Color Realism in the Cosmetic Glove

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IN ANY list of the attributes comprising that quality of the human hand described as "lifelike," color must occupy an important position. It therefore seems reasonable that, in the design of cosmetic gloves, provision should be made for obtaining a duplication of the color of normal human hands that is as realistic as possible. Failure to do so may lead to a finished product having a "wax-museum" look, a "dead" look, or a "sick" look *(15).*

The problem of representation of human skin engaged the attention of the artist first. Just how representation was achieved is difficult to determine because the artistic expression of attaining the effects of flesh varies so greatly. Many procedures were followed, and the use of several pigments became established. Very often the flesh tones in a painting are not dictated solely by the desire of the artist to duplicate realism but are modified to harmonize with the scheme of over-all color composition. In the development of portraiture, however, there was evolved during the fifteenth century a technique whereby the flesh areas were first undercoated with green or silvery tones of gray. Over this imprimatura were superimposed very thin layers of red, yellow, and white, so as to cause a fusion of the different and delicate colors of the skin. Although it cannot be said that early artists knew about the three-dimensional structure of skin, it seems they realized fully the unique nature of the problem of duplicating skin tone.

FACTORS IN SKIN COLOR

THE EFFECTS OF LIGHT

Before the color of human skin can be reproduced faithfully and with some degree of realism in a plastic medium such as a cosmetic glove, it is necessary first to inquire into the physical phenomena giving rise to color and to study skin pigmentation and structure. Visually, the color of an opaque or transparent object is dependent upon the character of the light used to illuminate it and upon the ability of the object to absorb selectively various portions of the illuminating energy. If white light, for example ICI Illuminant C (Fig. 1), is used to illuminate an object and the unabsorbed portion is transmitted, the object is colored and transparent. If, on the contrary, the unabsorbed light is reflected and no light is transmitted, the object is colored and opaque. In both cases, the color results from the unabsorbed constituents of the white light which reach the eye. Objects which reflect or transmit all spectral colors equally are white, those which reflect or transmit none are black.

Between these two limits are infinite tints that vary according to the degree to which objects reflect or transmit some colors and absorb others. An object appears red, for example, because it absorbs substantially all frequencies except those in the red portion of the visible spectrum. Hence, objects actually have no color of their own; to the observer the color changes with changes in incident light.

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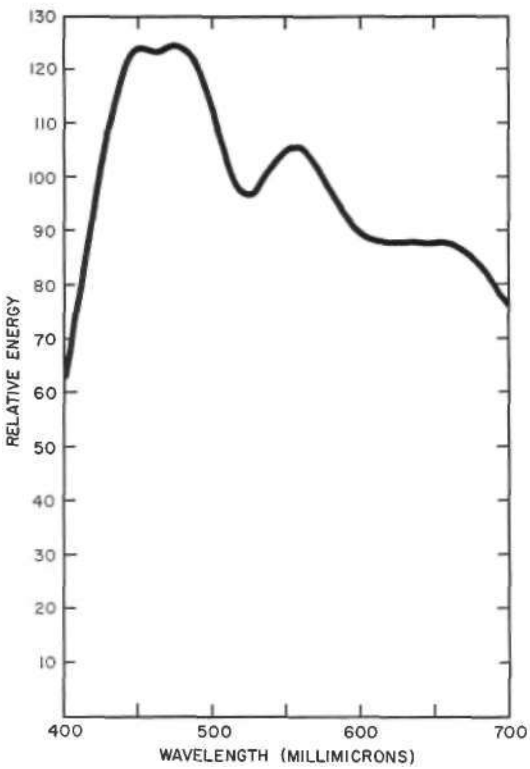

Fig. 1. Relative spectral distribution of the energy radiated per unit time by ICI Illuminant C. From Hardy *(11)*, by permission of The Technology Press, Cambridge, Mass.

If a white object is illuminated in a dark room by each of the colors of the spectrum successively, it has no fixed color but may appear to be red, orange, green, and so on, depending upon the light used to illuminate it.

