Masking Power of Dental Opaque Porcelains

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A technique was developed to qualify the masking power of un-diluted opaque dental porcelain by dilution of opaque powder with a clear glaze powder and by extrapolation of quantitative data gathered by reflectance spectrophotometry. Quantification of reflectance data was made on dilute opaque porcelains using the scattering and absorption coefficients in the Kubelka-Munk equation. Qualitative comparisons of undiluted opaque porcelains were made from quantitative data gathered from diluted opaque porcelains.

Introduction.

This study was designed to evaluate the relative opacity or masking power of five commonly-used brands of dental opaque porcelain. Nally and Meyer (1970) described opaque porcelain as a ceramic powder containing 15% opacifying metal oxides (such as titanium oxide, zirconium oxide, tin oxide, rubidium oxide, barium oxide, and/or zinc oxide). The function of the metal oxides is to mask highly reflective underlayers by scattering incident and reflected light. There exist in restorative dentistry today numerous mandates for the use of dental ceramics in minimum thickness (Jelenko, 1968; Johnston et al., 1971; Kuwata, 1980; Tylman, 1965), as in the restoration of labially-positioned anterior teeth, unusually thin anterior teeth, and lower incisors which normally present labio-lingually as thin teeth. To date, there has been only one published attempt to evaluate the optimum thickness of opaque porcelains: Gettleman et al. (1977) found that thinner layers of opaque dental porcelain could be applied to surfaces which had been coated with a gold flash coating, as compared with uncoated oxidized metal surfaces.

Materials and methods.

Preliminary unsuccessful attempts to prepare thin sections of dental porcelain opaque to be used in reflectance spectrophotometry dictated the use of dental porcelain glaze as a diluting agent. Ten and 20% dilutions of each opaque porcelain were examined in the visible spectrum from 410-700 nm. The brands* of dental opaque porcelain studied were Ceramco "B", Will-Ceram, Neydium "B", Biobond, and Vita VWK-68. For each brand of opaque, we evaluated five shades which were equivalent to Bioform

Shades[#] 59, 62, 65, 69, and 82 (Table). The Vita VMK-68 shades used were those suggested by a conversion chart furnished by the manufacturer.

Dental porcelain glaze and opaque powders were weighed to an accuracy of 1 mg on a single-pan balance. After being weighed, dry porcelain powders were mixed and placed in 20-ml plastic bottles, then tumbled in a lapidary tumbler for eight hr. The mixed powders were suspended in distilled water and formed in a custom-made elliptical stainless steel mold (10 mm by 4 mm), using hand condensation, instrument vibration (Lecron carver), and hand pressure. Excess water was absorbed from the powder suspensions in the stainless steel mold by absorbent tissue and hand vibration (Lecron carver).

[#]Dentsply International, York, PA

TABLE
DENTAL PORCELAIN OPAQUES AND BATCH NUMBERS FOR EACH BIOFORM SHADE AND MANUFACTURER

Bioform Shade	Porcelain Opaque	Batch Number
	Will-Ceram	
59	02	0244
62	02	0244
65	03	0238
69	05	0251
82	07	0259
	Neydium "B"	
59	01	C0102
62	02	D0203
65	03	D0703
69	05	D0903
82	07	D0702
	Biobond	
59	01	F50
62	02	F78
65	03	F83
69	05	F69
82	07	F05
	Ceramco "B"	
59	59	5079
62	62	4073
65	65	4079
69	69	3700
82	82	3032
	Ceramco Glaze	No batch number
	Vita-VMK-68	
59	2 pt. 531+ 1 pt. 535	No batch numbers were given
62	531	
65	531	
69	536	
82	534	

Molded samples of mixed powders were dried in an oven for eight hr at 200 °C.

