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Frictional properties of maxillofacial prosthetic elastomers

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An investigation was made of the surface characteristics of two silicone base maxillofacial prosthetic materials, in terms of surface roughness and coefficient of friction, in order to compare these characteristics with those of human skin. Both elastomers were found to display lower frictional coefficient than the human skin and their surface texture did not seem to have an effect on these results. Oxidative treatment of the silicon surface increases the value of the frictional coefficient, probably due to the adsorption of atmospheric moisture.

1. Introduction

Maxillofacial prosthetic materials are based on suitable formulations of elastomeric compounds with various additives. The base materials have been used for some time in prosthodontics, but application in the field of maxillofacial prostheses introduces an increased list of property requirements [1, 2]. Thus, an ideal material has to be soft, pliable and capable of adapting to facial movement. It also must be light in weight so that it may be supported without risk of detachment during wearing. Special attention has to be paid to the hygiene of the prosthesis, which requires a non-porous material, which can be washed and disinfected and which does not irritate the tissues in contact. In addition the material must be non-toxic, non-allergenic and non-carcinogenic. Durability, i.e resistance to ageing, is another important requirement, accompanied by aesthetic characteristics, ease of manipulation and production at a reasonable cost.

Silicones, primarily because of their ease of fabrication, commercial availability and excellent properties, have long been popular for maxillofacial prostheses [3]. These materials are room-temperature vulcanizing elastomers based on dimethylsiloxane. Crosslinking can be carried out by condensation or addition reaction, depending on the specific chemical structure of the elastomer and the crosslinking system used. Condensation of hydroxyl groups (Si–OH) catalysed by stannous octoate, can lead to a crosslinked structure. On the other hand, addition of silane groups (Si–H) to silicon vinyl units, catalysed by platinum compounds, is an alternative reaction that yields products with lower shrinkage and better dimensional stability [4, 5].

Many studies have been reported on the physicomechanical properties of silicones and their performance characteristics as maxillofacial prosthetic materials [6–10]. However, little attention has been paid to the surface properties, in terms of polarity, moisture adsorption and friction coefficient. Thus, it has been suggested that the friction value of a facial prosthetic elastomer should approach the friction value of the skin [11]. Other studies have focused on the surface topography [12] or the surface texture of these materials in order to establish methodologies of preparation that guarantee the absence of traumas in the tissue due to the prosthesis.

In this work, an investigation was made of the surface characteristics of two silicone base maxillofacial prosthetic materials, in terms of surface irregularities and coefficient of friction. The aim was to compare these characteristics with those of human skin and obtain adequate information for possible surface modifications of the elastomers. In this way, an optimal design could be anticipated regarding similarities of the prosthesis with the texture of human tissue.

2. Experimental procedures

2.1. Materials and methods

The silicone facial elastomers used in this study were Cosmesil HC2 (Cosmedica Ltd, UWIST-UWCC, Cardiff, UK) and A-2186 (Factor II, Lakeside Arizona, USA). A sandwich mould was employed to prepare 2 mm thick sheets from the silicone elastomers. The mould consisted of a polystyrene frame $50 \times 70 \times 2$ mm which was sandwitched between two glass plates. The sandwiched mould was filled with the material and kept for 48 h at room temperature (23 ± 2 °C) under a constant weight of 2 kg to allow polymerization to take place. In order to prepare a rough sample of Cosmesil HC2, a modified sandwich mould was used with a plaster plate at the one side instead of the smooth glass plate. The plaster (Special Formula True Plastic, Teledyne dental, Elk Grove Village, Illinois, USA) was the impression

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taken from the inner aspect of the forearm of a single volunteer.

A A-2186 sample was placed in an oxidizing mixture and treated at 50 °C, for 1 h. The mixture was a solution of 7 g of potassium dichromate in 50 g of sulfuric acid and 15 g of water.

The adsorption of moisture by the treated and untreated silicone samples was measured as the weight gain at equilibrium in a 75% relative humidity (75% RH) chamber. To maintain humidity at this level a saturated solution of sodium chloride was placed in the chamber which was kept at 30 °C. Equilibrium was reached within 24 h.

Measurements of the surface roughness and frictional coefficient for all the test specimens were carried out using the surface tester (Kato Tech Ltd, Japan) from a Kawabata Evaluation System shown in Figs 1 and 2. The instrument is equipped with a computer system capable of recording and treating the signal derived from the measuring probe.

The measurements of friction characteristics of human skin were carried out with a volunteer using the same area of the inner forearm.

