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An Insight into Advancements in Maxillofacial Materials: A Review of Current Trends

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KEYWORDS

Maxillofacial Materials

ABSTRACT:

Physical attractiveness is regarded as an important ingredient to success in this modern competitive society. Attractive individuals are said to be more successful at school, job interviews as they would possess a self confidence in them.

With the social premium effect placed on physical attractiveness, unattractive facial features can affect on individual's job, personal life and social interactions.

Thus, patients suffering from severely disfigured facial structures which can be due to various etiological factors such as acid attacks, chemical burn, fire attacks undergo severe emotional trauma leading them to depression and also to an extent of committing suicide.

Today, with recent advances in maxillofacial dentistry there is increased demand for the prosthetic rehabilitation of patients with facial defects. Increasing awareness of cancer resulting in early diagnosis and treatment employing many new surgical techniques, which are extensive and thus leave large defects that compromise function, aesthetics but also the psychological status of patient. These problems require prompt rehabilitation with surgery or prosthesis.

Prosthesis will offer the advantage of medically uncomplicated rehabilitation of defects and also, they can be readily removed to allow evaluation of the health of underlying tissues.

Introduction

Physical attractiveness is regarded as an important ingredient to success in this modern competitive society. Attractive individuals are said to be more successful at school, job interviews as they would possess a self confidence in them.

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Prosthesis will offer the advantage of medically uncomplicated rehabilitation of defects and also, they can be readily removed to allow evaluation of the health of underlying tissues.

Prosthetic reconstruction of maxillofacial defects has become easy with the help of Anaplastological team using various advanced materials. Deep knowledge and understanding about available materials is required because the success of maxillofacial

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prostheses relies heavily on the properties and performance of the materials used in their fabrication.

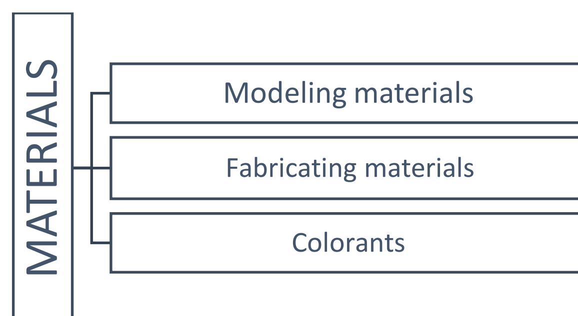
This article provides an overview of evolution of maxillofacial materials, from traditional options to recent advancement. Understanding these developments is essential for the Prosthodontists to effectively rehabilitate patients with maxillofacial defects, restoring their confidence and ability to smile with assurance in today's demanding world. This knowledge of latest trends and technologies will help the clinicians and prosthodontists to deliver successful treatments that transform patient's lives.

MATERIALS

The ideal requirements should be: -

1. Material should have physical and mechanical properties similar to human tissue being replaced. It should possess variable consistency, dimensional stability, allow detail reproduction, high edge strength, high elasticity and light weight.
2. Material must be compatible with human tissue, nontoxic, non-allergic and easily cleaned. It should be breathable, allow moisture release, non-porous, odorless, resistant to microbial contamination[1].
3. Material must be capable of adherence to human tissue, by adhesive or mechanical means. It should allow removal of adhesive without damage to patient or material.
   a) Material must be strong to incorporate frameworks for implant or other mechanical retention
4. Material must be compatible with intrinsic or extrinsic means of coloring or staining
   a) Capable of layering in the mold for depth and vitality in coloring
   b) Translucence and should possess soft luster on the surface.
   c) Extrinsic coloring without modifying surface characterization
5. Material should have relatively simple polymerization process, not sensitive to minor processing variables and molding procedures.
   a) Capable of adjustment/repair/reline
   b) Can be bonded /laminated to other materials for better properties
   c) Modifiable at marginal region
   d) Should be economic.
6. Completed prosthesis must maintain these properties for an acceptable period of service
   a) Prosthesis must have an acceptable durability of at least one to five years.
   b) Material must be capable of relining or readapting to the tissues surrounding the defect to prolong service life.
7. Material should be tolerant to environmental factors which may include
   a) Weather
   b) Tissue secretions (perspiration, sebum, saliva)
   c) UV light
   d) Tea, other foods
   e) Cosmetics like lipstick
   f) Cleansing agents[1]

