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Adhesion in biological systems

D H Retief

Dental Research Unit of the University of the Witwatersrand and the South African Medical Research Council, Johannesburg, South Africa.

INTRODUCTION

The term protein is derived from the Greek noun, *proteios*, meaning holding first place and I will therefore start by discussing the important role that adhesion plays in stabilizing protein structure.

Proteins can be grouped into at least 7 broad categories based on their structure and function:

1. Structural proteins, e.g. collagen.
2. Contractile proteins, e.g. in muscle.
3. Antibodies, e.g. δ-globulins.
4. Blood proteins e.g. albumins.
5. Hormones. They maintain order in a complicated complex of metabolic reactions.
6. Enzymes. These are biological catalysts.
7. Nutrient proteins. These serve as a source of amino acids including the essential amino acids.

The fundamental structural unit of proteins is the amino acid. It contains an amino group, a carboxyl group and a side chain that may be any one of 23 possible groups. In 1923, Bjerrum proposed the alternative Zwitterion formula for amino acids to explain their amphoteric nature. In this formula, the carboxyl group is presented as being ionized while the amino group is protonated.

The primary structure of proteins results from the combination of amino acids in a proper sequence through peptide bonds which are covalent bonds. Stabilization of an α-helical configuration by hydrogen bonding yields a secondary structure. The spiral is stabilized by hydrogen bonding between the carboxyl and the imido groups of the peptide chain which appear in a regular sequence along the chain. Compression of the very long spiral chain into a globular form results in the tertiary structure of proteins.

Several types of bonds stabilize tertiary protein structure (Conn and Stumpf, 1965). These include:

1. Electrostatic or ionic bonds.
   These occur between ionized carboxyl and protonated amino or imino groups.
2. Hydrogen bonding between tyrosine residues and carboxyl groups on side chains.
3. Van der Waals forces of the London type.
   These are hydrophobic interactions of nonpolar side chains caused by the mutual repulsion of solvents.
4. Van der Waals forces of the Debye and Keesom types.
   These result from dipole-dipole interactions between polar side chains.
5. Covalent bonds.
   Cysteine is the sole source of sulfhydryl groups which may participate in disulfide bonding.

The quaternary structure of proteins defines the degree of polymerization of a protein unit. Breaking of some of these bonds results in denaturation of a protein. This may be brought about by heat, enzymatic action or pH changes.

Because of the importance of adhesion in biological systems, some of the principles of adhesion will be discussed.

THE PRINCIPLES OF ADHESION

Adhesion is defined as the attraction between molecules at an interface. This force is called adhesion when unlike molecules are attracted and cohesion when molecules of the same kind are attracted. The material added to produce adhesion is known as the adhesive and the surface to which it is applied the adherend or substrate. The interface is the zone between the interacting substances.

The molecular forces involved in adhesion are divided into chemical or primary forces and physical or secondary attractive forces. The chemical attractive forces include those arising from electrovalent or ionic, polar and nonpolar covalent and hydrogen bonds.

The electrovalent or ionic bond is formed by the electron transfer from the valency orbit of one atom to the valency orbit of another atom. This type of bond is found in sodium chloride. The single outer valency electron of the sodium atom is transferred to the chlorine atom which already has 7 outer valency electrons. Positively charged sodium ions and negatively charged chloride ions are formed and the attractive force arises from the electrostatic attraction between these oppositely charged ions (Fig. 1).

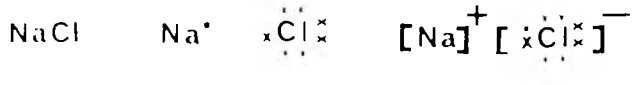


Fig. 1. Electrostatic or ionic bond between positively charged sodium ions and negatively charged chloride ions.

A covalent bond is formed by the sharing of electrons of the valency orbits and a shared pair of electrons constitutes a covalent bond. A purely covalent or nonpolar bond is formed by the equal sharing of electron pairs by similar atoms for example as in chlorine, Cl_2. The shared pair of electrons will be situated equidistant from the 2 chlorine atoms and the resultant bond has no ionic character (Fig. 2).

If the electron pairs are shared by dissimilar atoms, that is, those that have different degrees of electronegativity, they will be displaced closer towards the more electronegative atom. For example, in car-

bon tetrachloride, the shared pairs of electrons are displaced towards the more electronegative chlorine atoms which thus attain a negative charge and the carbon atom a positive charge. The bonds between the atoms will have a partly ionic character and hence a polar characteristic (Fig. 3). The ionic character of polar covalent bonds varies as it is dependent on the electronegativity of the atoms between which the electrons are shared.

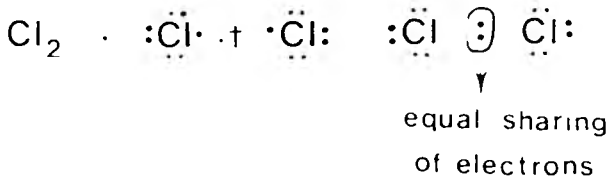


Fig. 2. Non polar covalent bond between chlorine atoms.

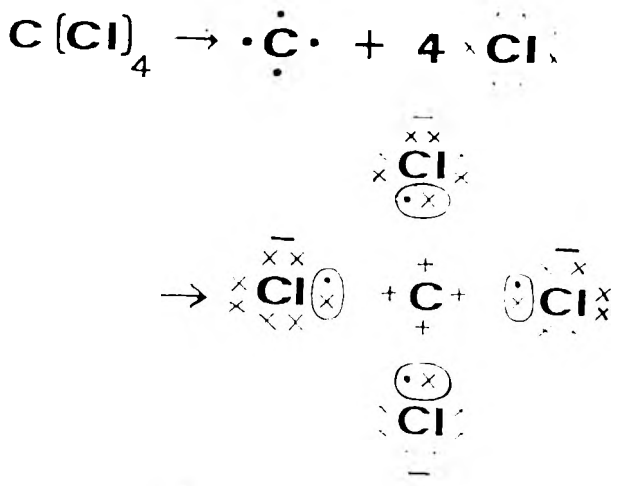


Fig. 3. Polar covalent bonds in the carbon tetrachloride molecule.

