|| Print ISSN: 2589-7837 || Online ISSN: 2581-3935 ||
International Journal of Medical Science and Diagnosis Research (IJMSDR)
Available Online at www.ijmsdr.com
PubMed (National Library of Medicine ID: 101738825)
Volume 3, Issue 8; August: 2019; Page No. 96-104
Original Research Article
crossref DOI: https://dx.doi.org/10.32553/IJMSDR/v3i8.19

THE COMPARATIVE EVALUATION OF SURFACE ROUGHNESS OF TWO MAXILLOFACIAL SILICONE MATERIALS BY USING TWO DIFFERENT TECHNIQUES - AN INVITRO STUDY

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Conflicts of Interest: Nil

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Abstract:

Introduction: Silicone is the most common material used to fabricate maxillofacial prostheses because of its texture, strength, durability, ease in handling and coloring, and the patient comfort. The surface topography of silicone is an important factor to be considered while making a maxillofacial prosthesis. The surface character of the Elastomer was controlled by the investment surface against which the Elastomer was processed.

Aim: To assess surface roughness of two maxillofacial silicones processed against three different molds made out of Dental Stone and Epoxy Resin and Stereolithography.

Materials and methods: A stainless steel master die of 1 inch diameter and 10mm thickness were fabricated. The master die were invested using type III dental stone and two mold spaces were created. The master dies were removed then each mold space was packed with maxillofacial silicone material for curing and 10 samples were processed. Epoxy resin mold was done by pattern investment technique and 20 samples were made, 10 samples. Stereolithography mold was fabricated using CAD-CAM technology. 20 samples were made with 10 samples each for M P Sai and Cosmesil Silicones respectively. These samples were subjected to 3-D Profilometer, Scanning Electron Microscope for evaluation of surface texture.

Results: Cosmesil yields smoother, uniform surface than MP Sai silicone. STL mold delivered the most uniform, regular surface to the samples followed by Epoxy Resin mold and Dental Stone mold respectively.

Conclusion: Cosmesil yields smoother, uniform surface then MP Sai Silicone. Among three molds STL mold delivered the most uniform, regular surface to the samples followed by Epoxy Resin mold and Dental Stone mold.

Keywords: Surface Texture, Surface smoothness, Maxillofacial Silicones, Stereolithography, 3-D Profilometer

Introduction:

Deformities in the maxillofacial area can cause embarrassment for patients. Plastic surgery is the most preferred choice of treatment. When surgery is inadvisable due to unfavorable conditions, rehabilitation with maxillofacial prostheses provides a means of improving patient's esthetics and self-esteem and facilitating their return to the society.

Silicone is the most common material used to fabricate maxillofacial prostheses because of its texture, strength, durability, ease in handling and coloring, and patient comfort. The surface topography of silicone is an important factor to be considered while making a maxillofacial prostheses. The environment in which the prostheses will be used determines whether a smooth or rough surface is preferred.[1] Silicone elastomers do not have an inherent surface texture but take on the surface texture of the surfaces against which they are processed. A review of literature revealed that only one study has discussed the surface topography of a silicone facial prosthetic elastomer.

Silicones elastomers donot have an inherent surface texture and surface roughness but take on the surfaces against which they are processed.[2] Degradation of static and dynamic physical properties of elastomers is the major problem associated with maxillofacial prostheses. Deterioration is mainly caused by environment, exposure to ultra-violet light, air pollution and changes in humidity and temperature.[3] Murray, Udagama and King have shown the potentially damaging abrasive effect of silicones on tissues. It is important to consider the abrasive potential when evaluating an elastomer that will have prolonged tissue contact. The abrasive potential should be measured for hardness and wettability in relation to the surface texture. Murray, Udagama and King have shown the potentially damaging abrasive effect of silicones on tissues.[6] Studies reveal that the techniques used in fabrication of the mold space has an effect on the surface characteristics of the silicones. New advances in Rapid Prototyping (RP) technique i.e Stereolithography have demonstrated significant advantages compared to conventional technique of wax and clay sculpted patterns of facial prostheses. Digital images such as Computerized Tomography and Magnetic Resonance Imaging are produced by additive process of building an object in layers defined by a computer model that has been virtually sliced. The technique can be used for production of highly realistic facial prostheses with accurate adaptation and external contours. These factors are important, as they can uplift patient confidence and eliminate any stigma or fear arising from the use of artificial facial organs that are exposed to view.[7] Numerous materials have been used to construct molds to fabricate maxillofacial prostheses like dental stone and metal molds which have their own disadvantages of use. Whereas Epoxy Resin is a chemically inert material which can be used to fabricate the molds and is compatible with the latest technologies like stereolithography.[8]