Although white, or actually "off-white," light (for example, daylight) is our most frequent source of light for normal visual comparisons of color, it is monochromatic light[4] that is most useful in the scientific analysis of color. Two objects that match under noonday light need not necessarily match under incandescent light. If, however, a wavelength-by-wavelength analysis of the energy reflection is made, and if it is found that two objects reflect equal amounts of light at all wavelengths of the spectrum, then the color of the two will match under all viewing conditions. Such an analysis can be made with an instrument called a "spectrophotometer," a graph of the percentage of the incident energy reflected (or transmitted) versus the wavelength of the incident light being called a "spectrograph." Not only are spectrographs useful for determining the match of two colors under all illuminating conditions, but they also can be used as an analytical tool for determining the constituents of a material. Because colored materials usually have unique and characteristic spectrographs, it is possible to determine quantitatively and qualitatively the components of mixtures contributing to the over-all shape of the color curve. Historically, it was only after instrumentation had progressed sufficiently for the rapid, automatic determination of spectrographs that it was possible to make a comprehensive study of skin pigmentation.

STRUCTURE AND PIGMENTATION

The History

Over a century ago, the anatomical structure of the human skin was revealed by microscopic sections. It was reported in 1837 in Berres' *Anatotnia Microscopica Corporis Humani (2).* Histological observations concerned with the pigments of the skin were carried out by Breul *(4)* in 1896 and by Adachi *(1)* in 1903. To Haecker (P) is attributed the discovery that black and bluish tinges are caused by heavy melanin concentrations beneath turbid skin layers. The distribution and quality of the peripheral blood supply was studied by Spalteholz *(17)* in 1893 and, in 1926, by Wetzel and Zotterman *(18)*, who used the technique of capillary microscopy. With the advent of spectrophotometry, analysis of the skin has been effected by Dorno (5), by Bode (J), and by Sheard and Brunsting *(16).* Edwards and Duntley (7) were the first to employ a Hardy spectrophotometer *(10),* and the subsequent discussion of skin pigmentation is derived largely from their work.

The Layers

Human skin is composed of a series of translucent layers—the epidermis, the dermis, and

[4] Colored light which has its total energy contained in vibrations at a single wavelength.

the subcutaneous tissue—all containing pigments contributing to over-all skin color (Fig. 2). When skin is illuminated, a small portion of the incident light is reflected from the surface unchanged, as though it were reflected from a mirror. The amount of light so reflected contributes to that quality of a surface called "gloss." Remaining light enters the epidermis where, selectively, it is either absorbed, transmitted, or reflected diffusely, according to the color characteristics of the pigments present in that layer. The reflected portion contributes to the visual stimulus, while the transmitted portion enters the dermis. In the dermis, as well as in the subcutaneous tissue, the process is repeated, so that over-all skin color is the result of a complicated process of absorption, reflectance, and transmission, depending upon the relative position and abundance of the color-producing pigments in the skin and upon the turbidity of each layer.

The Pigments

According to Edwards and Duntley (7), five pigments—melanin, melanoid, oxyhemoglobin, reduced hemoglobin, and carotene—play an important role in the production of skin color. Melanin, shown to be responsible for the difference in skin color among races, is found in the epidermis (Fig. 2). It is present in small amounts in certain cells in brunet whites, to a greater extent in the yellow races, and most abundantly in Negroes. Depending upon its concentration, melanin is responsible for yellow and brown effects in the skin and contributes to the bluish tinge sometimes seen in such shaven areas as the male cheek (7). After skin has been exposed to ultraviolet light, the melanin concentration increases, so that the total melanin content may be considered to consist of "primary" melanin and "secondary" melanin, the latter being that produced by ultraviolet exposure. Melanoid, also found in the epidermis, is a derivative of melanin. Its color characteristics are similar to those of melanin except in the violet portion of the spectrum, but it occurs as a soluble material rather than as discrete granules of insoluble pigment, as is the case with melanin.