MATERIALS IN MAXILLOFACIAL PROSTHESIS



I. MODELING MATERIALS:

a. Modeling clay (sculptor's clay)

b. Plaster

c. Plastolene

d. Waxes

e. Under taker's wax

A. Modeling clay (sculptor's clay)

A water- base clay which, when allowed to dry, becomes a hard stone like substance. (Fig:1)

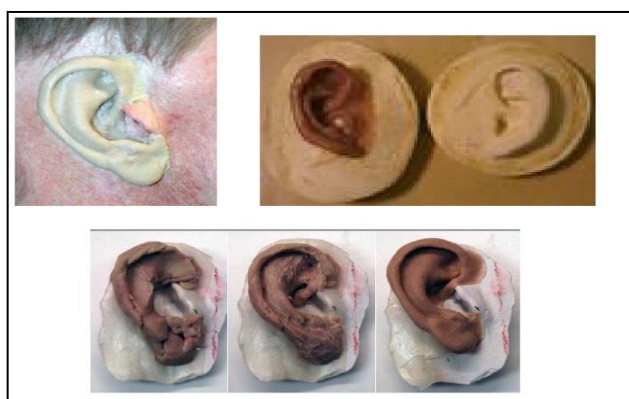


Fig: 1. Ear prosthesis fabricated using modeling clay.

Advantages

a) Consistency can be adjusted by adding water
b) Lends itself to gross sculpting of sweeping planes
c) Takes texture well
d) Can be feathered on the edge
e) Inexpensive
f) Readily available

Disadvantages

a) Must be kept moist at all times. If allowed to dry it tends to crack and flake.
b) The modeling must be set aside for any length of time.
c) The cloth utilized to keep it moist tends to wipe out the finer texture which has been incorporated into the model.
d) It is gray in color and the color differential causes visual distortion.

B. Plaster

To make impression for fabricating facial prosthesis a dental plaster is directly applied over the patient face (Fig: 2)

Fig: 2. Ear, Nose prosthesis fabricated using plaster

Advantages:

a) Readily available
b) Inexpensive
c) Easily and quickly prepared for use
d) Can be shaped or molded in its plastic state

Disadvantage:

a) Lacks elasticity
b) Cannot be used in undercuts
c) Relatively short setting time
d) Has a tendency to flake on the surface
e) Adding material to build contour is difficult

C. Plastolene

It is prepared by modeling clay with oil base or Filler's earth with oil base (Fig:3)

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Fig:3. Plastolene clay with oil base

Advantages:

a) Always ready for use
b) Requires comparatively little care
c) Can take and keep a feather edge
d) Easily malleable
e) Takes texture well
f) Withstands slight abuse well

Disadvantages:

a) Color does not match skin tone
b) Slightly more expensive than sculptor's clay
c) Oil base could seep into stone model and affect the finished product.

D. Waxes

A low molecular weight ester of fatty acids derived from natural or synthetic components such as petroleum derivatives that soften to a plastic state at a relatively low temperature. Wax have been a valuable commodity for over 2000 years. In ancient times beeswax was used for making sculptures and statues of highly regarded public figures. Although beeswax is still used today, modern waxes designed for dental procedures are made from natural plant and animal sources. Some types are derived synthetically from petroleum products and distillates which are called synthetic waxes (Fig:4). These synthetic waxes are typically composed of hydrogen, carbon, oxygen and chlorine. Synthetic waxes are more uniform than natural waxes in their organic structure and more homogenous in composition.

Types of waxes used:-

- Type I:- Medium waxes employed in direct technique
- Type II: - Soft wax used in indirect technique

No matter how a pattern is prepared, it should be an accurate reproduction of missing structures.

Fig: 4 - Commercially available waxes for fabrication of prosthesis.

Desirable properties of wax:-

- The wax should be uniform when softened.
- It should be compounded with ingredient that blend with each other so that there are no granules on the surface.
- The wax should not fragment into flakes when it is molded after softening.

- Such flakiness is likely to be present in paraffin wax, so modifiers must be added to minimize this effect.