MATERIALS AND METHODS

Preparation of the silicone samples from dental stone molds by conventional technique:

6 stainless steel master die measuring 1 inch diameter and 10mm thickness were machined to meet the demands of the measuring instrument in accordance with American Standards of Testing Materials (ASTM designation D2240-81) using CAD-CAM technology. A stainless steel metal case with lid of dimension 16cm*8cm*2cm was fabricated through CAD-CAM technology. Six master dies were invested in steel metal case using type III dental stone (Kalstone, Kalabahai,India) . The dental stone mold was lubricated with a thin layer of separating media (cold mold seal). MP Sai Silicone was squeezed into the mold spaces evenly. Care was taken to avoid air entrapment. The metal case was closed and pressure was applied according to the manufacturer's instructions and allowed to cure for 24 hours at room temperature. Completely set silicone samples from then retrieved. Totally ten samples were fabricated.

Cosmesil was dispensed in part A and part B in the ratio 10:1 and mixed according to the manufacturer's instructions and filled into the mold spaces without any air bubbles. Silicone packed dental stone molds was kept at 100^0c for one hour in a hot air than cooled for 24 hrs. Then the samples were retrieved from the molds without any damage. Total of 10 samples were fabricated.

Fabrication of silicone samples using Epoxy Resin mold in investment pattern technique:

A stainless steel metal case of dimension 16cm*8cm*2cm was fabricated through CAD-CAM technology. The metal case was lubricated uniformly with a synthetic lubricant for easy removal of the final mold. The Epoxy Resin supplied with a base and catalyst was mixed uniformly (10:3 by volume) for 5 minutes and allowed to flow in the stainless metal case upto a thickness of 5mm and allowed to set for 30 minutes. Six stainless steel master dies were placed on the Epoxy Resin layer and allowed to cure for 90 minutes. A second mix of Epoxy Resin was made to flow between the metal dies until these dies were immersed in the Epoxy material and kept for complete polymerization for 24 hours. The metal dies were retrieved from mold to obtain 6 mold spaces in Epoxy resin.

The mold was lubricated using silicone spray (Anabond, Pune, India) for easy separation of silicone from the mold space. Cosmesil was dispensed in a mixing container in ration of 10:1 and mixed thoroughly to get a homogenous mix, without air bubbles. The silicone was loaded into the mold spaces uniformly and allowed to cure as per manufacturer's instructions. The Epoxy Resin mold with Cosmesil was kept in hot air oven at 100^0C for one hour for complete cure of resin. Thus 10 samples of Cosmesil were fabricated.

The same Epoxy Resin mold was cleaned and lubricated again using silicone spray. MP Sai silicone was squeezed into Epoxy Resin mold space uniformly. The mold was kept for 24 hours complete curing of silicone. Thus 10 samples of MP Sai silicone were fabricated.

Fabrication of silicone samples using Stereolithographic mold:

A stainless steel master die of 1 inch diameter and 10 mm thickness was scanned to obtain 3D-Image of the die. This virtual die was replicated to six dies with the help of software.Virtual mold with six mold spaces formed the data for Stereolithography. This data was uploaded to Stereolithography machine (SLS 5000, 3-D systems, USA) to obtain the mold space. The material used by Stereolithography machine was laser cure Epoxy Resin (Renshape™ SL5510) with regular small cross sections as minimum as 0.002 inch which was completed in 3 hours. Stereolithographic mold was lubricated with a silicone spray (Anabond , Pune,India). Cosmesil was dispensed according to manufacturer's instructions. Thoroughly mixed silicone was filled into mold spaces. The mold was closed with its enclosure and pressure applied uniformly. It was kept in the hot air oven at 100^0C for one hour. Thus 10 samples of Cosmesil samples in Stereolithographic mold were fabricated.