Dried, diluted, opaque porcelain samples were sintered under vacuum in a porcelain furnace. Samples were fired at temperatures close to those suggested by the glaze manufacturers. Individual firing temperature adjustments were made for each dilution (10% and 20%) and for each brand of opaque. A firing schedule was derived for the 20% opaque samples using the suggested firing temperature of the Ceramco glaze plus 20% of the difference between the sintering temperature for each specific brand of opaque and the Ceramco glaze. Firing temperatures for the 10% opaque dilutions were determined by adding to the firing temperature of the Ceramco glaze 10% of the difference between the firing temperature for each specific brand of opaque and that of the Ceramco glaze.

Sintered samples of diluted opaque porcelain were embedded in polymethylmethacrylate mounting material and sectioned on a slow-speed diamond wheel saw. The embedded thin sections were polished using 400- and 600-grit paper, then 15-μm alumina. With a micrometer, we measured the embedded and polished samples of porcelain opaque for uniform thickness to an accuracy of 0.005 mm.

A double-beam spectrophotometer with an integrating sphere[§] was used to measure the reflectance spectra in the visible range from 410 to 700 nm. A zero cone[¶] and white porcelain blank 2 cm in diameter (B-2 Standard)[∞], standardized to a white enamel standard of known value for absolute reflectance, were used to calibrate the spectrophotometer. A beam-reducing accessory[•] was used to reduce the light beam to a dimension of 6 mm by 10 mm. The zero cone and standard were positioned in front of the light beam with a custom-made port plate coated with BaSO$_4$ powder.

Reflectance spectra from the 10% and 20% opaque porcelain dilutions were recorded using 1-cm-diameter light and dark standards (B-2 and B-3 Standards[§ §]), joined to thin dilute opaque samples by a thin layer of refractive index oil with a refraction index of 1.5. The reflectance profiles of the B-2 and B-3 custom standards were determined by comparison with the Beckman zero cone and a large 4 x 4-cm enamel standard[**] of known reflectance value.

Absolute reflectance values for each 10% and 20% sample were collected and plotted against both B-2 and B-3 standards. Plots for each shade, brand, and dilution of opaque were scrutinized for aberrations to eliminate possible errors in preparation or measurement of diluted opaque samples.

Relative translucency was determined with the opaque samples over light and dark backings (B-2 and B-3 Standards). When the reflectance of the opaque sample was nearly the same over both light and dark backings, the sample was considered to have strong masking power. Con-

versely, when the reflectance was greater with the sample over a light than a dark backing, the sample was considered to have weak masking power.

Compensation for surface reflectance from the specimen's outer top surface and internal reflectance of the underside of the same top surface (Fig. 1) was made using derivations of Saunderson (1942) and Duntley (1942), in the following equation:

$$R_t = \frac{R_m - k_1}{1 + k_1 R_m - k_1 - k_2} \qquad \text{(Eq. 1)}$$

where: Rt = reflectance measured in a transparent medium with the same refraction index as the sample; Rm = the % of light reflection from the sample, measured by a spectrophotometer; k_1 = fraction of incident light which is reflected from the front surface of the sample (k_1 = 0.04 for dental porcelain) (Kortum and Lohr, 1969); and k_2 = fraction of light reflected back into the sample from the front surface (k_2 = 0.3876 for dental porcelain) (Mudgett, 1973).

Optical coefficients for absorption (K) and scattering (S) were calculated using the secondary optical coefficients, a and b, in the following simplified notation (Broadbelt *et al.,* 1980; O'Brien *et al.,* 1982):

$$C_1 = R_1 + Rg_1 \qquad \text{(Eq. 2)}$$
$$C_2 = R_1 - Rg_1 \qquad \text{(Eq. 3)}$$
$$C_3 = R_1 Rg_1 + 1 \qquad \text{(Eq. 4)}$$
$$C_4 = R_2 + Rg_2 \qquad \text{(Eq. 5)}$$
$$C_5 = R_2 - Rg_2 \qquad \text{(Eq. 6)}$$
$$C_6 = R_2 Rg_2 + 1 \qquad \text{(Eq. 7)}$$
$$a = (C_3C_5 - C_6C_2)/(C_1C_5 - C_4C_2) \qquad \text{(Eq. 8)}$$
$$b = (a^2 - 1)^{1/2} \qquad \text{(Eq. 9)}$$
$$\text{if } |C_2| > |C_5| \text{ then: } Ct = (C_3 - aC_1)/(C_2b) \qquad \text{(Eq. 10)}$$
$$\text{if } |C_2| < |C_5| \text{ then: } Ct = (C_6 - aC_4)/(C_5b) \qquad \text{(Eq. 11)}$$

