The physical mechanisms of complete denture retention

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The purpose of this article is to assist the practitioner to understand which factors are relevant to complete denture retention in the light of the current understanding of physics and materials science and thus to guide design. Atmospheric pressure, vacuum, adhesion, cohesion, surface tension, viscosity, base adaption, border seal, seating force and muscular control have all been cited at one time or another as major or contributory factors, but usually as an opinion without proper reference to fundamental principles. Although there has been a detailed analysis published, it seems appropriate that a restatement of the points in a collated form be made. In fact, denture retention is a dynamic issue dependent on the control of the flow of interposed fluid and thus its viscosity and film thickness, while the timescale of displacement loading affects the assessment. Surface tension forces at the periphery contribute to retention, but the most important concerns are good base adaptation and border seal. These must be achieved if full advantage is to be taken of the saliva flow-related effects.

'Denture retention will be a subject perplexing and perpetual until its troubles find their logical solution in understanding its physics.' (Hall, 1918)[1] This understanding now in fact exists but it is obscured by repetition of long-held erroneous beliefs. Although the various issues have been analysed in detail and discussed at length, an up-to-date account based on modern research and understanding of materials science has yet to appear in an accessible form for the benefit of the practitioner. It is the aim of this article to address this deficiency.

Denture retention has been defined as 'resistance of a denture to vertical movement away from the tissues'[2] and as 'that quality inherent in the prosthesis acting to resist the forces of dislodgement along the path of insertion'.[3] It is clear then that ordinarily retention is regarded as a property of the denture rather than of the patient.

In brief
- A clear view of the underlying principles of retentive denture design.
- Confidence that 'best-practice' is founded on scientific principles.
- Allows the discarding of fanciful notions and gimmicks in favour of attention to detail on the part of the practitioner.

There is general acceptance among clinicians that to achieve retention in complete dentures there first needs to be an accurate fit of the denture base to the mucosa so that the space between the two is as small as possible. Secondly, there needs to be a border seal, which is achieved by extending the denture flanges to fill the sulci. The subject of this paper is not the means by which these conditions are achieved clinically but rather the physical mechanisms by which dentures of this design are retentive.

Many physical forces and factors have been credited with causing or enhancing retention, eg atmospheric pressure, vacuum, adhesion, cohesion, wettability, surface roughness, gravity, surface tension, viscosity, base adaptation, border seal and muscular control. However, while the majority of this list have survived for a long time in teaching texts (and examination answers) they do not all survive scientific scrutiny.[4]

Factors not important in complete denture retention

Atmospheric pressure

The pressure of the atmosphere has commonly been claimed to be an aspect of complete denture retention,[5–9] but this is readily shown to be false. It could only operate by way of a pressure difference, that is, beneath the denture there must be a lower pressure, and the full effect could only be felt if there were a vacuum there.

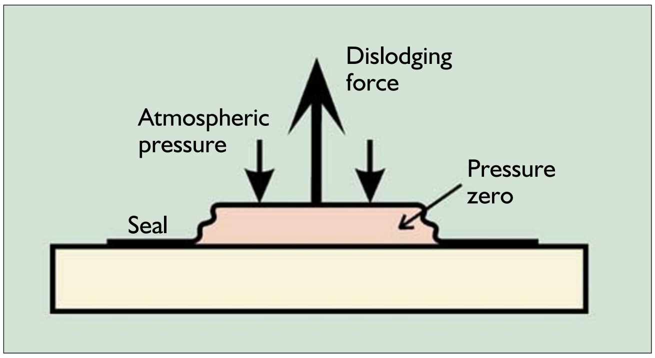

Fig. 1 Displacement of a sealed bellows-like device results in a vacuum in the emergent space, the displacing force being balanced by that from atmospheric pressure. There is no static retaining force otherwise. Comparable conditions are unlikely to occur in the mouth