The Stereolithographic mold was cleaned for second set of curing. The mold was lubricated with silicone spray. The second silicone, MP Sai was dispensed and packed into molds without entrapment of air voids and mold was allowed to set for 24 hours. The mold was kept in hot air oven at 100^0C for one hour and allowed to cool for 24 hours. Thus 10 samples were fabricated from this silicone. Thus 20 samples were fabricated from this STL mold, 10 each from MP Sai and Cosmesil silicones respectively.

Preparation of samples for SEM study:

Care was taken to protect the silicone samples surfaces against contamination, such as finger prints, dust, vapors and oils. The samples were washed in petroleum ether, followed by two rinses in absolute alcohol.The silicone samples were not compatible to SEM as its non conductivity. Hence, a procedure called "gold sputtering'' was carried out in ION SPUTTER (FINE COAT JFC-1100. California .USA) with current of 10mA and Voltage of 1kV for a period of 20 minutes in vacuum so that it conducts electrons in SEM. The samples were examined and photographed with LED 440i Scanning Electron Microscope operated at 20 kV at a distance of 25mm. the scan was conducted at a magnification of 500X and 2000X.

3-D Profilometer (Nan map 500LS.AEP technologies.USA) was used to assess the surface roughness of the silicone samples. Shore durometer is used to measure the hardness of the silicone samples.

RESULTS

In this in-vitro study, the surface texture of the two silicone materials which were processed in three different molds were evaluated. The test samples were subjected to Profilometer, which evaluates the surface roughness. Then to the Scanning Electron Microscope which magnifies the surface texture at 500X and 2000X. In this study there were two factors influencing surface texture viz Materials and mold. Materials used were MP Sai and Cosmesil, and the Mold were of three types Epoxy Resin mold, STL mold and Dental Stone mold.

Table 10 describes the mean surface roughness recorded between MP Sai (4.51) and Cosmosil (3.14) which was found to be statistically significant (P<0.001).

Table 11 describes the difference in surface roughness recorded between Epoxy Resin mold (3.38) , STL mold (3.35) and Dental Stone mold (4.75) which was found to be statistically significant (P<0.001).

Table 12 describes the interaction (joint effect) of material and mold on surface roughness i.e MP Sai with Epoxy Resin mold (4.42) , STL mold (3.35) and Dental Stone mold (4.75) & Cosmosil with Epoxy Resin mold (2.34) , STL mold (2.34) and Dental Stone mold (4.75) which was also statistically significant (P<0.001).

Table 14 Using Bonferroni method multiple comparisons was carried out to find which in pair of molds there existed significant difference. Significant difference with respect to mean surface roughness was observed between Epoxy Resin and Dental Stone (-1.37) and Between STL and Dental Stone (-1.40) which was statistically significant (P<0.001).

QUALITATIVE ANALYSIS OF SEM IMAGES

SEM images showed at lower magnification like 500X, both materials processed in Dental Stone yielded a microscopically rough and highly irregular surface (Fig-27, Fig-30). Epoxy Resin mold samples in both materials showed less roughness and irregular surface, when compared to that of Dental Stone samples (Fig-28, Fig-31). Among all the three molds, Stereolithographic mold samples yielded the most uniform, regular surface and relatively less surface roughness (Fig-28, Fig-29).

In higher magnifications of 2000X, more of irregularities and surface roughness were noticed with respect to Dental Stone mold samples (Fig-33, Fig-36), followed by Epoxy Resin mold samples (Fig-34, Fig-37). A relatively smooth surface was found in Stereolithographic mold samples (Fig-35, Fig-38) compared to the other mold samples which coincided with profilometer results.