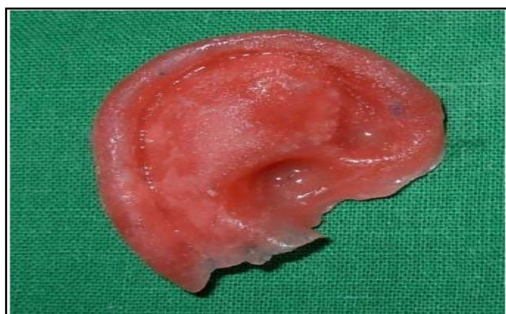

Fig: 5. Ear prosthesis fabricated using wax

Advantages:

a) Color is similar to skin tone

b) Readily available

c) Nominal cost

d) Withstands abuse

e) Takes and keeps a feather edge

f) Takes texture well. (Fig: 5)

Disadvantages:

a) Model must be carved rather than sculpted

b) Brittle when cool.

E. Under taker's wax

Properties are similar to standard dental waxes, except for two characteristics:

a) Due to its low melting point, body heat allows it to become malleable and modelled quite readily with fingers.

b) The color compatibility with the skin is acceptable (Fig: 6)

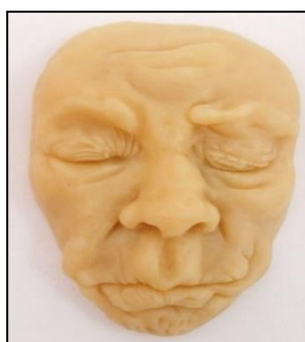

Fig: 6. Undertakers wax used in fab rication of prosthesis

II. FABRICATING MATERIALS

a) Acrylic polymers

b) Acrylic co-polymers

c) Polyvinyl polymers & co-polymers

d) Chlorinated polymers

e) Polyurethane

f) Latex

g) Chromium cobalt alloys

h) Silicones

A. Acrylic polymers & co-polymers

They became popular shortly before World War II. They are available in three forms- auto polymerizing resins, heat polymerizing resins and light polymerizing resins. It is rigid in nature therefore used in specific types of facial defects particularly in cases where there is least movement of tissue bed during function. It can be beautifully matched by both extrinsic & intrinsic coloration. Extrinsic coloration is done by acrylic paints using chloroform or monomer as solvent. It is compatible

with most of the adhesive systems and it is easily cleaned of adhesives or debris. Heat polymerizing resins is preferred over self-cure resin because of the advantages like increased strength, good color stability and increased shelf life up to two years.

B. Acrylic copolymers

a) They are of acrylic & methacrylic acid esters in monomer form & converted into polymeric form on processing. Palamed contains base powder, stain concentrates & solvent liquid for characterization of the finished prosthesis. They are available in three basic shades- pale, medium and dark. It has a chemical bond to hard acrylic, so a section of prosthesis is supported by hard acrylic. It produces a soft resilient skin with a spongy central mass, with a skin like prosthesis which is lighter in weight. Methyl methacrylate can be combined with plasticizers to produce a soft liner for removable oral prosthesis during healing. It is weak material which changes from flexible to hard material in short time so its use in maxillofacial prosthesis is limited. Shelf-life extends upto nine to eleven months.

Advantages:

a) It is soft, elastic, light in weight and highly esthetic.

Disadvantages:

a) Poor edge strength
b) Poor durability
c) Difficult Processing & coloration
d) Predisposition to dust collection
e) Stiffness with aging
f) Subject to degradation in sunlight

C. Polyvinyl polymers & co-polymers

- Presently the most widely accepted material for maxillofacial prosthesis. According to Clarke first vinyl resin was produced in 1833. Ivan Ostromislensky in 1929 plasticized polyvinyl chloride. In the year 1943, Vernon Ben Shoff used PVC for the first time in dental use. Shelf life extends upto one to six months.
- It is a clear, tasteless and odourless material and has been used widely for maxillo-facial applications. Plasticizer most commonly phthalate ester is added to produce an elastomeric effect at room temperature.
- Other ingredients include cross-linking agent such as ethylene glycol di-methacrylate (EGDMA) for added strength and ultraviolet stabilizers for colour stability.

Advantages:

Flexible with better appearance. Intrinsic & extrinsic coloration can be done (Fig: 7). Metal molds can be used. Range of flexibility depends upon the content of plasticizers.

Disadvantages:

a) Time consuming fabrication
b) Loss of plasticizer
c) Poor dimensional stability
d) Early staining
e) Short life expectancy (3-6 months)
f) Lacks life like translucency
g) Edges tear easily
h) Absorbs secretions
i) Soil easily due to surface tackiness.

Fig: 7. Hand prosthesis fabricated using polyvinyl polymer.