The scattering coefficient "S" is found by Eq. 12:

$$S = (\ln(1 + Ct) - \ln(Ct - 1))/(2bx) \qquad \text{(Eq. 12)}$$

The absorption coefficient "K" can be found by Eq. 13:

$$K = S(a - 1) \qquad \text{(Eq. 13)}$$

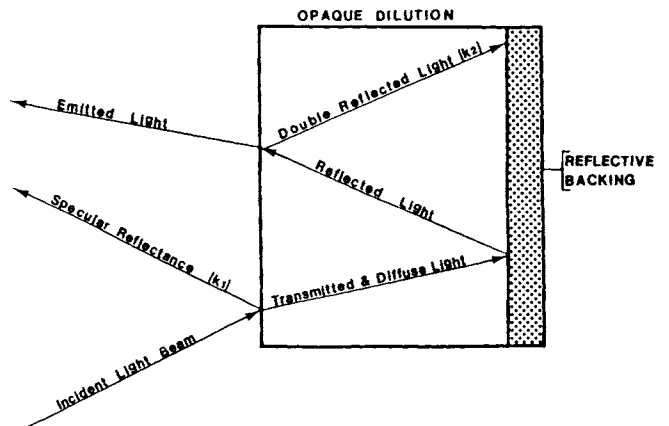Using the absorption (K) and scattering (S) coefficients, we calculated the optical infinite thickness values of each

Fig. 1 — The effects of interfacial reflection (k^1 & k^2) on a highly reflective backing.

10% and 20% opaque specimen using the Kubelka-Munk equation (Eq. 14) for 0.5% transmission:

$$Xi(0.5\%t) = (Arcsinh\ (200b) - Arcsinh\ b)/(bs)\quad (Eq.\ 14)$$

where: Arcsinh is the inverse hyperbolic sine function.

0.5% transmission was selected to provide an accurate statistical evaluation of the diluted dental porcelain opaque samples. In this Kubelka-Munk equation, "Xi(0.5%t)" means that indistinguishable light would be equal to or less than 0.5% transmission.

The optical infinite thickness (Xi) is the thickness needed by a sample of material to prevent the transmission of any distinguishable light through its substance (Judd and Wyzecki, 1975). At this thickness (Xi), no distinguishable form, shape, or color can be recognized through the sample. Materials with a high optical infinite thickness value (Xi) are poor masking agents, since a greater thickness of opacifying material is necessary to mask underlying materials of different colors. Materials with a low value of optical infinite thickness are good masking agents.

Statistical analysis was performed using a three-factor analysis of variance to study the effects of wavelength, concentration, and brand of opaque, for five Bioform Shades (Sokol and Rohlf, 1969). The three wavelengths selected for statistical comparison were 480 nm, 550 nm, and 620 nm. The analysis of variance provided a single value for each porcelain opaque. Replicants were provided by using two concentrations at each of the three wavelengths used.

Multiple pairwise comparisons among sample means were made with Scheffe multiple comparison procedures at the 95% level of confidence (Neter and Wasserman, 1974).

Results.

Shade 59. — Ceramco "B" Paint-O-Pake Shade 59 was not statistically different from Neydium "B" opaque of the same shade, and both were found to have the highest masking power for this shade. Will-Ceram was not statistically different from Vita VMK-68 opaque for this shade (Fig. 2).