SEM Images of MP Sai samples in all the three molds showed higher surface roughness when compared to Cosmesil silicone samples that is once again supported by Profilometer readings that was subjected to statistical analysis.

Table 5: Mean Hardness recorded in the two materials:

Material	Mean	SD	SE of Mean	Median	Min	Max
MP Sai	29.17	2.68	0.49	28.5	25	36
Cosmesil	19.33	3.55	0.65	18.5	14	25

Table 6: Mean Hardness recorded in the Molds:

Mold	Mean	S D	SE of Mean	Median	Min	Max
Epoxy Resin	26.65	5.41	1.21	26.5	16	36
STL	22.65	6.06	1.36	22.0	14	32
Dental Stone	23.45	5.57	1.24	24.0	15	32

Table 7: Mean Hardness recorded in combination of Material & Mold:

Material	Mold	Mean	Std dev	SE of Mean	Median	Min	Max
MP Sai	Epoxy Resin	31.00	3.16	1.00	30.5	28	36
	STL	28.30	1.95	0.62	28.0	25	32
	Dental Stone	28.20	1.93	0.61	28.5	25	32
Cosmesil	Epoxy Resin	22.30	3.13	0.99	23.5	16	25
	STL	17.00	1.70	0.54	17.5	14	19
	Dental Stone	18.70	3.40	1.08	18.0	15	23

Table 8: Anova test for surface hardness:

Source	df	Sum of Squares (SS)	Mean SS	F	P-Value
Material	1	1450.417	1450.417	208.360	<0.001*
Mold	2	179.200	89.600	12.872	<0.001*
Material * Mold	2	17.733	8.867	1.274	0.288
Error	54	375.900	6.961	---	---
Total	59	2023.250	---	---	---

*denotes significance

Table 9: Multiple comparisons using Bonferroni method.

(I) Mold	(J) Mold	Mean Difference (I-J)	Std. Error	P-Value	95% Confidence Interval	
					Lower Bound	Upper Bound
Epoxy Resin Mold	STL Mold	4.00	0.83	<0.001*	1.938	6.062
	Dental Stone Mold	3.20	0.83	0.001*	1.138	5.262
STL Mold	Epoxy Resin Mold	-4.00	0.83	<0.001*	-6.062	-1.938
	Dental Stone Mold	-0.80	0.83	1.000	-2.862	1.262
Dental Stone Mold	Epoxy Resin Mold	-3.20	0.83	0.001*	-5.262	-1.138
	STL Mold	0.80	0.83	1.000	-1.262	2.862

*denotes significant difference

Table 10: Mean Surface Roughness recorded in the materials:

Material	Mean	Std dev	SE of Mean	Median	Min	Max
MP Sai	4.51	0.20	0.04	4.5	4.2	5.0
Cosmesil	3.14	1.16	0.21	2.4	2.0	4.9

Table 11: Mean Surface Roughness recorded in the molds:

Mold	Mean	Std dev	SE of Mean	Median	Min	Max
Epoxy Resin Mold	3.38	1.08	0.24	3.4	2.0	4.6
STL Mold	3.35	1.04	0.23	3.4	2.1	4.5
Dental Stone Mold	4.75	0.11	0.02	4.8	4.5	5.0

Table 12: Mean Surface Roughness recorded in combination of Material & Mold:

Material	Mold	Mean	Std dev	SE of Mean	Median	Min	Max
MP Sai	Epoxy Resin Mold	4.42	0.11	0.04	4.5	4.2	4.6
	STL Mold	4.36	0.08	0.02	4.4	4.3	4.5
	Dental Stone Mold	4.75	0.12	0.04	4.8	4.6	5.0
Cosmesil	Epoxy Resin Mold	2.34	0.17	0.05	2.3	2.0	2.6
	STL Mold	2.34	0.10	0.03	2.3	2.1	2.5
	Dental Stone Mold	4.75	0.11	0.03	4.8	4.5	4.9

Table 13: Anova test for surface roughness*:*

Source	df	Sum of Squares (SS)	Mean SS	F	P-Value
Material	1	28.153	28.153	2008.732	<0.001*
Mold	2	25.504	12.752	909.841	<0.001*
Material * Mold	2	14.024	7.012	500.318	<0.001*
Error	54	0.757	0.014	---	---
Total	59	68.439	---	---	---

*denotes significance

Table 14: Multiple comparisons using Bonferroni method.

