Effect of Surface Roughness on Stain Resistance of Dental Resin Composites

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ABSTRACT

Background: Surface quality of dental restorations is one of the important factors that determine the success of the restoration. Unfortunately, exterior discoloration is still a problem for dental resin composites.

Purpose: The purpose of the study was to investigate the influential factors on stain resistance of dental resin composites.

Materials and Methods: Filtek Supreme (nanocomposite), Filtek A110 (microfilled composite), Filtek Z250 (microhybrid composite), and Filtek P60 (microhybrid composite) (all products from 3M ESPE, St. Paul, MN, USA) were tested. Thirty-six specimens per material were prepared and randomly assigned to 6 groups. The specimens in 5 groups were polished against 1,000-, 1,200-, 1,500-, 2,000-, and 2,500-grit sandpaper, respectively. The specimens in a sixth group were polished with 2,500-grit or 1,200-grit sandpaper and used as controls. Surface roughness (Ra) and gloss of the specimens were measured with a profilometer and a glossmeter, respectively. Specimens were immersed in a coffee solution (control group in distilled water) and kept in a 37°C incubator. Color was measured by a spectrophotometer at baseline, 3 days, 7 days, and 14 days, and color change (ΔE^*_{ab}) was calculated.

Results: Coffee, material, Ra, and the interaction of material × Ra had statistically significant influences on the stain resistance of the dental composites tested. For most materials in coffee solution, time squared and Ra had significant effects on the discoloration.

Conclusions: Coffee had a significant influence on discoloration of the dental resin composite materials tested. The different composites behaved differently in coffee solution. Discoloration increased as Ra increased for the composites tested, except with Filtek A110. The discoloration process was accelerated with time.

CLINICAL SIGNIFICANCE

Dental resin composite restorations should be polished as smooth as possible to increase stain resistance. Reduced contact with coffee can help avoid discoloration.

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Resin composites are widely used in dentistry and have become one of the most commonly used esthetic restorative materials because of their adequate strength, excellent esthetics, moderate cost compared with that of ceramics, and ability to be bonded to tooth structure. Surface quality of dental restorations is an important factor in determining the success of the restorations. Unfortunately, discoloration is still a problem for dental resin composite restorations.[1,2]

Surface roughness (Ra) is one reason for exterior discoloration, and it is closely related to the type of composite material and the polishing and finishing systems used.[3–5] During wear of dental resin composites, inorganic fillers debond from the resin matrix and leave a void, increasing the surface roughness and forming a surface susceptible to exterior stain.[6] The average particle size of inorganic fillers in microhybrid dental composites has been reduced to around 1 μm or less so that the polished restoration can achieve adequate gloss and, during long-term service, the wear of the restoration does not create a rough surface. Nanocomposites have been developed to improve the retention of polish and gloss as well.

Most studies on stain resistance of dental restorative materials have been conducted on specimens that were not polished or all polished with the same polisher.[7–10] However, different materials attain different surface roughnesses when polished with the same polisher.[3–5] No study has been conducted to establish a relationship between surface roughness and stain resistance.

The objective of this project was to study the influential factors on stain resistance of dental resin composites. The null hypotheses were that (1) Ra did not influence the stain resistance of the composite when it was < 0.1 μm (a surface roughness limit existed), and (2) different types of dental resin composites did not influence stain resistance.