Fig. 2. Cross-section of human skin showing the three main layers and representative distribution of pigments. *M*, melanin (and melanoid), occurring chiefly in the basal layers of the epidermis; *O, R*, oxy- and reduced hemoglobin, occurring in varying proportions at capillary tips beneath the epidermis and in the subcutaneous tissue; C, carotene, occurring in subcutaneous tissue and in limited amounts in the stratum corneum; *S*, light scattering, which occurs in all turbid regions.

The most important pigment of the blood, hemoglobin, is present as a mixture of oxy- and reduced hemoglobin, and as such it contributes to the red or pink tone of the skin. Oxyhemoglobin has twin absorption peaks at 542 and 576 millimicrons, and the influence of these peaks can be seen in the normal Caucasian skin curves of Figure 3. Reduced hemoglobin has less absorption in the blue region of the spectrum and has only one absorption peak at 556 millimicrons. The initial reddening effects of exposure of the skin to sunlight is caused by hyperemia *(6),* a condition that brings greater quantities of hemoglobin to the surface. Subsequent "tanning" is due to enhanced production of melanin and melanoid. The fifth pigment, carotene, found in the stratum corneum of the epidermis, absorbs blue light, thereby contributing to the yellow and red characteristics of the skin.

Light Scattering

In addition to the five pigments, light scattering also is partly responsible for skin coloring. As light strikes turbid regions such as the epidermis, there is transmitted a greater proportion of the longer wavelengths *(i.e.,* red) than is present in the incident light. By the same token, the reflected light contains a greater proportion of shorter wavelengths *(i.e.,* blue). The bluish cast produced in skin is dependent on the degree of turbidity in the various layers. Turbidity increases with age, so that the skin of older people tends to be bluish, that of children relatively pink. It is light scattering that tends to give both the sky and the skin a bluish cast when viewed by reflected light. When skin is viewed with transmitted light, it appears quite red, as can be seen by holding a strong light behind such translucent regions as the lobe of the ear.

OTHER FACTORS

Because the five skin pigments are present in different concentrations from person to person, the color characteristics of the human skin vary considerably. Other factors, such as the state of health and even the state of mind of the individual, the activity of the body, prior exposure to ultraviolet rays, ambient temperature, the effect of gravity upon blood flow, all contribute to the color of the hand at any given moment.