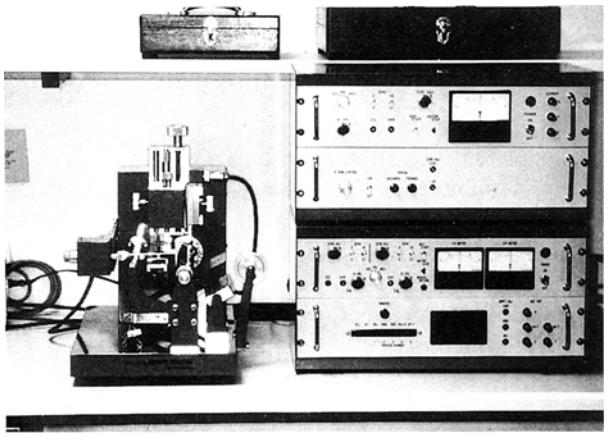

Figure 1 Overall picture of Kawabata evaluation system.

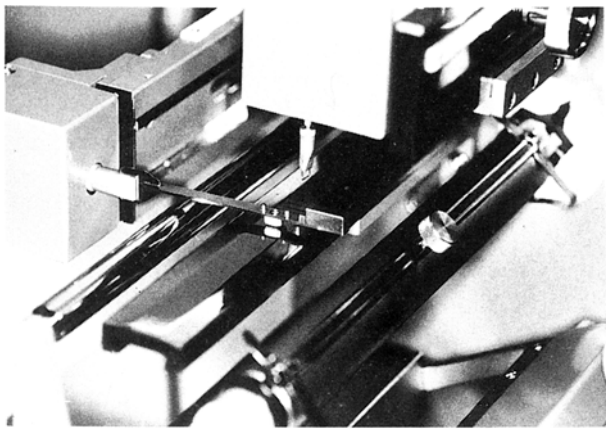

Figure 2 Surface tester for the measurement of coefficient of friction.

2.2. Theoretical background

The coefficient of friction (μ) is defined as follows

$$\mu = F/P$$

where F is the frictional force and P the normal force by which the probe of the instrument is pressed on the specimen surface.

The μ value fluctuates during the sweep on the test specimen. The mean coefficient of friction (MIU) is, therefore, defined by the following equation:

$$MIU = 1/L_{max}\int_0^{L_{max}} \mu dL$$

where L is the distance of the specimen surface and L_{max} the sweep length. Fluctuation of the coefficient of friction is represented by the mean deviation MMD

$$MMD = 1/L_{max}\int_0^{L_{max}} |\mu - \bar{\mu}| dL$$

For the determination of surface irregularities the probe moves vertically corresponding to the surface geometrical roughness of the specimen. When the vertical displacement of the probe from an arbitrary standard position is z, the surface roughness is represented by the mean deviation SMD of z:

$$SMD = 1/L_{max}\int_0^{L_{max}} |z - \bar{z}| dL$$

The Kawabata evaluation system integrates the input voltage as follows:

$$V_I = k/10\int_0^{t_m} V dt$$

where V is the input voltage, V_I the value indicated on the digital panel voltmeter, k is a constant of the circuit = 2.00, t the time and t_m is the integral time. The average V is:

$$\bar{V} = 10(V_I/k)(1/20) \quad \text{(s)}$$

On the other hand, the frictional force F is expressed as $C \times V$ where C is a constant equal to 20, when the usual sensitivity of 2×5 is used. When the normal force is 50 g, then

$$MIU = \bar{F}/50 = C\bar{V}/50 = (20/50)(10V_I/2)(1/20)$$
$$= 0.1V_I$$

Thus, MIU is obtained as

$$MIU = 0.1 \times V_I$$

3. Results and discussion

Representative graphs of the coefficient of friction and surface roughness for silicone specimens and human skin are shown in Figs 3 and 4, respectively. The average values are summarized in Table I. It is clear that regarding coefficient of friction (MIU) the silicone specimens can be characterized as low friction materials, in comparison with natural human skin. In fact, a MIU value between 0.19 and 0.28 was reported [13] and the values measured in this work for human skin are 0.22. Very interestingly, the mean deviation of