Shade 62. — Ceramco "B" Paint-O-Pake shade 62 was not statistically different from Biobond opaque or Neydium "B" opaque, which were found to have the highest masking power for this shade. Will-Ceram opaque was found to have the lowest masking power for Bioform Shade 62 (Fig. 3).

Shade 65. — Ceramco "B" Paint-O-Pake for Bioform Shade 65 had statistically the highest masking power for

this shade. Vita VMK-68 opaque had statistically the lowest masking power for Bioform Shade 65 (Fig. 4).

Shade 69. — Ceramco "B" Paint-O-Pake for Bioform Shade 69 was not statistically different from Neydium "B" or Biobond opaques for shade 69. Will-Ceram opaque was statistically different from Ceramco Paint-O-Pake for this shade (Fig. 5).

Shade 82. — Biobond opaque for Bioform Shade 82 was not statistically different from Ceramco "B" Paint-O-Pake or Neydium "B" opaque. Will-Ceram opaque was not statistically different from Vita VMK-68 opaque for Bioform Shade 82 (Fig. 6).

All values of optical infinite thickness increased with an increase in wavelength. Ceramco "B" Paint-O-Pake was statistically the strongest opaque for shade 65 only. Neydium "B" opaques were statistically never weaker than second strongest and were found three out of five times to be statistically equal in masking strength to the strongest opaque.

Discussion and conclusions.

The opacifying nature of dental opaque porcelain enhances its use in layers of less than 0.5 mm. This fact emphasizes the extreme power held by metallic oxides used in porcelain opaques. The concentration of opacifying
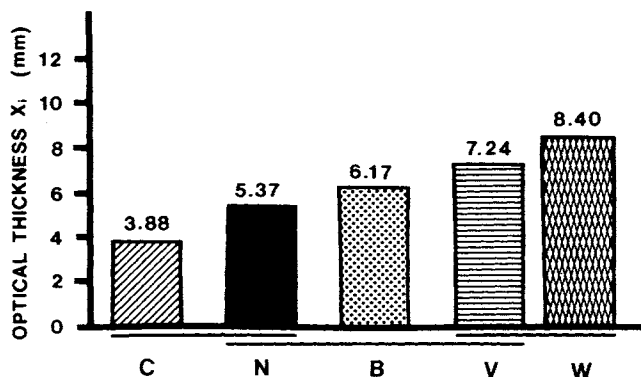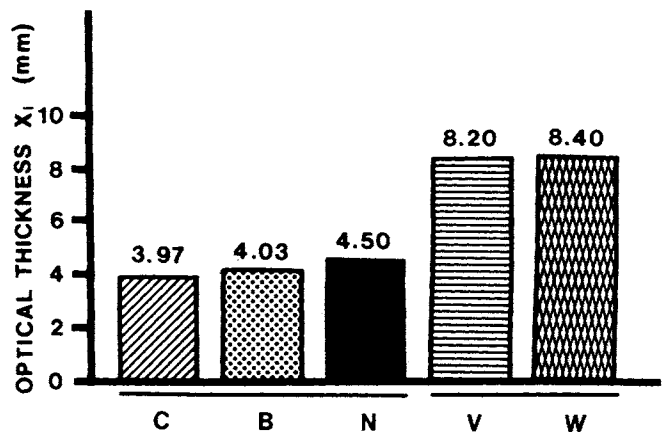
Fig. 3 — Relative optical infinite thickness from pooled data of opaque porcelain dilutions for Bioform shade 62. C = Ceramco; N = Neydium; B = Biobond; V = Vita; W = Will-Ceram.
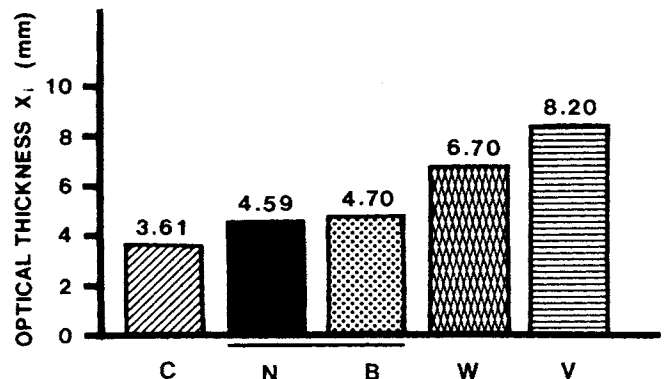
Fig. 4 — Relative optical infinite thickness from pooled data of opaque porcelain dilutions for Bioform shade 65. C = Ceramco; N = Neydium; B = Biobond; V = Vita; W = Will-Ceram.