MATERIALS AND METHODS

Four composites (shade A3, 3M ESPE, St. Paul, MN, USA) were chosen in this study: one nanocomposite for both anterior and posterior restorations (Filtek Supreme), one microfilled composite for anterior restorations (Filtek A110), one microhybrid composite material for both anterior and posterior restorations (Filtek Z250), and one microhybrid composite for posterior restorations (Filtek P60) (Table 1). Materials were light cured according to manufacturer's instructions with a light-curing unit (Elipar Highlight, 3M ESPE) in a split polytetrafluoroethylene mold (3 mm thick and 10 mm in diameter) covered with a polyester film strip (3M Flip-Frame, 3M Visual Systems Division, Austin, TX, USA) and a glass microscope slide. The tip of the curing light unit was 10 mm in diameter. The material was injected directly into the mold and packed carefully to let it spread and fill the mold before another Mylar strip and microscope slide was put on top of the mold. Extra material was squeezed out, and the bottom side of the specimen was cured first so that no bubbles were trapped and no packing marks were left at the bottom surface. The bottom surface was used as the polished surface in this study. The specimen was then flipped over, and the other side was cured. The intensity of the curing light (500 mW/cm^2) was monitored with a radiometer (Kerr/Demetron, Danbury, CT, USA). Thirty-six specimens per material were prepared and randomly assigned to 6 groups with 6 specimens per group.

Specimens in 5 groups were polished with 1,000-, 1,200-, 1,500-, 2,000-, and 2,500-grit sandpaper, respectively, using a variable speed grinder-polisher (ECOMET 6, Buehler, Lake Bluff, IL, USA) at a speed of 120 rpm with a force of 54 N. The specimens in the sixth group were polished with 2,500-grit or 1,200-grit sandpaper and used as controls. The reason for polishing with two grits in the control group was to verify whether Ra had an influence on the discoloration of specimens stored in distilled water. Since Ra was analyzed as a continuous variable, rather than a categorical one, those specimens were used in one group as a control. Average surface roughness (Ra) in micrometers of

TABLE 1. DENTAL RESIN COMPOSITES TESTED IN THIS STUDY.*

Composite (Shade)	Resin Matrix Composition (Filler)	Filler Average Particle Sizes	Filler Loading	Curing Time (s)
Filtek Supreme (A3B)	Bis-GMA, UDMA, Bis-EMA, and TEGDMA (zirconia/silica)	Primary 20 nm silica filler and loosely bonded cluster particle size ranging 0.6–1.4 μm	78.5% wt (59.5% vol)	20
Filtek A110 (A3D)	Bis-GMA and TEGDMA (silica)	0.01–0.09 μm with an average particle size of 0.04 μm	56% wt (40% vol)	40
Filtek Z250 (A3)	Bis-GMA, UDMA, and Bis-EMA (zirconia/silica)	0.01–3.5 μm with an average particle size of 0.6 μm	82% wt (60% vol)	20
Filtek P60 (A3)	Bis-GMA, UDMA, and Bis-EMA (zirconia/silica)	0.01–3.5 μm with an average particle size of 0.6 μm	83% wt (61% vol)	20

Bis-EMA = Bisphenol A polyethylene glycol diether dimethacrylate; Bis-GMA = bisphenol-A-glycidyl-dimethacrylate; TEGDMA = triethyleneglycol-dimethacrylate; UDMA = urethane dimethacrylate; vol = volume; wt = weight.
*Information from manufacturer's instructions.

the specimens was measured with a profilometer (Form Talysurf Plus, Taylor Hobson, Leicester, UK), and gloss was recorded with a small-area glossmeter (Novo-Curve, Rhopoint Instrumentation, East Sussex, UK) in gloss units (GU).

Specimens were stored in distilled water in a 37°C incubator overnight before polishing, then polished and immersed in a coffee solution (control groups in distilled water) and kept in the incubator. The coffee solution was prepared using 11 g powder (Folgers, Procter & Gamble, Cincinnati, OH, USA) to 500 mL water. The solution was changed every 2 days.

Color of the specimen was measured repeatedly on a spectrophotometer (Color-Eye 7000, GretagMacbeth LLC, New Windsor, NY, USA) against a white background using CIELAB color space relative to CIE (Commission Internationale de l'Eclairage) standard illuminant D55 at baseline, 3 days, 7 days, and 14 days. The color differences (ΔE^*_{ab}) between baseline and different stain intervals were calculated as follows[11]:

$$\Delta E^*_{ab} = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{\frac{1}{2}}$$

where L* stands for lightness, a* for green-red ($-a^*$ = green; $+a^*$ = red), and b* for blue-yellow ($-b^*$ = blue; $+b^*$ = yellow).