A dipole results whenever a covalent bond is formed by the unequal sharing of electron pairs. The degree of electron displacement is reflected by the dipole moment.

The electric dipole moment $\mu = ql$

Where q = the magnitude of the charges separated.
l = the distance separating the charges.

The hydrogen bond can be regarded as a special type of dipole-dipole interaction. According to Good (1967) the establishment of a hydrogen bond calls for 2 conditions.

1. A highly electronegative atom such as F, O or Cl or strongly electronegative groups like -CN with a hydrogen atom attached.
2. Another highly electronegative atom which may or may not be in a molecule of the same species as the first atom or group, to be in the vicinity.

Water, H_2O, for example does not exist as such but as $(H_2O)_3$ where the 3 associated molecules are held together by hydrogen bonds. The primary intramolecular bonds between the hydrogen and the oxygen atoms in the water molecule are of the polar covalent type. As the 2 shared pairs of electrons are orientated much closer to the strongly electronegative oxygen atom, the electron density around the oxygen nucleus will be much greater than around the hydrogen nucleus (proton). Consequently the hydrogen atoms of the water molecule are positive in relation to the oxygen atom (Fig. 4).

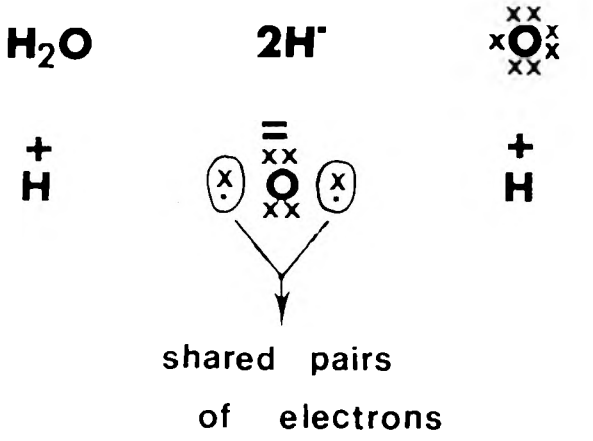


Fig. 4. Polar covalent bonds in the water molecule.

When a single water molecule intermingles with other water molecules, its positive hydrogen atoms are attracted to the negative oxygen atoms of neighbouring water molecules and 2 hydrogen bonds are established (Fig. 5).

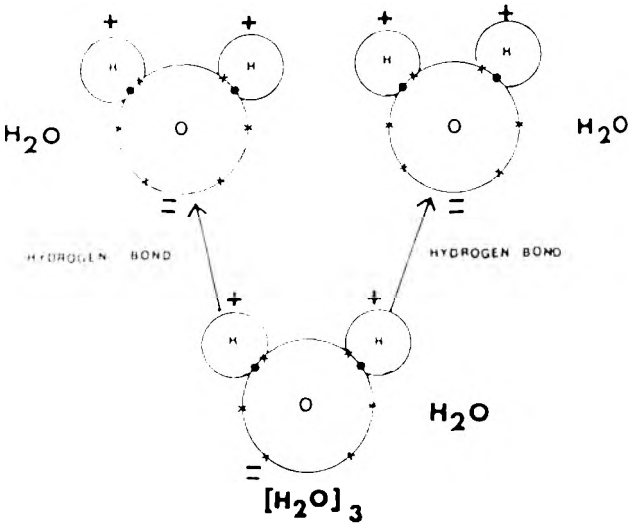


Fig. 5. Hydrogen bonding in the associated water molecule.

The physical or secondary molecular attractive forces arise from the Van der Waals forces which include:

1. Keesom forces — Orientation effect.
2. Debye forces — Induction effect.
3. London forces — Dispersion effect.

The Keesom forces result from the interaction of permanent dipoles in neighbouring molecules of polar compounds. Orientation of the dipoles to a head-to-tail or lowest energy configuration will result in molecular attraction across the interface.

The Debye forces take into account the influnce of a

dipole moment in a molecule which induces an additional dipole moment in a molecule across the interface. A dipole in a molecule may provide the electrical field to polarize a neighbouring symmetrical or nonpolar molecule.

Slight displacement of electrons in a nonpolar molecule is constantly occurring; it is instantaneous and at random and results in the formation of instantaneous dipoles which at any one instant induces another dipole in a nonpolar molecule across the interface. Attraction between the instantaneous and induced dipoles then occurs, and gives rise to London forces. The London forces, not depending on dipoles in polar compounds, are universal and play a most important part in adhesion. The Van der Waals forces are diagrammatically presented in Fig. 6.

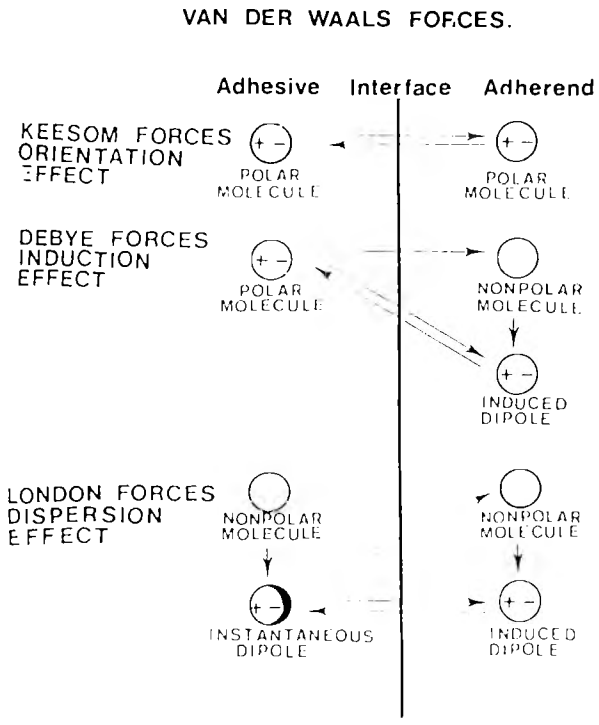


Fig. 6. Diagrammatic presentation of Van der Waals attractive forces.