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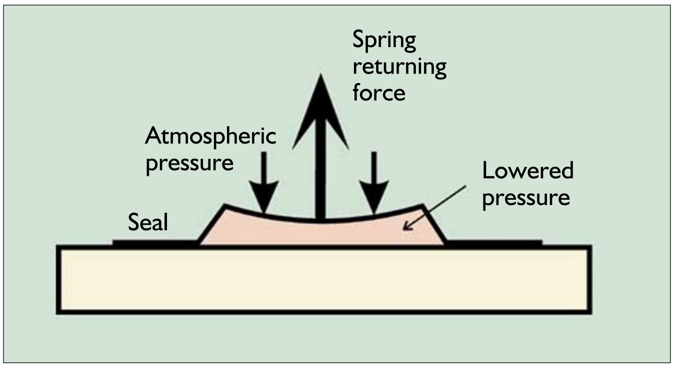

Fig. 2 All valve and suction retention systems are similar: a spring of some description attempts to maintain a region of lowered pressure. These all fail to be effective in the long run for physiological reasons

Assuming that a vacuum could be generated by virtue of a pull being applied that tended to increase the volume between the denture base and the tissue beneath, the requirement would be for a seal to be maintained around some area for the lowered pressure to be sustained (Fig. 1). The 'retention' thus generated is an emergent property, arising only because of the pull and consequent displacement. While it can be argued that this is precisely the condition that is to be attained, clearly other factors are required: the seal would be crucial. In any case, for example, it is not certain that a true 'seal' of acrylic to mucosa can be achieved. However all parts of the system of denture and wearer are exposed to the atmospheric pressure, and the hydraulic nature of the soft tissue means that, under 'resting' conditions this will be transmitted into the region between denture and tissue hydrostatically. Under normal conditions, therefore, there is no pressure difference, no static retaining force, and atmospheric pressure as such has no bearing on retention.

Vacuum

Conversely, a 'vacuum' has been claimed to be instrumental in retention.[10,11] The same arguments apply, of course, as for atmospheric pressure, except that the lowered pressure (it was never really imagined to achieve zero pressure) would have to be generated by some artificial means, ie prior to any pull being exerted. This has been attempted with suction cups and valves of one kind or another (Fig. 2), under various names, and although such devices have always failed — with poor consequences for the patient (soft tissue proliferation is but one common effect) — there is still an absolute dependence on a true seal being created around some area. To claim a vacuum is involved, therefore, is both overstating the case and misleading.

Adhesion

Adhesion ordinarily means some specific chemical interaction across the interface of two solids (Fig. 3). Whether this be through covalent bonds or chelation, the concept is of a fixed relationship at the molecular level. This has never been claimed for dentures, there being no known mechanism for a direct acrylic-mucosa reaction that would achieve this. Even so, the concept is frequently expressed in the denture retention field so vaguely as to be useless:[12–15] the fact that there is a resistance to separation is called adhesion regardless of the inability to identify a specific mechanism.

Cohesion

Cohesion is understood to be the 'internal' strength of a material, that is, as distinct from the strength of its interface with any other body. Cohesive failure therefore means the separation of molecules within the body against inter- or intramolecular forces (Fig. 3). Such strengths are high. It has never been claimed that a denture has failed to be retained because of such a breakdown, which might perhaps be expected to occur in the soft tissue rather than the acrylic. Indeed, the tensile strength of water (and therefore saliva) is very high, although demonstrating this is very difficult because of the need to avoid the nucleation of bubbles. Great negative pressures are required. The formation of bubbles in a saliva film would certainly cause loss of retention, but the effect is caused by the ease of their flow, not the loss of cohesion. Thus, although one can state that the cohesive strength of the materials involved is necessary for retention,[10,16–18] this is misleading if not irrelevant in that cohesive failure never has occurred, indeed never could occur without damaging the patient or the denture.