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D. Chlorinated polymers

The polyethylene polymers contain Chlorine atoms compounded with low density calcium stearate & soyabean oil. These are processed by heat polymerization using metal molds and colouration is done by using oil soluble dyes. Clinical trials of the materials have just been initiated.

Properties: -

- Less irritating to the mucosa than silicone.
- Less toxic than thermosetting silicone materials
- Non carcinogenic.
- Biocompatible

a) Advantage: High tensile strength and tear resistance

b) Disadvantage: Require special metal molds

E. Polyurethane

This material is chemically composed of an extended segment of di-isocyanate groups and a segment of polyol groups (a mixture of polyesters) and an organotin catalyst for the polymerization process to occur. As these segments are varied in proportion to each other, the softness of the end-product varies for its intended application as these maxillofacial prosthetics tend to require greater softness and flexibility. It has 3 component system which includes - Resin, Isocyanate & Catalyst. All 3 components should be mixed in correct proportions, if not, then the physical properties of the material get affected.

Water contamination results in bubbles, deficits and questionability in the curing of the final prosthesis. Although the final prosthesis has the isocyanate in a bound and presumably nontoxic form, there is evidence that the ternary composition for maxillofacial prosthetics is toxic to human excised donor orofacial tissue cells. Lontz et al have reported free isocyanates in cured restorations, which is an obvious concern regarding cytotoxicity and tissue irritation after prosthetic wear. Some of the positive qualities of this material is, that it has shelf life of 3 to 6 months**.** Epithane-3 and Calthane are the only polyurethanes currently available for fabricating facial prostheses.

Advantages:

a) High flexibility with movable tissue beds

b) Has life like feel on touch

c) Possess good edge strength

d) Customized colouration can be done

e) Superior cosmetic results

Disadvantages:

a) Difficult to process.

b) Moisture sensitive

c) Poor color stability

d) Short life

e) Improper adhesion

f) Free isocyanates – toxic

g) Poor compatibility with adhesives

F. LATEX

It was discovered by Clarke in the form of pre-vulcanized rubber. It can be made hollow so that there will be reduction in weight of the prosthesis there by increasing the retention. It is used as a temporary prosthesis as it is weak in its structure. It rapidly regenerates a synthetic latex in the form of Butylacrylate. Methyl Methacrylamide is used presently as it is superior to the natural latex.

Advantages:

a) Inexpensive

b) Easy manipulation

c) Life like feel on touch

Disadvantages:

a) It is time consuming

b) Colour instability

c) Poor edge strength

d) Short life span of 3-4 months

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G. COBALT – CHROMIUM ALLOYS

They are most commonly used in intra oral prosthesis because of their accurate fit, reproduction of the surface details and also because of its high dimensional stability (Fig: 8)

Composition of the cobalt chromium alloys are: -

- Cobalt:53%-68%
- Chromium:25%-34%

Trace elements of molybdenum, ruthenium are added. Chromium is a hardening agent that contributes to corrosion resistance whereas cobalt is used as a strengthener for the alloy. It acts as an alternative to the nickel-based alloy

Fig: 8. Hollow bulb obturator fabricated using cobalt chromium alloy

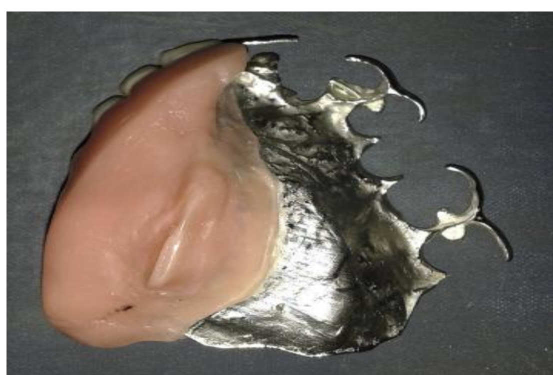

Fig: 9. Maxillary obturator prosthesis for hemi maxillectomy patient fabricated using cobalt chromium alloy

Disadvantage:

1. Inferior esthetic qualities. (Fig: 9)
2. Cannot be used in fabrication of extra oral prosthesis due to its metallic color display.