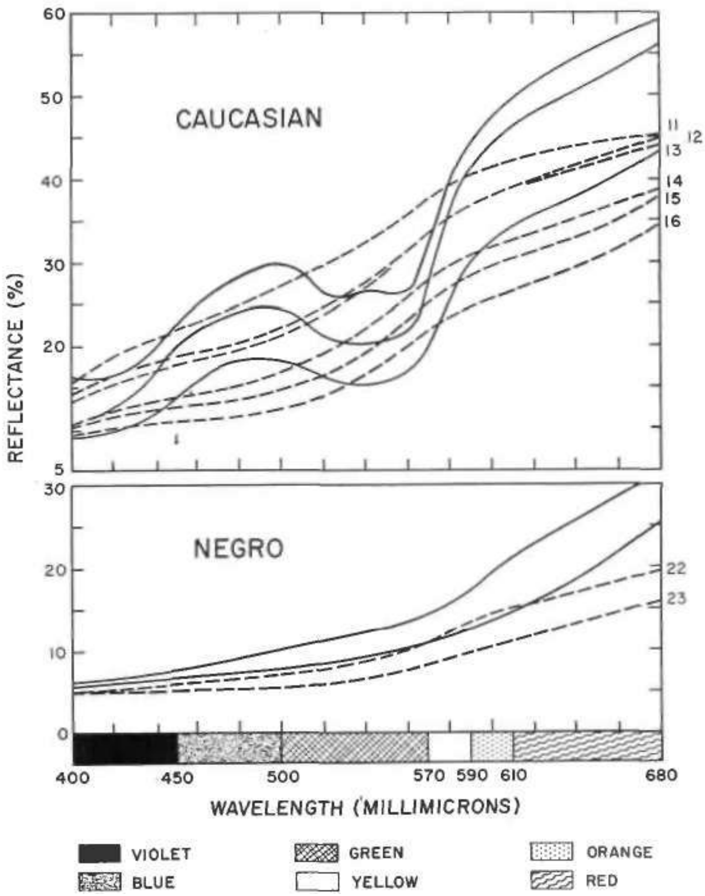

Fig. 3. Spectrophotometric curves for the dorsal skin of Caucasian and Negro hands and for Caucasian and Negro cosmetic gloves. Above, curves for Caucasian hands (solid lines, three subjects) and for cosmetic gloves, shades 11 through 16 (dashed lines). Below, curves for Negro hands (solid lines, two subjects) and for shades 22 and 23 of the Negro glove (dashed **lines).**

THE PROBLEM OF COLOR

That it would be impossible to provide a continuing match for a normal hand under all viewing conditions was a fact recognized at the start of the program established to provide a suitable cosmetic glove. With this circumstance, the problem became twofold—to provide a limited number of gloves which are statistically a "best fit" in color, and to provide hands which, above all, are colored realistically, especially if true matches cannot be realized in all cases. It is this second factor which is of primary importance in fulfilling the purpose of a cosmetic hand. No matter how favorable an impression is made on the viewer, the success or failure of an attempt to restore a missing hand (as a cosmesis) can be judged only by the absence of notice rather than by the occurrence of notice. The challenge, then, is to produce a hand that, on superficial examination, *could* be a human hand. To attain this end, the hand must be of a color that does not jar the observer's memory of the thousands of normal hands he has seen, thus taking advantage of the tendency of the human mind to accept as real that which it has no reason to believe is synthetic (page 55).

The match, or mismatch, between a normal hand and a cosmetic one is, of course, important. Primarily, it is important because an unaccustomed, extreme difference in coloration triggers the mind, causing it to search after the reason for the disturbing situation. Fortunately, two factors allow for latitude in pairing a normal and a cosmetic hand. First, color mismatch may occur even in normal pairs of hands. Differences in hand color may be produced, for example, by holding one hand above the head and the other at the side. Yet when the two hands are brought together the mind accepts them both as real despite the color difference. Second, the amputee does not often position his normal and cosmetic hands in such a way that direct comparison is invited. In fitting a cosmetic hand to a unilateral amputee, the closest match possible is of course desirable, but considering the changeability of the normal hand and the latitude afforded by the toleration limits of the observer's mind the concept of a limited number of colors is justifiable.

One cannot consider realistic coloring of a glove as a problem divorced from such contributing factors as the shape and form of the hand to which it is applied, the texture of the surface, or even the realism of the movements of a mechanical hand. For instance, in the compounding of colors for duplication of a particular skin tone, it has been observed that it is difficult to achieve a feeling of lifelike color on flat surfaces. If, however, the color is applied to a plastic model of the correct hand shape and texture, the feeling of realism is increased.

Use of such articles as rings and watches also may affect the degree of realism the glove achieves. One odd effect noticed, even in people who are quite familiar with the cosmetic glove, was the reaction to a glove on which a *Band-Aid* was used to cover a tear in one of the fingers, the *Band-Aid* creating a still greater realism. Perhaps even a more realistic effect could be achieved by painting in a cut or scar. Seemingly, the problem of cosmetic restoration involves building into the glove realistic situations and removing those factors unacceptable to the mind's concept of "normality."