Wettability[19–22]

This refers to the lowering of the energy of a system when a liquid wets a solid surface. Thus, to break such an interface is similar to breaking the adhesion between solids: work needs to be done to create the break and a

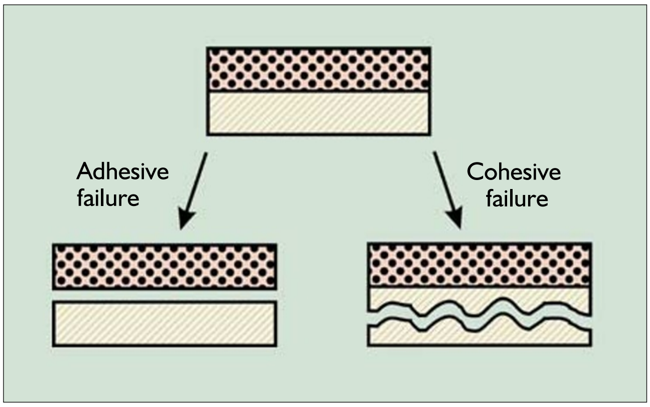

Fig. 3 Adhesive failure refers to the interface between two bodies; cohesive failure to within a material itself. Note: the cohesive strength of saliva is much greater than the adhesion of mucosa to PMMA

strength can be attributed to it as an interface. Conversely, it is true that if there were no wetting, no force would be needed to be applied to separate the denture from saliva and there would be no retention. Acrylic does, however, wet with water. With saliva, the effect is even better: proteins and mucopolysaccharides from the saliva adsorb to the acrylic rapidly and strongly and in so doing present a surface which is more wettable. Nevertheless, interfacial failure by a simple separation of denture and saliva does not occur. This strength is therefore quite adequate and its insufficiency can be discounted as a factor of any importance needing to be addressed (but see later).

Surface treatments have sometimes been advocated as an aid to wetting, but these are either of dubious validity or immediately negated by the adsorbed film from saliva — which happens anyway.[23,24] They therefore cannot contribute to retention.

Surface roughness[25–27]

Insofar as increasing roughness would increase the interfacial area for adhesion between saliva and denture, the strength of that union would be improved. However, since, as stated above, failure does not occur at this site in this way, roughness is irrelevant and can be discounted.

Gravity[8, 14, 17, 28]

This is a trivial force and clearly only applies to the denture that is resting on the mucosa under its own weight. Gravity obviously needs to be overcome to raise the denture, but equally it contributes to the lack of retention of the uppermost denture (depending on the orientation of the wearer at the time). Since gravity would be of no benefit there, or for a wearer in a face-down position for any reason, it can be discounted as unhelpful. The mass of a lower acrylic denture is typically only a few grams, and increasing this appreciably can only be at the expense of fatigue for the jaw carrying the load.

Muscular control

Muscular control is frequently cited as an important contributor to retention.[29–32] However, reference to the definitions of retention will show that although it is an important aspect of successful complete denture use it is not relevant to retention in the strictest sense because, as observed above, retention is a quality of the denture rather than the patient. Furthermore, muscular control is perhaps better referred to as the 'patients' manipulative skill' and as such goes beyond retention, including therefore other related aspects of denture design.

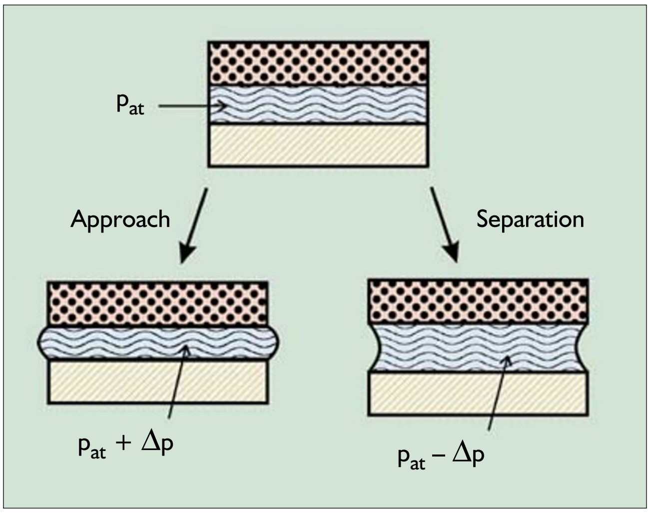

Fig. 4 Bulging liquid surfaces imply a higher pressure within the liquid; incurving surfaces imply a lowered pressure