Fig. 2 — Relative optical infinite thickness from pooled data of opaque porcelain dilutions for Bioform shade 59.

Fig. 5 — Relative optical infinite thickness from pooled data of opaque porcelain dilutions for Bioform shade 69. C = Ceramco; N = Neydium; B = Biobond; V = Vita; W = Will-Ceram.

Fig. 6 — Relative optical infinite thickness from pooled data of opaque porcelain dilutions for Bioform shade 82. C = Ceramco; N = Neydium; B = Biobond; V = Vita; W = Will-Ceram.
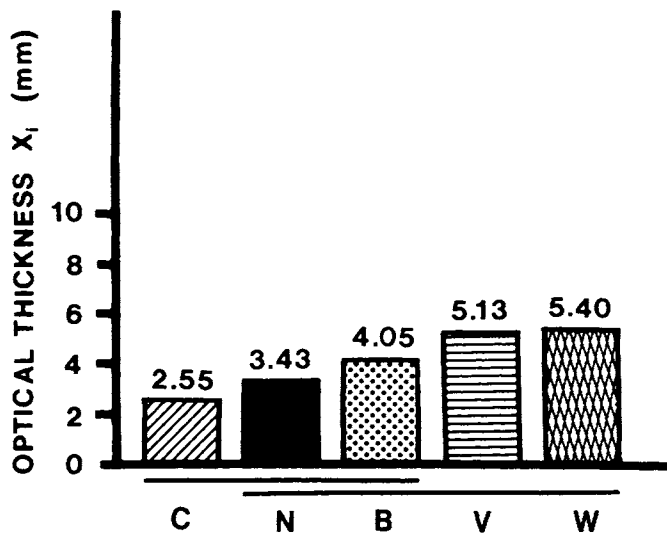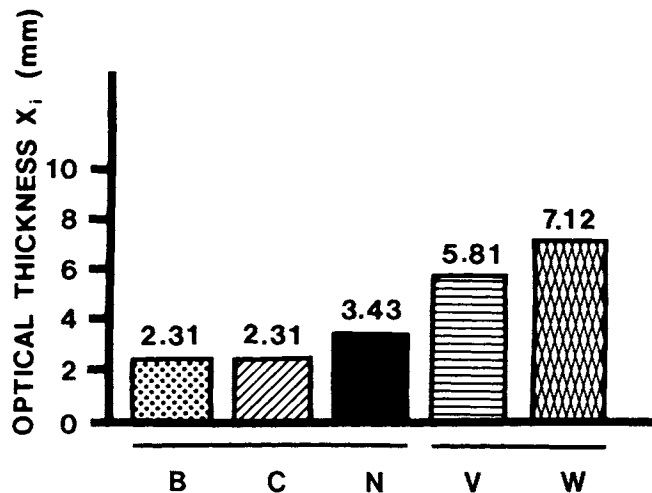
metallic oxides is usually less than 15% (Nally and Meyer, 1970).

In this study, Ceramco "B" Paint-O-Pake was either the strongest or not significantly different from the strongest opaque for all shades studied.