THE COLOR SURVEY

To select hand colors that would satisfy the greatest number of amputees, the dorsal surfaces of the hands of 175 Caucasian and 175 Negro subjects were examined with a Hunter Color-Difference Meter *(8,13),* a tristimulus color comparator. The device gives a uniform measure of the visual perceptibility of color differences and describes color in terms of three numbers that can be converted to the standard ICI specifications *(11)* by a series of linear equations *(8).*

On the basis of the results of these measurements, a statistical analysis of the data was made. Considering the proportion of amputees to be fitted by a specific shade, the economic feasibility of supplying cosmetic gloves in a number of shades, and the required closeness of color match, it was decided that six shades for Caucasians and six for Negroes would be satisfactory. The calculated colorimetric values are shown in Table 1, where the color characteristics represent the average integrated color taken from a circular area, totalling 1.5 sq. in., in the middle of the dorsal surface, this particular area being selected because it is thought to be of prime visual importance with regard to color.

As one progresses visually from shade 11, the lightest of the Caucasian colors, to shade 16, the darkest, the appearance of the hand changes from that of a pale, light skin to that of a dark, ruddy skin (Fig. 3). Similarly, shades 21 through 26 vary in appearance from what usually is considered light Negro skin to dark Negro skin. Interestingly enough, the hue, represented by dominant wavelength values, overlaps considerably in Negroes and Caucasians, and the data thus seem to be in agreement with the conclusions of Edwards and Duntley (7) to the effect that the skin pigments responsible for pigmentation in the dark races also are responsible for pigmentation in the white. The calculated values shown in Table 1 also agree essentially with measurements made on Negro and Caucasian hands

Table 1
COLORIMETRIC VALUES FOR CAUCASIAN AND NEGRO SHADES

Race	Shade No.	Brightness[a] (Value)	Dominant Wavelength[a] (Hue)	Purity[a] (Chroma)
Caucasian	11	31.8	587.3	23.7
	12	28.3	587.3	26.0
	13	25.8	587.3	26.8
	14	23.3	588.6	29.0
	15	20.8	588.6	29.3
	16	17.8	590.0	31.7
Negro	21	14.5	586.9	45.2
	22	12.4	587.3	43.2
	23	10.4	587.3	41.7
	24	8.6	589.6	38.0
	25	7.2	590.0	37.0
	26	5.8	594.3	32.4

* The terms "brightness," "dominant wavelength," and "purity" represent colorimetric values describing appearance in diffuse daylight *(11).* They correspond roughly to value, hue, and chroma, respectively, found in the Munsell system of color nomenclature *(14).*

by Heer and White *(12),* who used a General Electric recording spectrophotometer.

Of course, cosmetic gloves would not appear lifelike if they were simply painted homogeneously with pigments having the required color characteristics. It is necessary for the artist to reproduce the required shade as convincingly as possible. For example, it appears advantageous to tint the glove on the inner surface, so that colors are seen through a layer of material, thereby giving the illusion of depth. Furthermore, the pigments should be applied in a heterogeneous manner to emulate that found in the human skin. The local color of knuckles and veins must be placed in the respective areas, half-moons and fingernails must be painted, and, where necessary, freckles and other fine details must be incorporated.

LIGHT AND COLOR

Caucasian and Negro cosmetic gloves carefully tinted by a competent artist to the color specifications recorded in Table 1 appear realistic in daylight. But as the kind of lighting changes *(i.e.,* from daylight to artificial) glove color, especially in the Caucasian shades, varies in a manner different from that seen in human skin. Indeed, under some kinds of artificial light the cosmetic glove may appear unrealistic or even "dead." Hence it is not enough to provide a color match that appears real under one kind of lighting only. The cosmetic glove must be so tinted that it appears to change color in the same manner as does the human hand. Thus, colorwise, a lifelike cosmetic glove could be defined as one that has a distribution of pigments equivalent to that of human skin and whose over-all color appears to change precisely as does that of the natural skin under all types of illumination.