Factors important in complete denture retention

Surface tension[33–36]

One of the consequences of the surface tension of liquids is the tendency to minimize the area of the free surface, generating the familiar curved surfaces of raindrops and menisci. The mere existence of a curved surface generates a pressure difference across that surface. If the surface is convex (which is described as a positive total curvature) the pressure is higher within the drop than without — therefore, positive pressure. If the total curvature is negative, such as for the 'waisted' shape of a drop held between one's fingertips, the pressure is negative. This is the crucial point: that negative pressure exerts a force tending to draw the fingertips together. This is the force that retains two wet microscope slides together against a straight pull (not a sliding action). At the edge is a very thin film of water, with a large negative curvature because the separation of the slides is small, thus the force is great (Fig. 4). Notice that if the bead of liquid at the edge were bulging out, the force would be positive — tending to separate the slides — and some movement would be easy. However, the moment the liquid surface is withdrawn inside the boundary of the slides it becomes negatively curved. This is because the edge of the liquid (the 'contact line') is pinned in position on the edge of the slide when the glass is wetted by it. This force can be seen to be the familiar one of 'capillarity'. The tendency to advance a wetting liquid into narrow spaces — maximizing the wetted area — is caused by the force acting at the contact line, drawing it over the surface. There is necessarily a lowered pressure behind the meniscus, which is negatively curved.

Thus, on the assumption that the denture base is wetted by saliva (which we have seen is the case), an attempt to withdraw the denture generates along its periphery a narrow, highly negatively-curved saliva surface. There is therefore a lowered pressure in the liquid-filled space and a retentive force is experienced. Atmospheric pressure is not involved: only the generated surface tension-mediated pressure difference is effective. However, the existence of this effect is contingent on the wetting of the denture base by saliva, and to this extent only the issue of wettability can be reinstated as a factor of importance.

Even so, the question remains as to whether such a situation can arise in the

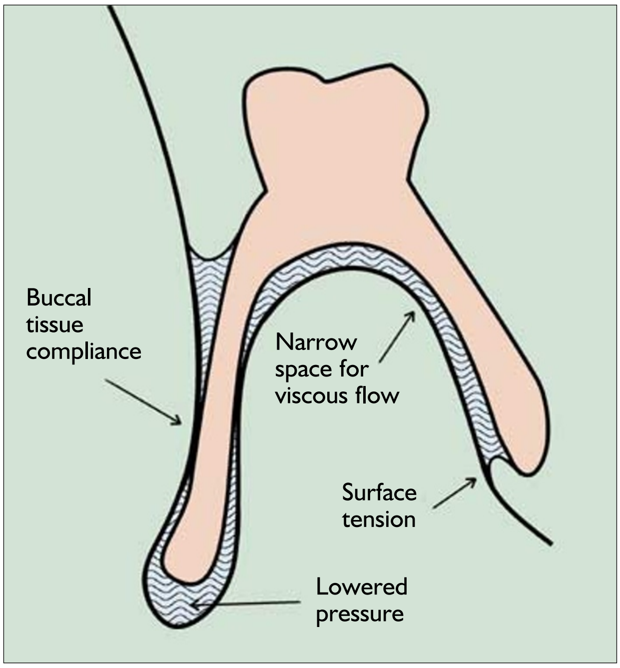

Fig. 5 Simplified cross-section to illustrate the seal arising from compliant tissue, flow restriction in narrow spaces, and the effect of surface tension in a well-fitting denture

mouth. If we consider the peripheral conditions we can see that the only extended location where this can be directly relevant is the posterior border of the palate of an upper complete denture. The remainder of the margin tends to be enveloped in soft tissue such that withdrawal of the denture results in a sliding action rather than straight separation. Thus, for separation to occur, ie, a space develops between the tissue and acrylic, flow of saliva must occur, either from somewhere else to fill that space, or at least as the meniscus is drawn back over the opposing surfaces (Fig. 5).