(I) Mold	(J) Mold	Mean Difference (I-J)	Std. Error	P-Value	95% Confidence Interval	
					Lower Bound	Upper Bound
Epoxy Resin Mold	STL Mold	0.03	0.04	1.000	-0.060	0.125
	Dental Stone Mold	-1.37	0.04	<0.001*	-1.459	-1.274
STL Mold	Epoxy Resin Mold	-0.03	0.04	1.000	-0.125	0.060
	Dental Stone Mold	-1.40	0.04	<0.001*	-1.492	-1.306
Dental Stone Mold	Epoxy Resin Mold	1.37	0.04	<0.001*	1.274	1.459
	STL Mold	1.40	0.04	<0.001*	1.306	1.492

*denotes significant difference

SEM IMAGES AT 500X

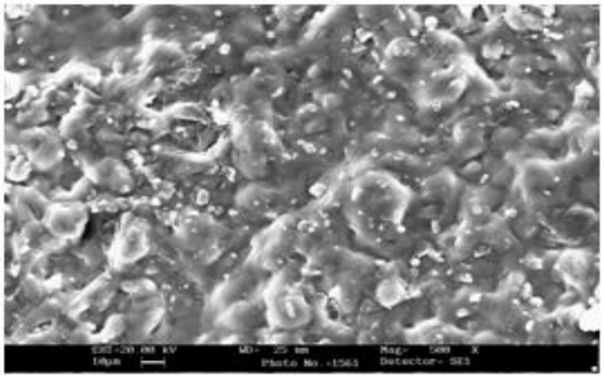

Fig 27: **Cosmesil – Dental Stone (CD) Mold Scanning image**

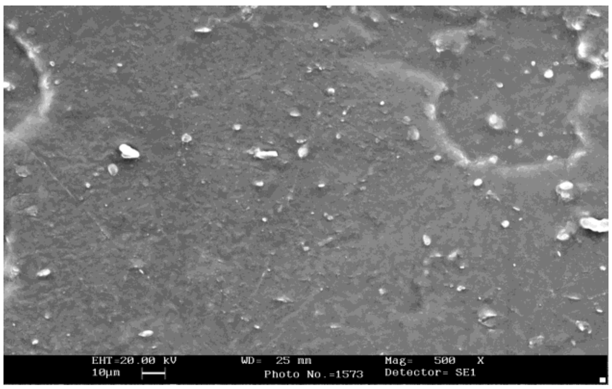

Fig 28: **Cosmesil – Epoxy Resin (CE) Mold Scanning image**

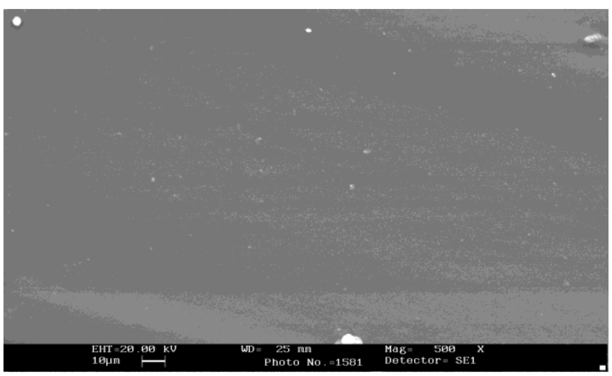

Fig 29: **Cosmesil – Stereolithographic (CS) Mold Scanning image**

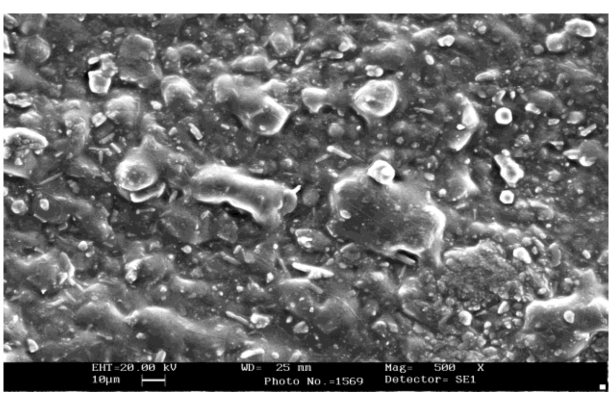

Fig 30: **MP SAI Dental Stone (MD) Mold scanning image**

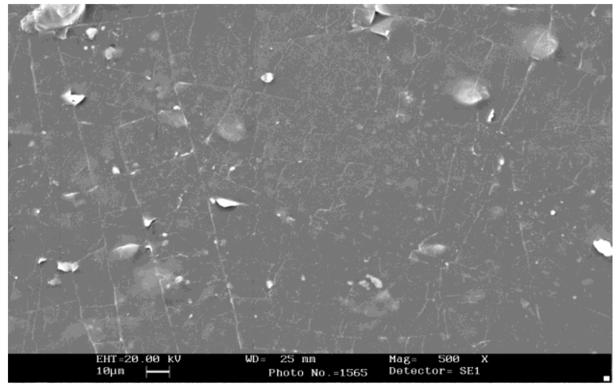

Fig 31: **MP SAI Epoxy Resin (ME) Mold scanning image**

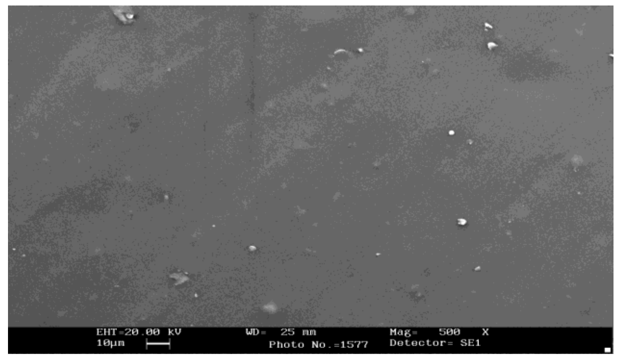

Fig 32: **MP SAI Stereolithographic (MS) Mold scanning image**

SEM IMAGES AT 2000X

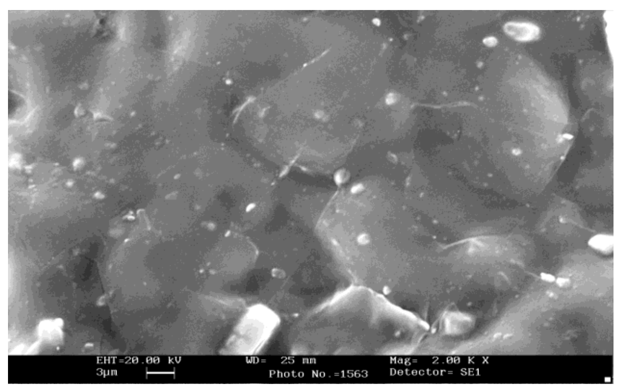

Fig 33: **Cosmesil – Dental Stone (CD) Mold Scanning image**

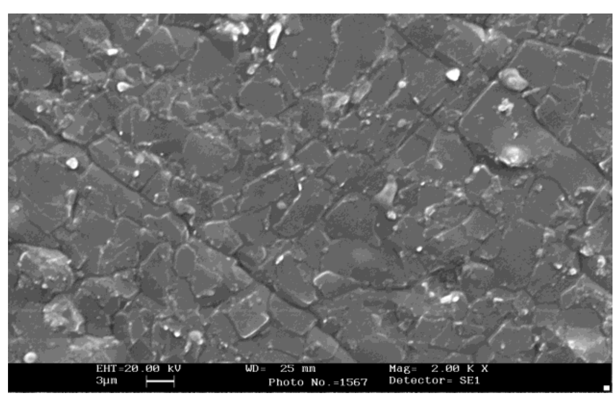

FIG 34: **Cosmesil – Epoxy Resin (CE) Mold Scanning image**

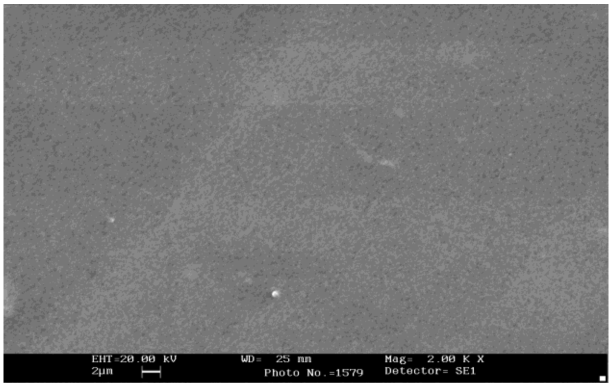

***Fig 35*: Cosmesil – Stereolithography (CS) Mold Scanning image**

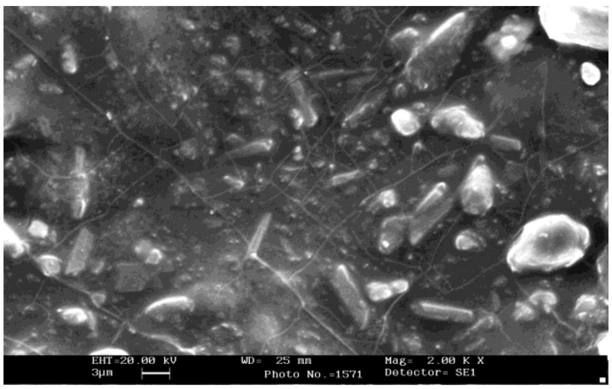

***Fig 36*: MP SAI Dental Stone (MD) Mold scanning image**

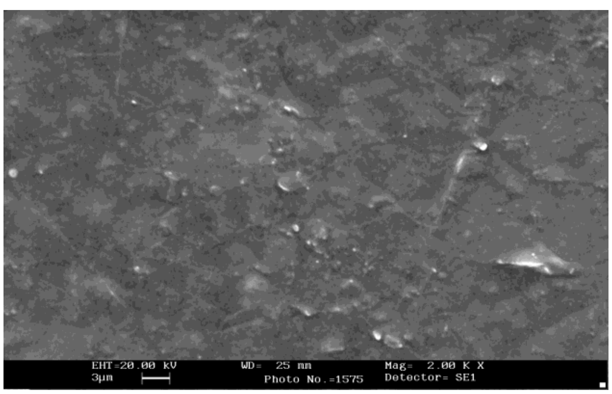

***Fig 37*: MP SAI Epoxy Resin (ME) Mold scanning image**

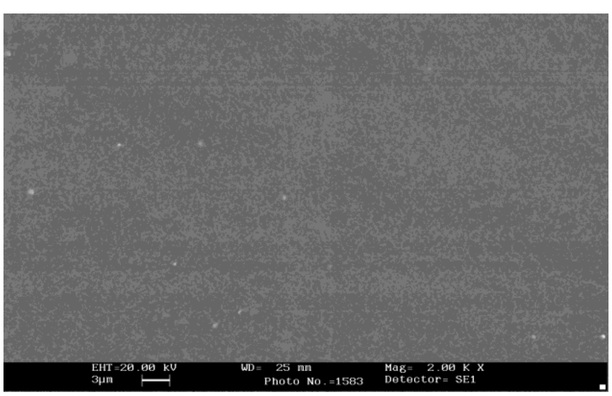

***Fig 38*: MP SAI Stereolithographic (MS) Mold scanning image**

DISCUSSION