H. SILICONES

Silicones (1960 to 1970), also known as polydimethyl siloxane is the most successful maxillofacial prosthetic material. These became more popular over other materials as they have a good range of physical properties such as excellent tear and tensile strength, easier to manipulate, high degree of chemical inertness, low degree of toxicity and high degree of thermal and oxidative stability.[2]

Further they can be stained intrinsically and/or extrinsically to give them more lifelike natural appearance. When adequately cured, silicone elastomers resist absorbing organic materials that lead to bacterial growth and so with simple cleaning these materials are relatively safe and sanitary compared to other materials. Silicone is a combination of organic and inorganic compounds and chemically they are termed as polydimethyl siloxane. The inorganic backbone makes the unique difference of this material as siloxane bonds Si—O—Si in the main chains, as well as Si—C bonds where side groups are bonded to silicone.

Silicone and methyl chloride react to form dimethyldichlorosilane. When water is added to dimethyldichlorosilane, a fluid polymer, polydimethyl siloxane (PDMS), is formed that is white and translucent and of varying viscosity, which is determined by the length of the polymer. The PDMS chains and the silica fillers and the interactions between these two components affect the overall strength and service life of the silicone based maxillofacial prosthetic material. To increase the strength various types of fillers are added to reinforce the elastomers. Fumed silica, precipitated silica, aero gels are the most frequently used silica with the silicones. Polysiloxanes must be cross-linked to form solid elastomer materials. Antioxidants and vulcanizing agents are added to change the raw mass into rubbery resins during processing and the process of cross linking is known as vulcanizing.[3]

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Depending whether the vulcanizing process uses heat or not, silicones are available as:-

1. Heat vulcanized (HTV)
2. Room temperature vulcanized (RTV)

Heat-vulcanized silicones: -

1. They are used occasionally for maxillofacial prostheses. It is usually a white, opaque material with a highly viscous and putty like consistency. It is available as one component or two component putty. (Fig: 10)
2. The vulcanization mechanism is achieved by an addition reaction. The components of heat-vulcanized silicones are polydimethylvinyl siloxane co polymer with approximately 0.5% vinyl side chains, 2,4 dichlorobenzoyl peroxide as an initiator (vulcanizing agent) and a silica filler obtained from burning methyl silane[4].
3. Catalyst of HTV is platinum salt (salt of chloroplatinic acid).
4. The desired physical and mechanical properties can be achieved by altering the ratio of the matrix and the filler particles. Addition of opaque fillers increases strength but can compromise with translucency of prosthesis.
5. Vulcanization/ cross linking is by free radical addition polymerization (so no by product), which results from thermal decomposition of the initiator to form free radicals that cross-link the copolymer into a three-dimensional resilient structure. The processing temperature is 180°C- 220°C for about 30 min under pressure using metal molds. The copolymer is supplied as a rubbery solid with a high viscosity. The pigments are incorporated into the polymer with roller mills. Although this material is more difficult to pigment and process, excellent results can be obtained[4].

Advantages:

a. Excellent tear strength and highest tensile strength at 5.87 MPa (polyurethane the lowest at 0.83 MPa.).
b. Excellent thermal, color and chemical stability (rendering it more biologically inert).
c. High percent elongation.

Disadvantages:

a. Poor esthetics due to opacity.
b. Less elasticity.
c. Low edge strength.
d. Technique sensitive.

Examples: Silastic S-6508, 370, 372, 373,382, 379, Q7-4635, Q74650, Q7-4735 and SE-4524U.

Fig: 10. Heat vulcanized silicone

Room temperature vulcanized: -

There are two types:

a. **Cross linking by condensation reaction:** They have reactive groups such as silariols (hydroxyl- terminated polysiloxanes). This method of cross-linking requires a cross linking agent such as tetraethyl silicate and a catalyst (dibutyltin dilaurate.)

Eg.: Medical Adhesive Type A (Dow Corning) (Fig: 11), where methyl triacetoxy silane (II) is used as the cross-linking agent. The cross linking however, requires water molecules to hydrolyze the silane and produces acetic acid (an irritant) as the by-product. The use has therefore been limited to that of an extrinsic colourant carrier applied to the surface of the prosthesis.

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Disadvantages:

- Produces by- products.
- Curing time is excessively long making it impractical for curing the material inside a mold
- Degradation reactions such as hydrolysis.
- Relatively low tear strength and are incapable of maintaining edge resistance.

b. Cross-linking of polysiloxanes by addition reactions: The reactions generally involve the addition of silyl hydride groups (—SiH) to vinyl groups (CH2=CH—) attached to the silicone with the aid of a platinum containing catalyst. These silicones are not truly room vulcanized silicones. The curing of these silicones, in fact, requires heating the material at 150°C for a time, possibly an hour. These materials have improved tear strength over the first type of RTV silicones.