To achieve such a result, it is necessary first to examine the spectral reflectance curves of human skin and to compare these curves with those of the tinted cosmetic gloves currently available. The curves in Figure 3, obtained from measurements made with a General Electric recording spectrophotometer, are profiles of the amount of light reflected by the hand or glove at each wavelength in the visible range, *i.e.,* from 400 millimicrons (violet) to 680 millimicrons (red). It is apparent that the reflectance curves for the three Caucasian subjects are markedly different in shape from those for the present Caucasian cosmetic gloves. None of the absorption characteristics of reduced and oxyhemoglobin in the region of from 520 to 540 millimicrons are observable in the tinted gloves, and none of the gloves show the sharp increase in reflectance in the blue and red regions. Notwithstanding the fact that the present Caucasian gloves may match human skin in brightness, dominant wavelength, and purity when viewed under ICI Illuminant C (*i.e.,* diffuse daylight), it is clear why they may not match at all under other viewing conditions, such as when illuminated by incandescent or fluorescent lights.

The spectrophotometric curves for two Negro hands and for two Negro gloves also are shown in Figure 3. In this instance, because of the high concentration of melanin in Negro hands (7), the absorption bands due to oxy- and reduced hemoglobin are obscured, and the curves show a steady rise in the amount of reflected light from the violet to the red regions. The curves for the Negro gloves have essentially the required shape and should be a fairly good match for the human counterparts over the whole wavelength range, a fact that has been borne out by experience.

The question now arises as to what can be done to make the spectrophotometric curves for the Caucasian gloves coincide in shape with the curves for the normal skin. The problem could, of course, be solved simply if the skin pigments were available in sufficient quantities and if they were sufficiently stable in the plastic medium for use in tinting the cosmetic glove. But such is not the case. The solution to this aspect of the problem lies in combining specific pigments in such a manner that the shape of the skin curve is duplicated precisely. To date, a large number of commercially available pigments have been examined for their spectrophotometric properties. Exact spectrophotometric duplicates of the skin pigments have not been found, but, by making judicious combinations of several pigments, representative curves duplicating that of living skin have been achieved to a reasonable degree. Such a curve is shown in Figure 4. It remains, however, for this or similar pigment mixtures to be applied to gloves in order to produce a number of shade guides that will satisfy the amputee population.

COLOR AND GLOVE MATERIAL

It appears that in the not-too-distant future synthetic pigment mixtures will be available for achieving color realism in cosmetic gloves. Unfortunately, the pigments themselves represent only one aspect of the materials problem associated with color realism. Another important factor is the permanence of the plastic

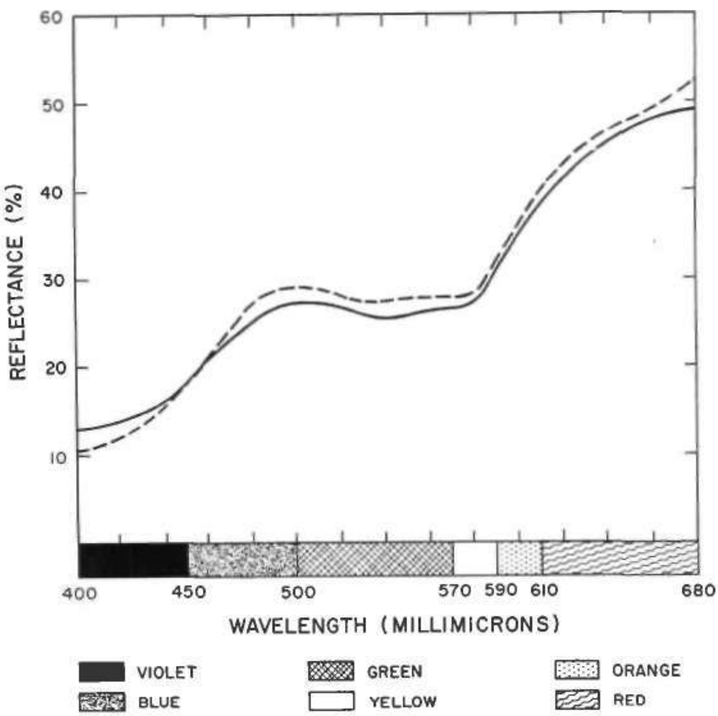

Fig. 4. Actual reflectance curve of the dorsal skin of a Caucasian hand (solid line) and of an experimental synthetic pigment mixture (dashed line).

material. Even if it were possible to fabricate a precise skin duplicate in the form of a cosmetic glove, unless the glove retained its proper color for a reasonable period of wear it would not merit serious consideration. A satisfactory glove must therefore be made from a material that remains stable colorwise when exposed to conditions of amputee use.