The surface topography of silicone is an important factor to be considered while making a maxillofacial prosthesis. The environment in which the prosthesis will be used determines whether a smooth or rough surface is preferred. Due to the natural physical characteristics of processed poly (dimethyl siloxane), it is inappropriate to attempt visualization of the material's surfaces or interfaces using conventional Light Microscopy or Transmission Electron Microscopy. Because silicone rubber is basically impervious to most agents, impregnation with supportive materials such as Methacrylate and Epoxy Resins would be impossible or extremely tenuous. The difficulty of impregnation and the natural resilience of the material make thin sections of silicone unacceptable for conventional microscopy. Silicone rubber is nonreactive and resists attempts to "stain" or impart electron density by addition of heavy metals. If the characteristics of silicone surfaces of the variously molded prostheses are to be determined, Scanning Electron Microscope (SEM) should be used.[1]

The desirable properties of a material used as a maxillofacial prosthetic material include a low hardness and water absorption, less surface roughness and good surface wettability.[5] Data for Stereolithography can be obtained from laser scanner, CT and MRI scans. Normal data which will be in DICOM format should be converted to STL format. This technology has various applications in dentistry like production of Maxillofacial prosthesis, Obturator , Surgical shields for radiotherapy treatment , Burn stents, wax patterns for fixed partial dentures, E-models and mock up surgery models. This technology enables accurate reproduction of the designed prosthesis without