Viscosity[37–39]

A major consideration is the rheology of the saliva and where its viscosity is located. Simply put, this is the rate of separation of the two surfaces under a given applied force and it depends inversely on the viscosity. However, the viscosity of the wearer's saliva is not readily controllable, although there is some variation from time to time for a variety of reasons. Thus the use of more viscous media as denture retention aids would seem logical, but flushing and solubility would mean a limited time of efficacy. As the viscosity of saliva is many times that of air separation is therefore much more difficult when this fluid fills the space.

Time

It is worth noting that flow is a time-dependent phenomenon.[16,25] That is, the amount of separation of denture and mucosa that can occur depends on the duration of the application of any force. If a reseating force is applied before detachment has occurred, such as in chewing, the displacement will only be transitory and may never reach the point of collapse. Equally, a long period unsupported may in theory see an upper denture fall away simply because enough time has been allowed for sufficient flow to occur. (A patient may be expected to reseat the denture long before this happens.) Thus care is needed in judging retention because it is a dynamic affair: so-called static test results may not offer very helpful comparisons because there is always some time-scale for the test, and the results can only be interpreted on that time-scale.

Base adaptation[40–42]

In plain terms, how well the denture fits is singularly important. This is so because the measure of the fit is the size of the gap between the fitting surface and the mucosa, since it is this that controls the flow occurring there. For a fully immersed system (that is, no air being admitted), the force required for separation at a given rate depends inversely on the cube of separation. Once air is admitted at the edges, the force depends inversely on the fifth power of separation, ie collapses more readily but still implying the benefits of close adaption (this is because, as indicated above, the flow of the air is so much easier that it provides no appreciable resistance to separation in comparison with the effect of the saliva). These relationships also show that the fit must be uniformly good over the entire tissue surface: the viscous retardation contribution from a region of even slightly greater separation will be substantially less than that from a closer fitting area, perhaps even negligible. A secondary feature to note is that the narrowness of the gap contributes a retentive force through the effects of surface tension, via the curvature that results in the liquid surface (Fig. 5). The deduction from this is that the retention of dentures against a tipping action will be less effective than against a straight pull.

Border seal[15,43–45]

Attention was drawn under 'Surface Tension' to the fact that along most of the border of a denture there is double contact of acrylic and soft tissue such that displacing the denture in the separation sense does not open a gap along that border. There are two effects arising from this. Firstly, the cross-section through which saliva must flow in order to fill the space is small, and the viscous retardation of displacement correspondingly large. Secondly, the compliance of the buccal tissues in particular means that the lowered pressure beneath the denture caused by that displacement would tend to hold them in place in close approximation to the acrylic, maintaining the seal (Fig. 5). It is therefore apparent that the design of the denture should take this into account in terms of extension into the buccal sulcus and in ensuring a smooth enough, grooveless surface so that no leaks occurred.

Seating force

It has been suggested that when a denture is put in place a firm seating force be applied as this aids retention.[14,46,47] Certainly, the immediate effect will be to ensure the thinnest possible saliva film and so the best effect is caused by the viscous retardation of displacement. However, this must also be achieved at the expense of some displacement of the supporting soft tissue, and if this created a better fit, it would not last long as that tissue rebounded elastically. The continued secretion from mucosal glands would also offset any immediate benefit. It may, however, be useful that the deliberate seating force would tend to expel air which, as noted above, would not contribute to retention. But one imagines that the first displacement (which must be considered inevitable at some point) would reintroduce such bubbles, thereby reducing retentiveness.

Soft tissue

Denture retention is therefore a dynamic issue as it mostly depends on factors controlling the flow of the interposed fluid.[48] The better the fit to the tissue, and the better the linear extent of the seal at the border, the better the denture will resist short term displacing forces. Brill's analogy of a piston in a cylinder of water[49] offers a partial description of the fluid dynamics of the border seal but without alluding to the compliant behaviour of the soft tissues (ie when the pressure in the denture-mucosa space drops), which is relevant at least when the denture is first fitted. In the medium term soft tissue remodelling can be expected to maintain mucosal contact on both the tissue surface and at the borders. But, in the longer term, resorption and remodelling of the hard tissue may exceed the adaptive capacity of overlying soft tissues and retention may eventually be lost. However, the patient will have learned progressively to use the dentures as the fit changes and have developed the manipulative skill and control required to compensate for that deterioration. It is therefore in this later-stage context that the so-called 'muscular control' becomes particularly important, and also therefore the design of the polished surface to facilitate this.