The physical forces of attraction result in the adsorption of the adhesive on the adherend. This process is rapid and reversible as it requires no activation energy. The physical forces of attraction precede chemisorption. In the latter reaction the adsorbed molecules are held to the adherend surface by strong chemical bonds. The rate of chemisorption is relatively slow as it requires an activation energy. It gives rise to strong attractive forces and once established, is not easily reversed.

Adhesion is dependent on intimate interfacial contact as the molecular forces of attraction do not operate beyond 3 or 4 Angstrom Units. To produce intimate interfacial contact, the liquid adhesive must flow easily over the entire surface to be bonded thereby ensuring the wetting of the surface. The extent to which an adhesive will wet a surface depends on, amongst others, the contact angle, θ, at which the surface of the adhesive meets the adherend surface upon which it rests (Zisman, 1963).

The relationship between contact angle, wetting and adhesion is diagrammatically presented in Fig. 7. If the contact angle is small, the adhesive will wet the adherend surfaces and the molecular forces of adhesion will operate along the entire interface and strong adhesion will result. If, on the other hand, the contact angle is large, incomplete wetting will occur and a weak adhesive bond will be obtained. The contact angle is therefore a useful inverse measure of the wettability of a surface; hence the cosine of the contact angle is a direct measure of wettability.

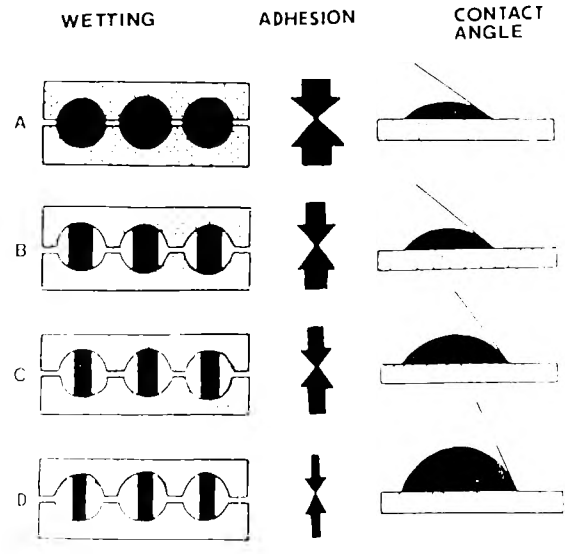


Fig. 7. Diagrammatic presentation of the relationship between contact angle, wetting and adhesion.

A molecule in the bulk of a liquid or a solid is surrounded by neighbouring molecules and is attracted equally from all sides. Thus intermolecular attraction is neutralized and all molecules in the depth of a liquid are in a state of equilibrium. These cohesive forces, which result from the attraction between molecules of the same kind, will try to keep a fluid together whether the fluid is moving or not. A molecule on the surface, however, is attracted from below and from the sides but hardly from above because the number of molecules per unit volume is greater in the bulk of the liquid than in the vapour above it. As a result molecules on the surface of a liquid or solid are in a one-sided field force pulling them downward into the bulk of the liquid or solid. This inward force is responsible for the surface tension of solids and liquids. It is designated the symbol γ_{SV} or γ_{LV} and is expressed in dynes per cm.

Wetting is a manifestation of the attractive forces between the molecules of the adhesive and the adherend. When a liquid contacts a solid surface, 2 opposing forces will operate at the point of contact. These forces are γ_{LV}, the surface tension of the liquid drop directed towards the centre of the drop and γ_{SV} the surface tension of the solid directed in the opposite direction (Fig. 8). Spreading will occur if $\gamma_{SV} > \gamma_{LV}$. The greater the difference between these surface tensions, the smaller the contact angle of the liquid drop on the solid surface and hence the greater the wettability of the surface.

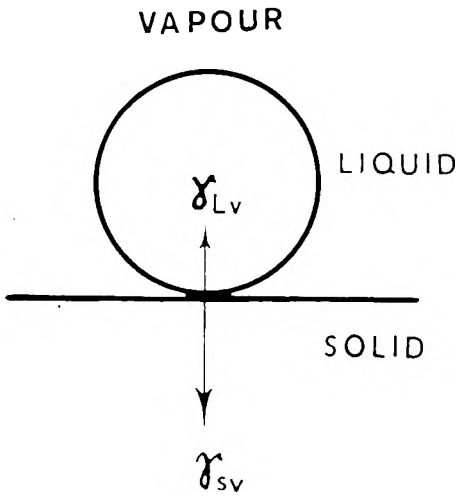


Fig. 8. Attractive forces operating at the point of contact of a liquid adhesive on a solid surface.

Liquids exhibit a resistance to flow known as viscosity. It is the property which opposes the relative motion of adjoining portions of the liquid and can be regarded as a type of internal friction. When a liquid is forced through a capillary tube, the movement can be considered as a laminary movement (Brill, 1967). The various layers of liquid will stream next to each other and the central layers will move with the greatest speed (Fig. 9). Towards the walls of the capillary the speed will decrease and in the peripheral layers the speed will be zero because the molecules are tied to the walls of the capillary tube by adhesion. Therefore, the smaller the distance between the walls of the capillary, the closer the rate of flow becomes to the speed of the peripheral layers. Viscosity therefore opposes the displacement and flow of fluid between two plates. Liquids having low coefficients of viscosity are said to be mobile since they flow readily.

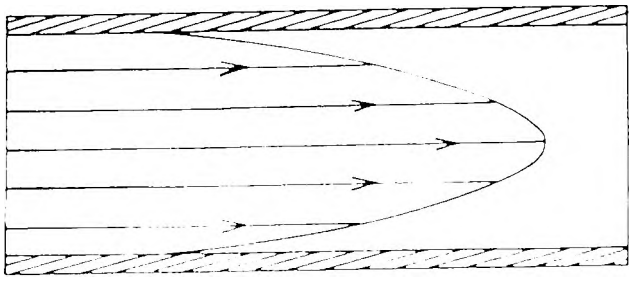


Fig. 9. Laminary flow of a liquid through a capillary tube.