Nally and Meyers found that the principal opacifying metal oxides in Ceramco "B" Paint-O-Pake were tin oxide and zirconium oxide. A table of refractive indices (Kingery *et al.*, 1976) lists titanium oxide as having a refractive index greater than that of tin oxide or zirconium oxide. Hence, titanium oxide would be expected to be the best

opacifier, ignoring the effects of particle size and assuming concentrations to be equal. This study found opaque porcelains containing small amounts of tin oxide and large amounts of titanium oxide, as reported by Nally and Meyers, to have significantly less masking power than opaques with greater amounts of tin oxide and smaller amounts of titanium oxide. This suggests that small differences in particle size might dramatically affect the masking power of dental opaque porcelains.

The brittle nature and extreme opacity of dental porcelain opaque made the study of their masking properties difficult. This study described a technique of evaluating the relative masking power of dental porcelain opaque using dental porcelain glaze as a diluting agent. Qualitative assessment of the relative masking power of undiluted porcelain opaques was made by extrapolation of quantitative reflectance spectrophotometry data obtained from dilute opaque porcelains, using the scattering and absorption coefficients in the Kubelka-Munk equation.

REFERENCES

BROADBELT, R.; O'BRIEN, W.J.; and FAN, P.L.: Translucency of Dental Porcelain, *J Dent Res* 59:70-75, 1980.

DUNTLEY, S.Q.: The Optical Properties of Diffusing Materials, *Optic Soc Am J* 32:61-70, 1942.

GETTLEMAN, L.; HERZBERG, T.W.; WEBBER, R.L.; and MOFFA, J.: The Effect of Metal Surface Treatment on Masking Power of Opaque Porcelain. In: Dental Porcelain: The State of the Art–1977, Yamada, H.N., Ed., Los Angeles: Univ. of Southern Calif., 1977, p. 317.

JELENKO, J.F.: Crown and Bridge Construction, 5th ed., New Rochelle: J.F. Jelenko Co., 1968, p. 123.

JOHNSTON, J.F.; PHILLIPS, R.W.; and DYKEMA, R.W.: Modern Practice in Crown and Bridge Prosthodontics, 3rd ed., Philadelphia: W.B. Saunders Co., 1971, p. 420.

JUDD, D.B. and WYZECKI, G.: Color in Business, Science and Industry, New York: John Wiley and Sons, 1975, p. 431.

KINGERY, W.D.; BOWEN, H.K.; and UHLMANN, D.R.: Introduction to Ceramics, 2nd ed., New York: John Wiley and Sons, 1976, p. 669.

KORTUM, G. and LOHR, J.E. (translator): Reflectance Spectroscopy, New York:Springer Verlag Publishing Co., 1969, pp. 5-13.

KUWATA, M.: Theory and Practice for Ceramo Metal Restorations, Chicago: Quintessence Publishing Co., 1980, p. 35.

MUDGETT, P.S. and RICHARDS, L.W.: Kubelka-Munk, Scattering and Absorption Coefficients for Use with Glossy, Opaque Objects, *J Paint Technol* 45:44-53, 1973.

NALLY, J.N. and MEYER, J.M.: Recherche Experimentale sur la Nature de la Liaison Ceramo-Metallique, *Schweiz Monatsschr Zahnheilkd* 80:250-277, 1970.

NETER, J. and WASSERMAN, W.: Applied Linear Statistical Models, Homewood, IL: Richard D. Irwin, 1974, p. 477.

O'BRIEN, W.J.; JOHNSTON, W.M.; and FANIAN, F.: Filtering Effects of Body Porcelain on Opaque Color Modifiers, IADR *Progr & Abst* 60:No. 330, 1982.

SAUNDERSON, J.L.: Calculation of the Color of Pigmented Plastics, *Optic Soc Am J* 32:727-736, 1942.

SOKO, R.R. and ROHLF, F.J.: Biometry, San Francisco: W.H. Freeman, 1969, pp. 320-328.

TYLMAN, S.D.: Theory and Practice of Crown and Bridge Prosthodontics, 5th ed., St. Louis: C.V. Mosby Co., 1965, p. 992.