Disadvantages:

- Very hydrophobic.
- Selective adhesive property.
- No extrinsic colouration can be done.

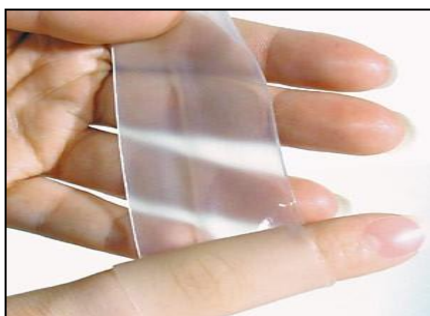

Fig: 11. Medical Adhesive

Cure of the materials may be inhibited by traces of amines, sulfur, nitrogen oxides and organo-tin compounds. Room-temperature-curing silicones are supplied as single component materials that cure by evaporation of acetic acid. They are characterized by a natural flesh-like appearance by using dyed rayon fibers, dry earth pigments and oil paints.

Prostheses are polymerized by bulk multiple packing. Recently epoxy resins and stainless-steel molds are being used. The top three advantages of the RTV silicone material were the use of stone molds, ease of manipulation and ease of colouring. Other advantages are colour stability and biological inertness.

Examples: Silastic 382, 399, 891, MDX4-4210 (Fig: 12), Cosmesil, A-2186 and A-2186F. MDX4-4210, a clear-to-translucent two parts (10:1, base: catalyst)

Fig: 12. MDX4-4210

Several other commercially available silicone products are:

- Cosmesil (Fig:13),
- Realastic silicone (Fig:14)
- VerSil- Tal (VST)
- Liquid Silicone Rubber (LSR) Systems. (Fig:15)

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Fig: 13. Cosmesil silicone

Fig: 14. Realastic silicone

Fig: 15. liquid silicone rubber

III. COLORANTS

They are used to improve the aesthetics by enhancing the characterization of the prosthesis which would increase the patient's satisfaction and acceptability. Basic skin tones should be developed into a shade guide for each material. Shade selected should be lighter than the skin of the patient[6].

Few people instinctively match, mix and reproduce color well. It takes many years of practice to develop good color sense. A knowledge of certain basic principles aids in the matching and reproduction of skin color in facial prostheses.

There are three dimensions of color: Hue, Chroma and Value. Hue describes and differentiates one color from another. e.g., red from green or blue, etc[5].

Chroma describes the degree or amount of hue present in an object. Therefore, a low chroma indicates very little hue (low saturation); conversely a high chroma indicates a greater amount of color.

Value is the proportion of white and black in a hue on a scale going from black to white; it distinguishes a light color from a dark color.

Ostwald's value triangle (Fig. 16) aids in understanding the terms trots, shades and tones. Tints indicate the lightening of a hue, i.e., an increase in value, while shades indicate the darkening of a hue, i.e., a decrease in value. Tones are the greyed colors that distinguish the chroma of the hue. However the terms tint and shade when used as verbs, designate the addition of other colorants to produce the desired color effect.[6]

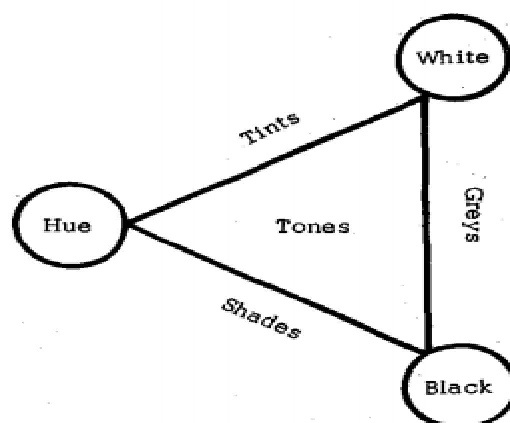

Fig: 16. Ostwald's value triangle

Various colorants used by the clinicians are: -

a) Enamel porcelain

b) Ceramics

c) Artist's paint

d) Water soluble dyes

e) Celluloid paints

f) Photographic stains

g) Acrylic resin stains

h) Food coloring

i) Oil colors

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j) Dry earth pigments

k) Nylon flockings

l) Commercial cosmetics

m) Ceramic pigments.