ADHESION IN RESTORATIVE DENTISTRY

As recently as 1967, Gwinnett and Matsui, with perhaps a note of dispair, reported that none of the materials available to the dental profession adhere to untreated tooth surfaces in the oral environment.

This lack of adhesion presents a serious problem in restorative dentistry as it leads to seepage of harmful agents along the interface between the restoration and the tooth. The microleakage leads to breakdown of the marginal areas of the filling and results in the development of secondary decay along the interface. It is even likely that certain post-operative phenomena such as tooth sensitivity and pulp pathology are associated with the leakage pattern (Phillips, 1966).

The microleakage can readily be demonstrated by means of various techniques involving the use of radioactive isotopes, fluorescent dyes, scanning electron microscopy and a study of bacterial penetration. The microleakage could be eliminated by a restorative material or film capable of forming strong adhesive bonds with enamel and dentine which would survive in the intra-oral environment. Extensive research programmes aimed at the development of such a material are under way. The complexity of the problems encountered in the oral cavity has hampered the development of an adhesive restorative material (Retief, 1970).

Some measure of success has been achieved by the introduction of a new dental cement composed of a polyacrylic acid liquid and a modified zinc oxide powder (Smith, 1968). According to Smith (1971), setting of the cement is due to a chemical reaction in which zinc ions link adjacent polyacrylic acid molecules producing a large cross-linked structure. The acid groups in the long chain molecule also have the ability to chelate to calcium ions and thus bond to tooth structure (Fig. 10). Direct evidence of this chemical interaction has been presented by infrared spectroscopic studies (Beech, 1972).

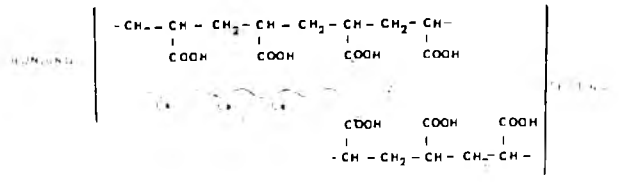
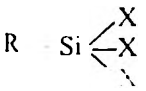


Fig. 10. Setting and bonding mechanisms of polycarboxylate cements.

Another exciting development in the field of restorative dentistry is the advent of the composite restorative materials. The base resin in many of these materials consists of the reaction product of bis phenol A and glycidylmethacrylate – BIS-GMA – a molecule originally synthesized by Bowen (1962). The term composite indicates the presence of a large percentage of reinforcing filler in the form of glass, quartz or silica. The physical properties of the resin matrix such as increased hardness and abrasive resistance, reduced shrinkage on polymerization and reduced marginal leakage, are significantly improved by the incorporation of an inorganic filler (Buonocore, 1968). Bowen (1963) also demonstrated that the incorporation of an organofunctional silane coupling agent produced effective bonding of the filler particles to the polymerizing resin phase.

The organofunctional silane molecule possesses 2 different kinds of reactive groups. It is able to interact with both the organic polymer or resin phase and the inorganic phase to provide a chemical bond at the interface.

An organofunctional silane has the general formula:



Where R = The organofunctional reactive group which combines chemically with the resin phase.
X = Hydrolyzable groups which are usually ethoxy or methoxy groups.

The alkoxy groups are hydrolyzed by the free water present on glass or quartz surfaces to form the corresponding silanol. The silanol groups of the organofunctional silanes react with similar groups on the glass surface to form siloxane (-Si-O-Si-) linkages. The reactive organic group of the silane has the ability to combine with the resin phase of the restorative material. An effective chemical link is thus established between the inorganic and organic phases of the composite resin systems.

The organofunctional silane most commonly used at present is glycidoxy propyl trimethoxy silane. It is employed as an adhesive booster in some restorative systems (Lee, 1973). An additional application of this silane is its use in conjunction with the acid etch technique for the direct bonding of orthodontic attachments. The silane reduces the surface tension of the etched enamel surface which results in increased wetting of the enamel by the curing adhesive (Miura, Nakagawa and Ishizaki, 1974).

Lee and Swartz (1970) furthermore showed that the use of organofunctional silane primers substantially increased the bonding of a wide range of adhesive materials to tooth structure. These authors have proposed a mechanism by which a silane primed tooth surface may react with an epoxy resin.

The composite restorative materials may be regarded as contact adhesives which unfortunately lose their adhesive qualities in the mouth soon after exposure to oral moisture (Buonocore, 1968). Adhesion can be considerably improved by utilizing yet another phase in the restorative formulation. Bowen (1965a) synthesized a surface-active comonomer, the reaction product of N-phenyl glycine and glycidyl methacrylate (Fig. 11), which functions as a coupling agent between the organic phase of the restorative material and tooth structure. He demonstrated that significant improvement in the water-resistant bonding of restorative materials to various substrates was obtained by the introduction of the surface-active comonomer (Bowen, 1965b; 1965c). A hypothetical schematic representation of the manner in which the various phases of a composite material may be connected by chemical bonds was proposed by Bowen (1965d). The interaction between a composite material consisting of BIS-GMA resin and inorganic filler coated with a methacrylate organofunctional silane and tooth structure based on this proposal is shown in Fig. 12.

The mechanical bonding between dental materials and etched or conditioned enamel surfaces is not true adhesion and will not be discussed in this paper.

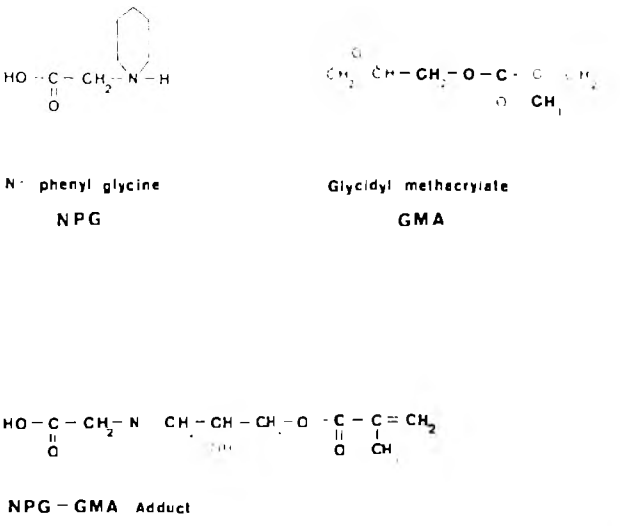


Fig. 11. Surface-active comonomer. NPG-GMA adduct. (N-(2-hydroxy-3-methacryloxypropyl)-N phenylglycine).