requiring sculpting skills. The technology works much faster than the conventional methods. This study has both Dental stone mold processed through conventional manual method and CAD-CAM generated mold created by laser cured Epoxy Resin. Study has involved another mold by same Epoxy Resin which is chemically cured and manually done by pattern investment method. Silicones do not have inherent surface properties , rather it acts like an impression material and just duplicates the mold surface.[6]

Silicones processed against Dental Stone were not as smooth and possessed uniform surface as Epoxy

Resin. Among Epoxy Resin molds, Stereolithographic mold samples were of superior surface smoothness[9].

The present study, among the two commercially available silicones, Cosmesil was relatively smoother and produced fewer irregularities in any of the samples created by the three different mold spaces than MP Sai. Among the three mold spaces, the samples generated by Stereolithographic mold gave smoother surface than the other two molds, i.e, Dental Stone mold and Epoxy Resin mold[10]. The difference observed in the physical and mechanical properties of the silicone materials were due to different components used in their formulation. The surface topography of silicone prostheses may be controlled by altering the surface character of the material used to mold the surface. The resultant surface of silicone rubber prostheses was created by the mold in which the prosthesis was fabricated and was not an inherent property of the material itself. Cosmesil samples under scanning electron microscope shows a relatively uniform surface under different magnification of 500X and 2000X in all three molds compared to MP Sai silicone. This is due to