Data were analyzed by fitting analysis of covariance (ANCOVA) and material specific generalized estimating equations (GEE) models with SAS (SAS Institute Inc., Cary, NC, USA), using ΔE^*_{ab} as outcome. ANCOVA was conducted for cross-sectional data (3, 7, 14 d separately) to identify significant factors. GEE was conducted for longitudinal data to identify significant factors while taking time effects into account and was conducted for the coffee-exposed group only. Predictors were considered statistically significant with a p value < .05.

RESULTS

The initial Ra and gloss measurement results are shown in Figure 1. Ra and gloss had a linear relationship (p < .001) for the four composites tested, although the slopes of the regression lines were different.

Color change results are shown in Figure 2. Overall for the specimens in coffee solution, as time and surface significantly. However, with A110, only variables time and time squared had a significant influence on the outcome; the change of Ra did not affect the color change of the specimens in coffee solution.

DISCUSSION

The four composites responded differently to the polishing procedure in this study. The distributions of Ra in Figure 1 show that with the roughness (Ra) increased, the color change increased accordingly. On the other hand, minimal color changes were found as time went by when the specimen was stored in water. Statistical analysis results are listed in Tables 2 and 3. In the ANCOVA model, the independent variables include Ra, a continuous variable; material, coded as 1, 2, 3, and 4 for Supreme, A110, Z250, and P60, respectively; and coffee, coded as 1 and 0 for immersion in coffee solution and water, respectively. Material, Ra, coffee, and the interaction between material and Ra had significant effects on the color changes of the specimens at all three time points (see Table 2). The repeated measurement data for specimens immersed in coffee solution were analyzed by the GEE model for each material. With Supreme and P60, Ra and time squared (Time × Time) had a significant influence on color change; for Z250, all predictors (time, Ra, time squared, time-Ra interaction) influenced the results

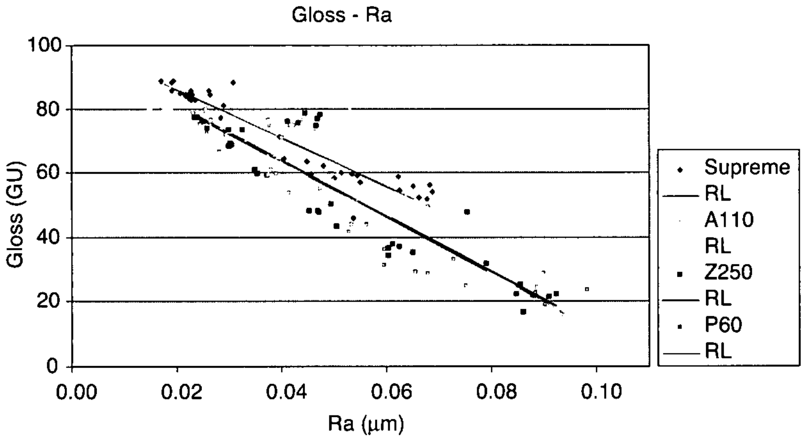


Figure 1. Initial relationship between surface roughness (Ra) and gloss. RL = regression line.