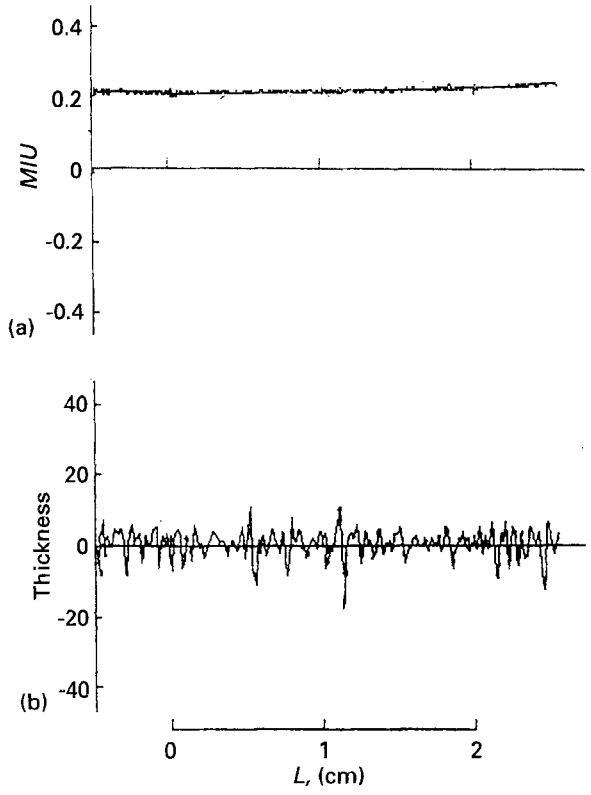

Figure 3 Surface characteristics of rough Cosmesil HC2 specimen (a) mean coefficient of friction; (b) surface roughness.

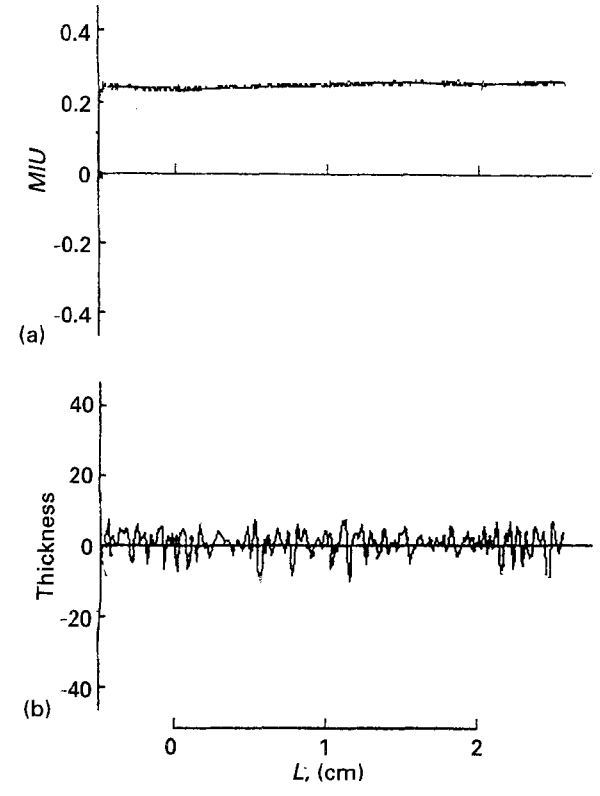

Figure 4 Frictional coefficient (a) and surface roughness (b) of human skin.

MIU is essentially the same for all three silicone specimens.

The differences in *MIU* for Cosmesil HC2 and A-2186 are accompanied by differences in surface roughness (*SMD*) as is demonstrated in Table I. However, surface irregularities do not seem to affect the determined values of *MIU*, since the smooth and rough Cosmesil HC2 samples displayed the same friction although their surfaces are dramatically different.

TABLE I Frictional and geometrical data of specimens

Specimen	*MIU*	*MMD*	*SMD*
Smooth Cosmesil HC2	0.20	0.0016	0.325
Rough Cosmesil HC2	0.19	0.0016	2.720
Smooth A-2186	0.12	0.0014	0.110
Surface oxidized A-2186	0.18	0.0021	0.412
Human skin	0.22	0.0038	1.987

TABLE II Moisture adsorption by the surface of silicone specimens, at 30 °C and 75% RH (saturated NaCl solution)

Specimen	Weight gain (%, 24 h)
Smooth Cosmesil HC2	0.49
Rough Cosmesil HC2	0.64
Smooth A-2186	0.28
Surface oxidized A-2186	2.04

It appears therefore that frictional properties cannot be modified by changing surface roughness. Such a procedure should be very convenient since silicone elastomers do not have an inherent surface texture but duplicate the profiles of the surfaces against which they are processed [14]. Thus, it was attempted to alter frictional properties by changing surface polarity and, subsequently, moisture content of the silicone material.

From the results indicated in Table II it is evident that oxidative treatment of the elastomer increases considerably the content of moisture adsorbed from an atmosphere of 75% RH. The differences observed between the smooth and rough Cosmesil HC2 sample can be attributed to the much higher surface area exposed by the rough specimen. Furthermore, higher moisture content is accompanied by increased friction, as expected from the existing literature data [13], so that a better approach of skin properties is achieved, at least in terms of frictional behaviour. Also, oxidative etching is capable of creating surface roughness that might be interesting with respect to aesthetic factors.

4. Conclusions

From the above discussion the following conclusions can be drawn:

1. Commercial silicone maxillofacial prosthetic materials are often characterized by low friction in comparison with normal human skin.
2. The value of the coefficient of friction is not influenced by the surface roughness.
3. The control of moisture adsorption on the elastomer surface, based on the formation of polar groups by chemical or other procedure, can provide a means of controlling frictional properties.

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