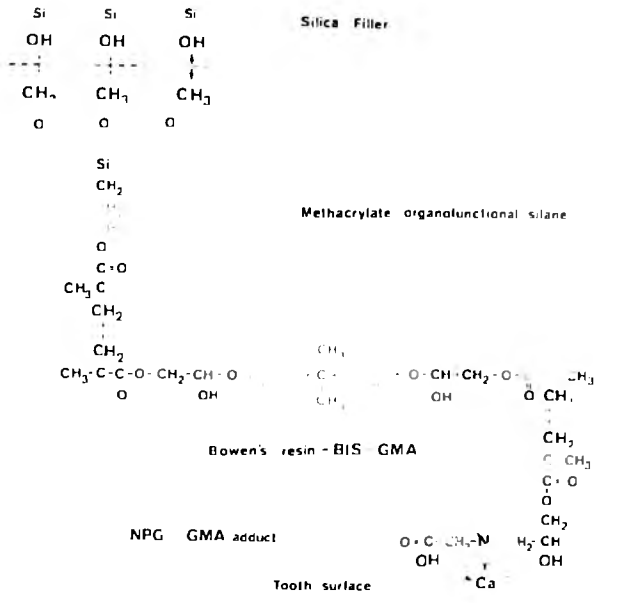


Fig. 12. Hypothetical schematic diagram of the interaction between the various phases of a composite dental material and tooth structure. (With kind permission of Dr. R.L. Bowen).

EPITHELIAL CELLULAR ADHESION AND ADHESION IN PERIODONTICS

According to Weiss (1970) cell contact phenomena may be divided into 3 basic processes, namely:

1. Cell contact.
2. Cell adhesion and attachment.
3. Cell separation.

1. Cell contact

All vertebrate cells carry a net negative surface charge and cell contact is determined by the balance of electrostatic forces of repulsion which tend to keep the charged cells apart and the attractive London Van der Waals forces which tend to bring them together. The surface potential of living cells does not remain constant throughout their life. The surface charge density of mitosing gingival cells increases and, on the other hand, proteolytic enzymes

present in inflammatory cells could reduce the surface charge (Weiss, 1970).

2. Cell adhesion and attachment

When cell contact is made and opposing regions of 2 cell peripheries are brought close enough together, in the order of 2 or 3 Angstrom units, adhesion can occur between them. The physical Van der Waals forces and the chemical attractive forces arising from electrovalent, polar and nonpolar covalent and hydrogen bonds may be of possible importance in cellular adhesion. In addition, radially orientated calcium bridges linking adjacent anionic groups at the surfaces of 2 adjacent cells will contribute to the strength of adhesion between the 2 cells. Tangentially orientated calcium bridges will, however, increase the cohesive strength of the individual cell and therefore impede separation (Weiss, 1970).

As cells are dynamic systems, long term adhesive interactions between them and to noncellular surfaces are established by the synthesis and secretion of cell surface material and by the development of specialized structures such as desmosomes and hemidesmosomes (Fig. 13). Listgarten (1966) demonstrated that epithelial cells show microvilli and secretory vacuoles which indicate cellular secretion. A characteristic feature of epithelial cells is the specialization of certain portions of cells of the surface membrane for adhesion or attachment. Examples are desmosomes which provide intercellular attachment and hemidesmosomes which hold epithelial cells to noncellular surfaces such as the basal lamina on the enamel surface (Taylor, 1970). Cleaton-Jones and Fleisch (1973) recently suggested that besides adhesion between epithelial cells arising from physical and chemical attractive forces, mechanical factors may play an important part in the retention of epithelial cells.

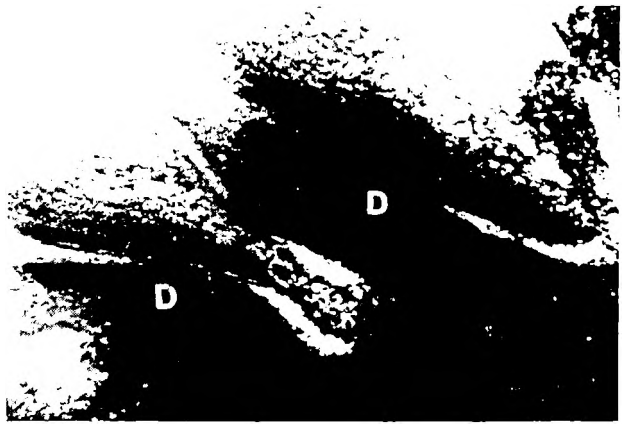


Fig. 13. Desmosomes (D) between epithelial cells. X 100,000 (Printed with kind permission of Dr. P.E. Cleaton-Jones).

3. Cell separation

If 2 adherends A and B are separated, the separation seldom, if ever, occurs at the substrate interface A/B. Ruptures, which may be at a microscopic level, occur within the 2 adherends because of cohesive failure resulting, after separation, in pieces of A being left on surface B if B is stronger or more coherent than A resulting from cohesive failure is often observed in extracted teeth. Attached periodontal tissues are often observed on extracted teeth.

The adhesion of epithelial cells to enamel is of great importance in periodontics as it provides the first barrier to the ingress of bacteria and their products in the initiation of gingival inflammation (Fig. 14).