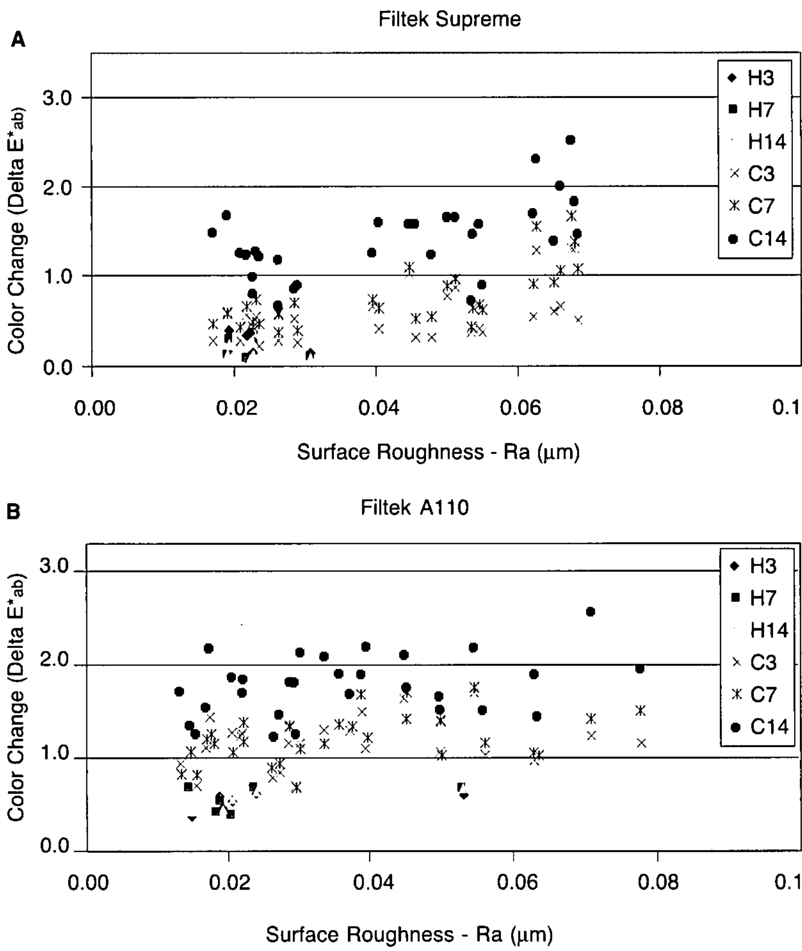
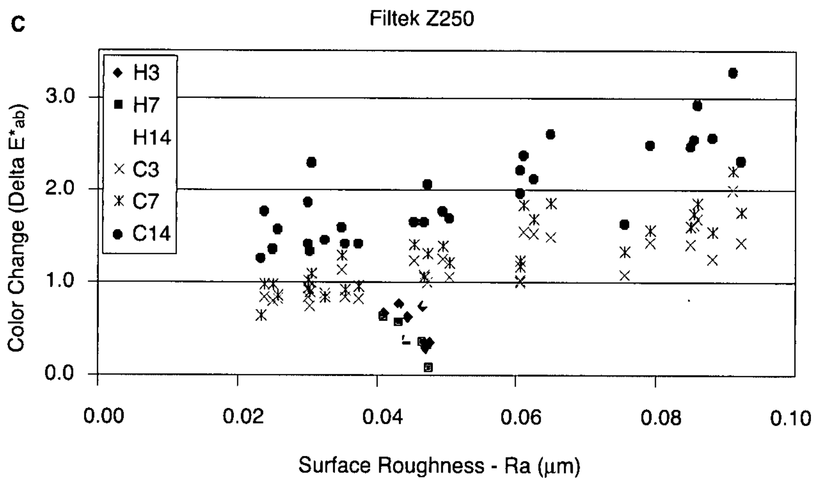


Figure 2. For Filtek Supreme (A), Filtek A110 (B), color changes (ΔE^*_{ab}) of the specimens tested. (H3, H7, H14 are results of the control group in 3, 7, and 14 days, respectively; C3, C7, C14 are results of coffee groups in 3, 7, and 14 days, respectively.)