Such an application requires, in effect, a super skin. Human skin itself is far from permanent. Its apparent permanence stems from its ability to regenerate itself continuously. Thus living skin may be stained, burned, scarred, torn, cut, or otherwise generally maltreated. If the damage is not too severe, the whole skin is, after a lapse of time, once again renewed, and substantially the original appearance is restored. No such regenerative process characterizes inanimate materials. Artificial skin must have intrinsic resistance to staining, outdoor exposure, tearing, and so on. Stains that cannot be removed, and degradation evidenced by yellowing, reddening, and gradual over-all darkening and graying, obviously affect glove realism adversely. Fortunately, laboratory methods are available for determining the rate of degradation of plastic materials, one such method of evaluation being shown in Figure 5.

With respect to color, the materials problem involved is one of major importance, and it is therefore necessary to inquire into the factors producing irremovable stains, degradation, and yellowing. As for stains, it is to be noted that the commercially available plasticized polyvinyl chloride glove contains approximately 50 percent of a solvent-type liquid plasticizer, included to impart the necessary flexibility. Because of the presence of the plasticizer, staining agents are adsorbed at the surface and then diffuse into the glove material. Thus, to enhance the stain resistance of a cosmetic glove, it would be desirable to eliminate plasticizer—if not completely then at least on the surface subject to staining.

Two factors may contribute to the phenomenon of gradual discoloring. For one, inadvertent rubbing against objects may result in plasticizer (and perhaps stabilizer) extraction from the glove and/or absorption of colors from the objects. For another, oxidative degradation also probably plays a part in discoloration. Plastic materials that are chemically unsaturated, or those having labile chemical groups, are most susceptible to oxidative degradation. Thus, a material should be chosen that is chemically saturated and free from labile chemical groups.

THE FUTURE IN COSMETIC GLOVES

Once realistic pigment mixtures and a stable, stain- and discoloration-resistant plastic medium can be specified, the manner in which these materials are to be mixed and molded to achieve optimum effect becomes important. This phase of glove development still is largely a matter for conjecture. At present, the glove is cast, reversed, and pigmented on the inner

Fig. 5. Apparatus, consisting of ultraviolet lamp and turntable, for determining color fastness of pigments and degradation of plastic materials under exposure to simulated sunlight. *Courtesy Army Prosthetics Research Laboratory.*

surface to give the illusion of depth. Perhaps a more realistic effect could be obtained by using a compounded dispersion of pigment in a diversified multiple laminate to provide a compatible filter medium consistent with the reflectance characteristics of the individual color, thus emulating the character of the living skin. Or perhaps certain of the pigments could be dispersed in the plastic medium itself, the glove reversed, and the inner surface pigmented by the present technique. Research to produce gloves of increased realism colorwise continues therefore along three major lines—application of pigment mixtures that will reproduce the spectrophotometric curves of skin more closely than do the present colors, development of a material exhibiting a high degree of resistance to staining and discoloration, and, finally, development of techniques for combining these materials in such a way as to give optimum realism.

Whatever the final materials and techniques selected, assurance must be had that the cost of the glove will be such that it can be purchased by most of the amputee population. As opposed to the idea of custom-made gloves, commercial production of gloves at a reasonable price poses a challenge for those involved in achieving glove realism. Although there must be no sacrifice of ultimate realism to economic necessity, unit cost is an unavoidable consideration. The ultimate goal is a product of first-rate quality at a reasonable price.

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