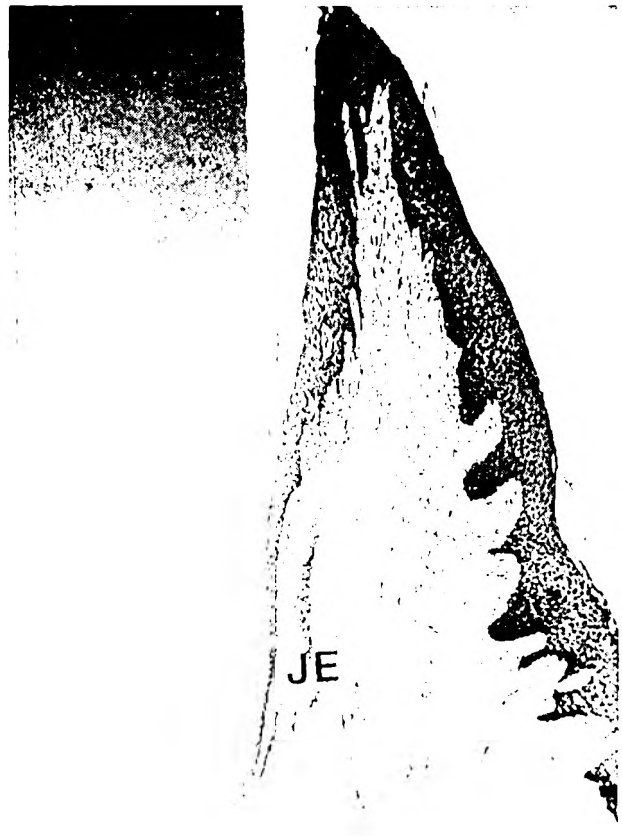


Fig. 14. Junctional epithelium (JE) and related structures in a tooth of the vervet monkey. .. 100.

The adhesion of cells in culture to hard surfaces has been repeatedly demonstrated and it is therefore not surprising that enamel provides a satisfactory substrate for cellular adhesion. The epithelial cells of the gingival crevice have the ability to adhere to enamel but it cannot be inferred that such adhesion plays the major role in maintaining the integrity of the dentogingival junction. Other factors such as the blood-pressure in the subepithelial vascular network of the crevice and the gingival collagen fibres themselves, may also play an important part in this process (Powell, 1968).

Prior to 1921 it was the general belief that a definite space separated the enamel surface from the surrounding gingival epithelium. The attachment between tooth and surrounding tissues was believed to be mediated only through connective tissue fibres inserting into cementum and bone (Schroeder and Listgarten, 1971). The concept of a firm organic union between the tooth and adjacent epithelial cells was first proposed by Gottlieb (1921) and this union was called the "attachment epitheluim". This classic theory of the epithelial attachment being a static structure with organic continuity from cell to primary cuticle to enamel matrix does not, however, fit the physiology of

Waerhaug (1952) concluded that there was no firm attachment of the epithelium to the enamel surface. He considered that the connection between the epithelium and the tooth depended on adhesion and introduced the term "epithelial cuff" to replace epithelial attachment. Waerhaug's concept implied a dynamic attachment mechanism which would provide for the cellular movement, associated with the normal cycle of cell replacement, over the enamel surface. That the renewal of gingival epithelium occurs, has been clearly demonstrated by the autoradiographic studies of Skougaard and Beagrie (1962).

The ultrastructural features of the dento-epithelial junction have been reviewed in detail by Schroeder and Listgarten (1971). Amongst others, they defined the junctional epithelium as "the epithelial collar which provides the epithelial attachment to the tooth surface, continuous with, but structurally distinct from the oral sulcular epithelium" and the epithelial attachment as "the biological mechanism which unites epithelial cells to the tooth surface. Its morphologically recognizable components are hemidesmosomes and the internal basement lamina"

Listgarten (1972) studied the epithelial reattachment after gingivectomy in monkeys and found that the reattachment may occur in 12 days or less. A photomicrograph obtained 4 weeks post-operatively (Fig. 15) clearly demonstrates how the junctional epithelium provides a union between the connective tissue of the gingiva and the enamel surface. On the tooth side the union is mediated by an attachment apparatus, the epithelial attachment, which consists of an internal basement lamina and hemidesmosomal junctions. The basement lamina is produced by epithelial cell activity. Desmosomes provide inter-junctional epithelial cell adhesion.

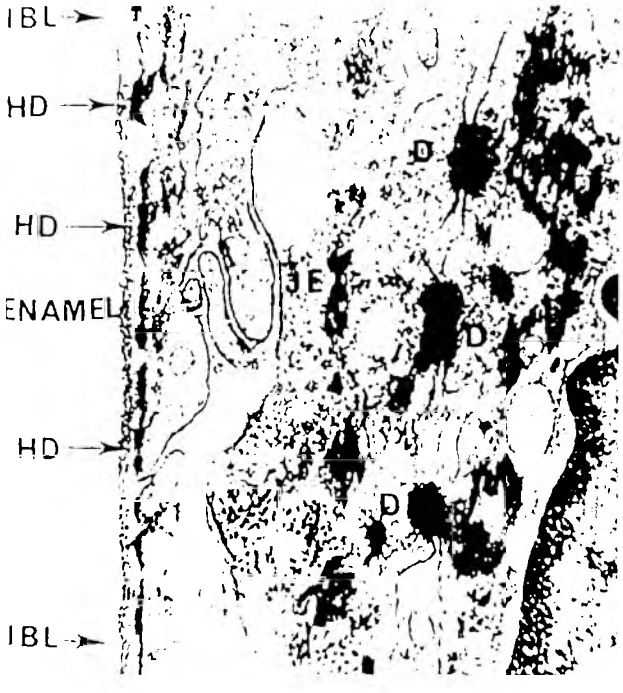


Fig. 15. Junctional epithelium (JE) connected via hemidesmosomes (HD) and an internal basement lamina (IBL) directly to the enamel surface. Desmosomes (D) provide interjunctional epithelial adhesion. X 35,000. (Reprinted with kind permission of Dr. M. Listgarten (1972) Journal of Periodontal Research, 7, 151-160).

ADHESION IN PROSTHETIC DENTISTRY

The factors affecting the retention of full dentures can be divided into physical and physiological forces. Only the physical forces involved in denture retention will be discussed. The physical forces operate in the saliva film between the denture and the surrounding tissues and include adhesion and cohesion, surface tension, atmospheric pressure, viscosity of the saliva and capillarity (Stanitz, 1948; Lawson, 1965; Brill, 1967; Barbenel, 1971; Blahova and Neuman, 1971). Phenomena associated with surface tension and adhesion are frequently considered under the general title of capillarity or capillary action and capillarity will therefore not be considered as a separate entity.