Ultimately, the central factors for the success of a denture depend primarily on the quality of the fit of the denture to soft tissue.[50] This in turn hinges on the impression technique and subsequent denture base design and fabrication — but that is another story altogether.

This paper is dedicated to the memory of Michael Dominic Murray (1931–1995), whose PhD research under our supervision stimulated our interest in this subject.

1 Hall R E. Retention of full dentures. *Dent Rev* 1918; 32: 175-191.
2 Nairn R I, Shapiro N M S (eds). *Prosthetic Dentistry Glossary.* London: Quintessence, 1995.
3 Anon. *Glossary of Prosthodontic Terms.* 7th ed. *J Prosthet Dent* 1999; **81**: 45-106.
4 Murray M D, Darvell B W. The evolution of the complete denture base. Theories of complete denture retention — A review. *Austral Dent J* 1993; **38**: 216-229, 299-305, 389-393, 450-455.
5 Hoffman-Axthelm W. *History of Dentistry.* Philadelphia: Quintessence, 1981.
6 Lufkin A W. *A History of Dentistry.* 2nd ed. Philadelphia: Lea and Feibiger, 1948.
7 Skinner E W, Chung P. The effect of surface contact in the retention of a denture. *J Prosthet Dent* 1951; **1**: 229-235.
8 Abdullah M A. Surface tension in retention of complete dentures. *J Prosthet Dent* 1972; **28**: 141-144.
9 Jacobson T E, Krol A J. A contemporary review of the factors involved in complete denture retention, stability, and support. Part I: Retention. *J Prosthet Dent* 1983; **49**: 306-312.
10 Hall R E. Retention of full dentures. *Dent Items of Interest* 1919; **41**: 292-305.
11 Kubali K N. The theoretic basis of the functional vacuum method for complete denture construction. *J Prosthet Dent* 1960; **10**: 673-681.
12 Ambler H L. History of Dental Prosthesis. In: Koch C R E (ed.) *History of Dental Surgery.* Vol. 1. Fort Wayne, IN: National Art Co 1909; 245-264.
13 Howland C A. The retention of artificial dentures. *Dent Dig* 1921; **27**: 159-162.
14 Ostlund S L G. Some physical principles in the retention of dentures. Northwestern University Bulletin 1947; **49**: 11-20.
15 DeMagistris D P. *Physicomechanical characterization and formulation of natural, modified natural, and synthetic polymers including polymer salt and ester derivatives as oral bioadhesive materials.* Thesis. Purdue University. 1981: 1-48.
16 Lindstrom R E, Pawelchak J, Heyd A, Tarbet W J. Physical-chemical aspects of denture retention and stability: a review of the literature. *J Prosthet Dent* 1979; **42**: 371-375.
17 Lammie G A. The retention of complete dentures. *J Am Dent Assoc* 1957; **55**: 502-508.
18 Barbenel J C. Physical retention of complete dentures. *J Prosthet Dent* 1971; **26**: 592-600.
19 Craig R G, Berry G C, Peyton F A. Physical factors related to denture retention. *J Prosthet Dent* 1960; **10**: 459-467.
20 O'Brien W J, Ryge G. Wettability of poly(methylmethacrylate) treated with silicon tetrachloride. *J Prosthet Dent* 1965; **15**: 304-308.
21 Boucher L J, Ellinger C, Lutes M, Hickey J C. The effect of a microlayer of silica on the retention of mandibular complete dentures. *J Prosthet Dent* 1968; **19**: 581-586.
22 Gesser H D, Castaldi C R. The preparation and evaluation of wetting dentures for adhesion and retention. *J Prosthet Dent* 1971; **25**: 236-243.