the amount of filler added to the silicone. Dental Stone mold revealed highest degree of roughness. MP Sai silicone samples in STL mold yielded smoothest surface followed by Epoxy Resin mold and Dental Stone mold respectively under the magnification of 500X and 2000X. Dental stone mold samples of both the silicone materials showed same surface roughness in SEM study and Profilometer readings. This confirms that the surface texture is directly depended on the surface against which silicones were processed.[12] Surface roughness is a factor in the entrapment of microorganisms on surfaces and their protection from shear forces.[15]

Both the samples under SEM study at different magnifications of 500X and 2000X yielded results comparable to that of Profilometer readings. All the results for both maxillofacial silicones were statistically significant ($P<0.001$) and could be used under different clinical situations. Various methods can be employed to obtain the mold space using different investment materials like Dental Stone, Epoxy Resin etc. The mold space can be created with the help of latest technology known as Rapid Prototyping, which is the recent advancement of CAD-CAM technology. Stereolithography is one of the additive Rapid Prototyping technologies of building physical models through layer by layer polymerization of a photosensitive resin.[22]

CONCLUSIONS

Based on the results of this study, the following conclusions were drawn:

1) Among two materials Cosmesil yielded smoother, uniform surface than MP Sai silicone.
2) Among three molds, STL mold delivered the most uniform, regular surface to the samples followed by Epoxy Resin mold and Dental Stone mold respectively.

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