There is no general agreement, but often disagreement, concerning the relationship and the relative importance of the physical forces that influence denture retention.

The force exerted on the flat bounding surface of a fluid at constant pressure is equal to the difference in pressure between the fluid and the atmospheric pressure, multiplied by the area of the surface (Stanitz, 1948).

Force Pressure difference X area.
F (Pf - Pa) A . . . . . (1)
Where: Pf The fluid pressure
Pa The atmospheric pressure
A - The surface area

A similar force is required to separate 2 circular parallel plates separated by a film of fluid (Fig. 16).

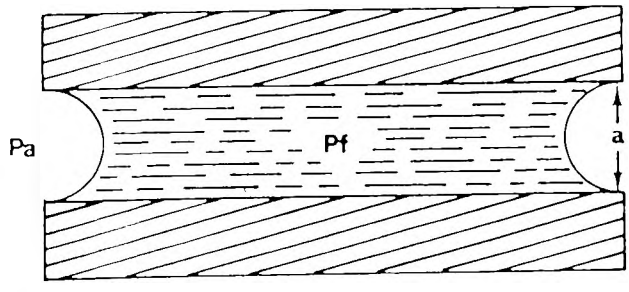


Fig. 16. Fluid film between two circular flat plates. The film thickness is a.

Stanitz (1948) used the familiar example of the rise of a fluid in a capillary tube to portray the parts played by adhesion and surface tension in denture retention. The pressure immediately below a meniscus in a capillary tube is less than on the same level outside the capillary tube. As a result of this difference in pressure, the meniscus is forced up the tube and equilibrium is attained only when the fluid surface inside the capillary is h cm above the free surface of the fluid (Fig. 17). The adhesive force, A, between the fluid and the capillary wall pulls the column of fluid up the capillary tube. The adhesive force could not succeed in doing this if it were not for the surface tension forces, B, which transmit the adhesive force along the upper surface of a fluid column, i.e. along the meniscus. The heights of the column are determined when the weight of the column is equal to the surface tension force.

Weight of the column = Surface tension force
i.e.
$d\pi r^2 h = 2\pi r \gamma$

$$h = \frac{2\gamma}{dr} \quad \ldots\ldots (2)$$

Where: d = Density of the liquid
h = Height of the column
r = Radius of the capillary
γ = Surface tension of the liquid

In this analysis, Stanitz (1948) assumed that the contact angle of the fluid surface on the capillary wall was zero.

The pressure at the bottom of the fluid column at C is equal to atmospheric pressure, Pa, at the free surface of the fluid. The pressure at C must be greater than the pressure in the fluid at the top of the column by an amount equal to the weight of the fluid column divided by the cross-section area of the capillary tube. The fluid pressure at the top of the column, Pf, is therefore less than atmospheric pressure, Pa. The pressure difference can be calculated from the following formula:

$$\text{Pressure difference} = \frac{\text{Weight of fluid column}}{\text{Cross-section area of tube}}$$

i.e.

$$Pa - Pf = \frac{d\pi r \cdot h}{\pi r^2}$$

$$= dh \quad \ldots\ldots (3)$$

By combining equations (2) and (3), h and d are eliminated.

$$Pa - Pf = \frac{2\gamma}{r} \quad \ldots\ldots (4)$$

If the capillary tube is replaced by 2 circular parallel plates separated by a film fluid with thickness, a, (Fig. 16), the surface tension at the meniscus similarly sustains a pressure difference across the surface. The fluid pressure, Pf, is constant throughout the fluid and is less than the atmospheric pressure, Pa. Equation (4) can be replaced by:

$$Pa - Pf = \frac{2\gamma}{a} \quad \ldots\ldots (5)$$

A force, F, is required to pull these plates apart (Fig. 18). This force equals the pressure difference multiplied by the area of the plates as indicated in equation (1). By combining equations (1) and (5), the term Pa-Pf is eliminated:

$$F = -\frac{2\gamma A}{a} \quad \ldots\ldots (6)$$

The minus sign indicates that the forces, F, act away from the plates.

Although this model of 2 circular flat plates separated by a thin film of fluid is an oversimplification of the conditions encountered in the mouth, the above formula can be profitably employed to explain the role that physical forces play in denture retention. Let us assume that the denture is seated on a firm base permitting a uniform thickness along the periphery of the denture and that the space between the denture and the base is filled completely with fluid (Fig. 19). The pressure difference sustained by the surface tension across the meniscus along the periphery of the denture will be transmitted throughout the body of the fluid film. The force required to dislodge the denture is equal to this pressure difference multiplied by the projected area of the denture in the direction of force. The force per unit area of the denture varies inversely with the film thickness, a, along the periphery of the denture (Stanitz, 1948).

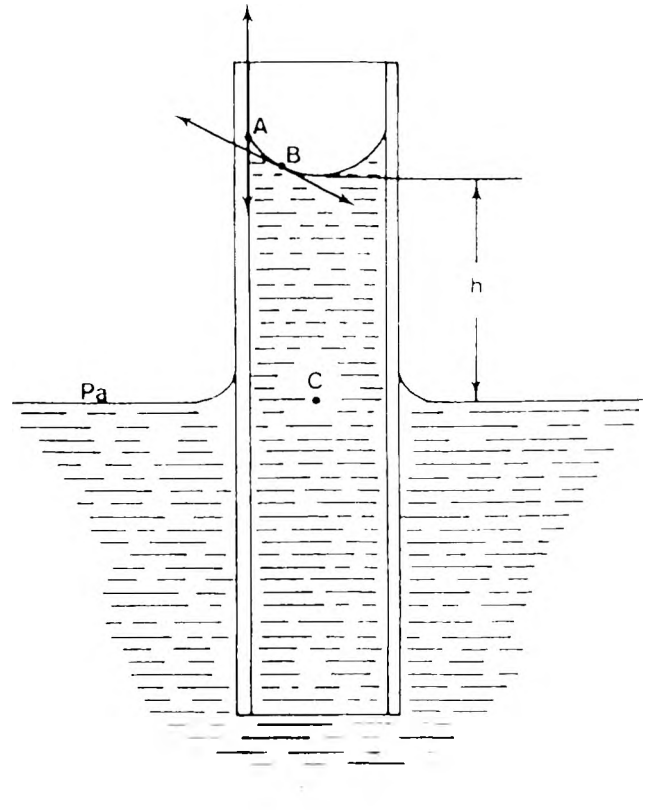


Fig. 17. Fluid rise in a capillary tube.