23 Murray M D. Investigation into the wettability of poly(methylmethacrylate) *in vivo. J Dent* 1986; **14**: 29-33.
24 Murray M D. An investigation into the effectiveness of surface treatment on PMMA when exposed in the mouth. *J Prosthet Dent* 1988; **59**: 368-273.
25 Roydhouse R H. The retention of dentures. *J Am Dent Assoc* 1960; **60**: 31-35.
26 Tyson K W. Physical factors in retention of complete upper dentures. *J Prosthet Dent* 1967; **18**: 90-97.
27 Kilani B H I, Retief D H, Guldag M V, Castleberry D J, Fischer T E. Wettability of selected denture base materials. *J Prosthet Dent* 1984; **52**: 288-291.
28 Pryor W J. The physical forces or phenomena utilized in the retention of dentures. *J Am Coll Dent* 1945; **12**: 125-133.
29 Cox A M. A consideration of the fundamental physical principles involved in the retention of artificial dentures. *Br Dent J* 1926; **47**: 1059-1071.
30 Snyder F C, Kimball H D, Bunch W B, Beaton J H. Effect of reduced atmospheric pressure upon retention of dentures. *J Am Dent Assoc* 1945; **32**: 445-450.
31 Lawson W A. Fundamental principles of full denture prosthetics. *Int Dent J* 1960; **10**: 497-517.
32 Brill N. Factors in the mechanism of full denture retention – a discussion of selected papers. *Dent Pract Dent Rec* 1969; **18**: 9-19.
33 Schulze W. Ueber Adhaesion und Luftdruck und ihre Verwendung bei der Fixierung kunstlicher Gebisse. *Dtsch zahnartzl Wschr* 1921; **24**: 538-543.
34 Eberle W R. Rationale of denture retention. *Dent Dig* 1946; **52**: 315-322.
35 Stanitz J D. An analysis of the part played by the fluid film in denture retention. *J Am Dent Assoc* 1948; **37**: 168-172.
36 O'Brien W J. Base retention. *Dent Clin North Amer* 1980; **24**: 123-130.
37 Moses C H. Physical considerations in impression making. *J Prosthet Dent* 1953; **3**: 449-463.
38 Ostlund S L G. Palatine gland and mucin: Factors affecting the retention of complete dentures. *Odontol Tids* 1954; **62**: 7-128.
39 Blahova I, Neuman M. Physical factors in retention of complete dentures. *J Prosthet Dent* 1971; **25**: 230-235.
40 Page H L. Mucostatics, a Principle not a 'Technique'. Chicago, Published by the author, 1946; 22-23.
41 Giglio J J, Lace W P, Arden H. Factors affecting retention and stability of complete dentures. *J Prosthet Dent* 1962; **12**: 849-856.
42 Barco M T, Dembert M L. Removable Prosthodontics — Cast aluminium denture base. *J Prosthet Dent* 1987; **58**: 179-186.
43 Ames W B. Atmospheric pressure in the retention of entire dentures. *Br Dent J* 1885; **6**: 601-604.
44 Padgett F. On obtaining the maximum adhesion. *Dent Mag Oral Topics* 1933; **50**: 22-29.
45 Skinner E W, Campbell R L, Chung P. A clinical study of the forces required to dislodge maxillary denture bases of various designs. *J Am Dent Assoc* 1953; **47**: 671-680.
46 Ostlund S L G. Saliva and denture retention. *J Prosthet Dent* 1960; **10**: 658-663.
47 Stamoulis S. Physical factors affecting the retention of complete dentures. *J Prosthet Dent* 1962; **12**: 857-864.
48 Murray M D. *Physical aspects of complete denture retention.* PhD Thesis. The University of Hong Kong, 1989.
49 Brill N, Tryde G, Hvoltz I L. *Odontologisk Protetik.* Copenhagen: Odontologisk Boghandels Forlag, 1973.
50 Murray M D, Darvell B W. A reappraisal of the physics of denture retention. *Int J Prosthodont* 1989; **2**: 234-242.