Coloration is of three types: -

a. Intrinsic / sub – dermal

b. Extrinsic coloration

c. Combination

Intrinsic

According to Chalian *et al*., (1927, 1974) Intrinsic coloring is accomplished with milling machine. Metallic oxides/ pigmented silicone concentrates are generally used. Red fibers are incorporated to simulate blood vessels. According to Chalian *et al*., (1972) and Beder (1974) the intrinsic coloring is more effective than extrinsic techniques due to longer service[4]. (Fig: 17)

Fig: 17. Intrinsic coloration- Incorporating pigments in silicone build up

Extrinsic

J.E.Quellete (1969) described spray coloring of silicone elastomer maxillofacial prosthesis. Pigments selected to match the patient's skin are mixed in proper proportions with clear elastomers and solvents.[17] Mixture is sprayed on the prosthesis until the desired color is obtained. According to Schahf (1970), the color easily peels off during manipulation of prosthesis or during daily cleansing. He introduced tattooing for surface characterization.[6]

Common name	Color index name/ number	Light fastness ASTM D430	Chemical type/ class	Chemical formula description
Ivory black	Pigment black 9 (PBk9) 77267	I	Inorganic synthetic Carbon black	$C.xCaPO_4$ Calcined animal bones
Cobalt blue	Pigment blue 28 (PB28) 77346	I	Inorganic synthetic Mixed metal oxide	$CoAl_2O_4$ Calcined cobalt oxide /aluminium oxide.
Raw sienna	Pigment brown 7 (PBr7) 77491 or 77492	I	Inorganic Iron oxide	Fe_2O_3 Ferric oxide produced from ores
Burnt sienna	Pigment brown 7 (PBr7) 77491 or 77492	I	Inorganic Iron oxide	Fe_2O_3 Calcined ferric oxide
Raw umber	Pigment brown 7 (PBr7) 77491 or 77492	I	Inorganic Iron oxide	$Fe_2O_3.xMnO_2$ Calcined ferric oxide with manganese

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Green earth	Pigment green 23 (PG23) 77009	I	Inorganic	Ferrous silicates, aluminum and magnesium
Alizarin crimson	Pigment Red 83 (PR83) 58000.1	III	Organic synthetic Anthraquinone	$C14H8O_4$ Calcium salt of anthraquinone dye
Cobalt yellow	Pigment yellow 40 (PY40) 77357	II	Inorganic synthetic	$CoK3N_6O_{12}$ Potassium nitrite/cobalt salt solutions
Mars violet	Pigment red 101 (PR101) 77491	I	Inorganic synthetic Iron oxide	Fe_2O_3 Ferric oxide produced chemically
Cadmium-barium red (medium)	Pigment red 108:1 (PR108.1) 77202.1	I	Inorganic synthetic Cadmium	$CdS \cdot xCdSe \cdot yBaSo_4$ Cadmium seleno-sulfide precipitate w/$BaSO_4$
Titanium white	Pigment white 6 (PW6) 77891	I	Inorganic synthetic opaque white	TiO_2 Titanium dioxide with zinc oxide
Yellow ochre	Pigment yellow 43 (PY43) 77492	I	Inorganic colored oxide of iron	$Fe_2O_3 \cdot H_2O$ Hydrated ferric oxide from limonite ore

Fig: 18. Pigments

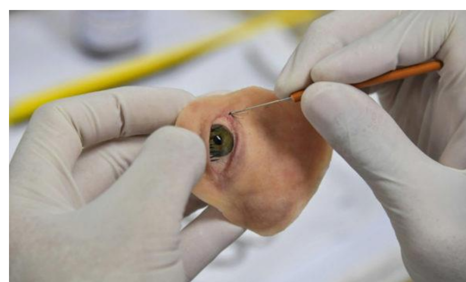

Fig: 19. Extrinsic Colouration

Combination

This technique is widely used. Utilization of a wide range of dyed pigments as colorants has enabled a wide range of subtle tissue tones with a desirable attribute of optical values. The intrinsic color characterization and minimal extrinsic tinting are used to simulate translucent appearance that has resulted in a reproduction of skin tone which is acceptable. The color characterized areas have a three-dimensional appearance. This effect and translucency of the material has resulted in a viable, more natural appearing prosthesis that blends well with the surrounding tissues. [6]

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