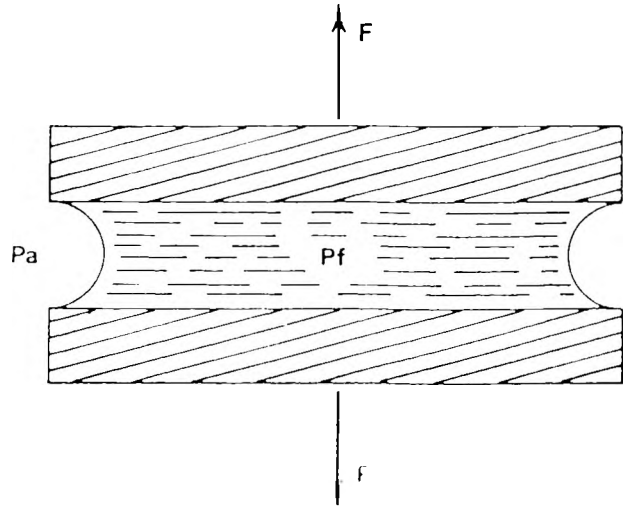


Fig. 18. A force, F, is required to pull the plates apart.

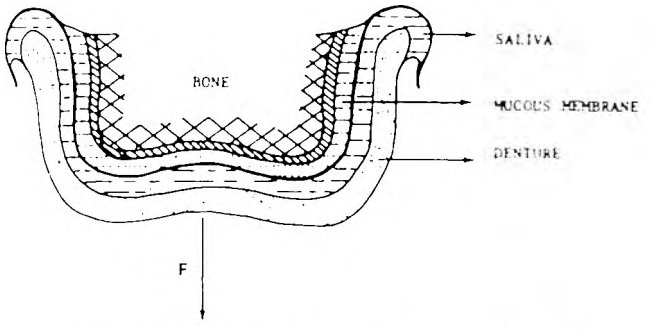


Fig. 19. Cross section of upper denture seated on its base.

The part played by the fluid film in denture retention therefore arises as a result of the difference in pressure between the atmosphere and the fluid film. The adhesive and surface tension forces are not large and do not in themselves exert an appreciable retentive force on the denture. They do, however, sustain the pressure difference across the meniscus of the fluid film. Thus, the total force exerted on the denture is equal to the pressure difference multiplied by the projected area (Avant, 1973).

Stanitz (1948) assumed in his calculations that the contact angle of the fluid surface on the capillary wall was zero. Few liquids wet an adherend surface completely but usually exhibits a contact angle, θ, at which the fluid intersects the wall of a capillary tube. Furthermore, Craig, Berry and Peyton (1960) showed that the gravitational constant, g, should also be considered when calculating the forces involved in denture retention. By incorporating these 2 factors in equation (6), it becomes:

$$F \quad \frac{-2\gamma A \cos\theta}{dg} \ldots\ldots\ldots (7)$$

O'Brien (1973) recently suggested an additional mechanism whereby surface tension could play an even more important part in denture retention. Isolated capillaries are formed when liquids are trapped in crevices isolated from a reservoir. An isolated capillary (isocap) and connected capillary system are illustrated in Fig. 20. He suggested that a marked increase in the surface tension of saliva occurred in isolated capillary systems. In the case of denture retention, the tight peripheral seal creates the isolated capillary which results in greater wettability and hence increased adhesion.

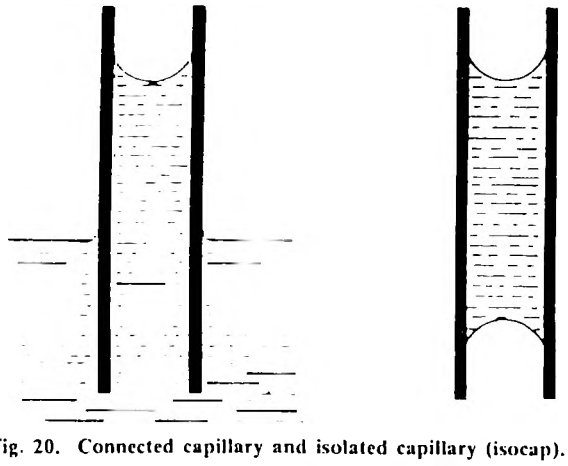


Fig. 20. Connected capillary and isolated capillary (isocap).

Several investigators contend that denture retention is supported by atmospheric pressure. This contention is based on the assumption that when the denture is dislodged from the basal seat, a lower pressure is formed under the denture in comparison with the pressure of the surrounding atmosphere. This mechanism would only function, however, if a perfect border seal was possible and if the space between the denture base and the mucous membrane was filled with air. Blahova and Neuman (1971) believe that atmospheric pressure in itself cannot be the cause of denture retention but that retention results from the difference of pressure under the denture and outside it.

Viscosity opposes the displacement and flow of fluid between 2 plates or of saliva between denture base and mucosa. Increased salivary viscosity will aid denture retention by resisting inflow of saliva from the oral cavity. If this inflow is not opposed, the increase in fluid thickness between the denture base and mucosa will result in reduced denture retention.

The prosthodontist can therefore obtain increased denture retention by adopting the following procedures:

1. Ensure maximal extension of the denture base. This will result in maximum projected surface area, A, of the denture base.
2. Achieve the closest possible contact between denture base and mucosa. This can be achieved by careful impression taking and processing of the denture.
3. Develop a posterior palatal border and peripheral seals which cause elastic displacement of the border tissues. This will ensure a narrow salivary film and meniscus and create an isolated capillary system.
4. Avoid the incorporation of palatal relief areas which result in decreased retention of the denture (Skinner and Chung, 1951).

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