal gingival margins.

3. In the anterior regions of the mouth, certain stresses occur which can be resisted along certain planes, when the various incisal relationships exist.

4. Certain mechanical factors arise in the various retention forms in use, and these place them at a mechanical advantage or

disadvantage depending upon the lever system to which each retention form belongs.

5. Certain types of retention form are used in other arts, the main features of which can be and are incorporated in inlay cavity designs.

6. The application of these forms to simple geometric models and then to models of the teeth has enabled the comparison to be more readily perceived.

7. The importance of economy of tooth substance has been stressed throughout and the means whereby the inlay permits this economy to be effected has been demonstrated.

8. A classification of inlay cavities mainly based upon the mechanical factors in each type, has been attempted and has been suggested as an addition to, not as a substitution for, those classifications already in use.

CONCLUSIONS.

The aim of the work has been to examine various cavity designs and approve of or modify them. In many cases, it has been found that the form of the inlay and its cavity has been developed from, and maintains the excellent features of, other fundamental forms of joint, but the peculiar demands made upon restorations in Operative Dentistry sometimes produce deficiencies in the finished restorations, which may be made good in the inlay whilst maintaining those retentive features. In general the cavity designs in existence for other materials have been justified, but, because of the strength of the cast gold inlay with its rigid whole it is possible to reduce in amount the tooth structure which generally has to be removed to make adequate resistance and retention form for the plastic materials, and to achieve the necessary "extension for prevention" by the use of slice preparations without reducing the mechanical efficiency of the design.

In some cases it is possible to dispense with the use of the auxiliary step, in others it is necessary to amplify the methods of retention by means of supplemental grooves, dowels and dovetails, in the first case gaining retention without too great a sacrifice of tooth structure, and in the second case where loss of tooth structure through disease has been extensive.

In the case of the lower incisors an attempt, based upon mechanical concepts, has been made at a modification of the existing form; this attempt has in certain cases promised to lessen the difficulty of a problem in restorative work of this nature.

In practice it has been found that grooves seem preferable to dowels or pins when the step formation does not admit of other retention forms; the groove has certain advantages such as the absence of any great depth, simple alignment with other walls

of the cavity, absence of any difficulty in obtaining the wax pattern, and function for the full width of the step in which it is placed.

In general I have found an accurate retention form, correct in outline and placed to advantage with a flat floor in the occlusal, or the incisal, or the lingual, to be the important feature in the design of the inlay cavity; and it would seem that the inlay is very much more dependent upon correct outline form than are the plastic materials which will withstand stresses when the internal dimensions of the cavity are greater than the external. The proximal portion of certain inlays does not help to increase retention very much, so that in extreme cases, if the tooth structure is not available, the retention of the inlay will not suffer as much as might be expected. In anterior teeth in which a lingual lock is used a slice preparation on the proximal surface requires some further assistance to prevent rotation about its pivotal centre, and in these cases, the introduction of a gingival floor is necessary. It would seem, therefore, that the use of the cast gold inlay does permit a reduction in the sacrifice of tooth structure in most cases, combined with, in certain anterior restorations, an improved aesthetic result. The mechanical disadvantage which may result from the use of any particular design can be balanced by accurate cutting according to the modifications advocated.

The modification of any design may be undertaken in accordance with the mechanical factors which may exist in the particular region and are inherent in the design, such modification being limited by the restrictions imposed by the varying quantity and quality of the remaining tissues.

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