C



D

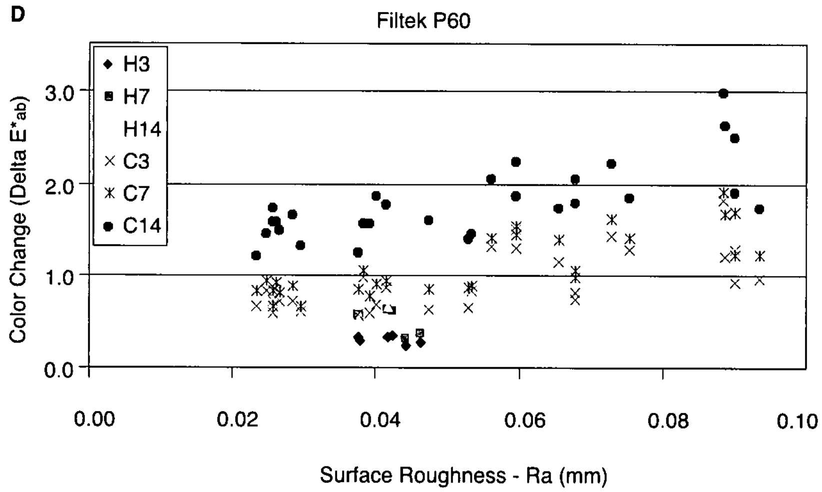


Figure 2. (continued). Filtek Z250 (C), and Filtek P60 (D), color changes (ΔE^*_{ab}) of the specimens tested. (H3, H7, H14 are results of the control group in 3, 7, and 14 days, respectively; C3, C7, C14 are results of coffee groups in 3, 7, and 14 days, respectively.)

same polishing procedure (using a variable-speed grinder-polisher at a speed of 120 rpm with a force of 54 N), Supreme (nanocomposite) and A110 (microfilled composite) had lower Ra values than did Z250 (microhybrid composite) and P60 (posterior composite). An explanation is that the average particle sizes of the primary filler in Supreme and A110 were in the nanometer range (20–40 nm), whereas those of Z250 and P60 were in the micrometer range (0.6 µm).

Surface roughness and gloss had a linear relationship in the range of Ra tested. As Ra increased, gloss decreased rapidly, although the rate of decrease differed for different composites (see Figure 1). From Figure 1 it could be deduced that if Ra continued to increase, gloss would decrease but at a slower rate toward zero since that was the lowest value that could be measured. Z250 and P60 have the same resin matrix and inorganic fillers, and their gloss-Ra regression lines almost overlapped. The only difference between these products is the filler loading. P60, which is loaded with 1% more filler than Z250 to increase its packability, was a little rougher than Z250 when polished with the coarser sandpaper (see Figure 1).

Gloss had a better fit than Ra did in the regression equations for all the composites tested. But since gloss was a measure of the overall surface characteristics (macrocharacteristic) and Ra was measure of a microcharacteristic of the surface, Ra was chosen for the models as it was easier to explain the results fundamentally. Gloss measurement was

TABLE 2. STATISTICAL ANALYSIS RESULTS.*

Source	Color Change at 3 d	Color Change at 7 d	Color Change at 14 d
Material	<.0001	<.0001	.0003
Ra	<.0001	<.0001	<.0001
Coffee	<.0001	<.0001	<.0001
Material × Ra	.02	.02	.01

Ra = surface roughness.
*From analysis of covariance, p values.

TABLE 3. STATISTICAL ANALYSIS RESULTS.*								
	Filtek Supreme		Filtek A110		Filtek Z250		Filtek P60	
Parameter	Estimate	*p* Value	Estimate	*p* Value	Estimate	*p* Value	Estimate	*p* Value
Intercept	0.1057	.31	1.1819	<.0001	0.5853	<.0001	0.3747	.0003
Time	−0.0049	.73	−0.0615	.0001	−0.0384	.005	−0.0168	.14
Ra	9.5843	.0009	3.2771	.21	10.1012	<.0001	10.6555	<.0001
Time × Time	0.0040	<.0001	0.0066	<.0001	0.0048	<.0001	0.0049	<.0001
Time × Ra	0.2813	.33	0.1307	.68	0.5867	.0015	0.1854	.31

*From generalized estimating equations.

not as sensitive as Ra to the minor changes on the surface, so its value was more stable, which may be one of the reasons that gloss fit the models better than Ra did.

Different materials responded differently to coffee solution in terms of stain resistance. Table 3 shows that in different material-specific models, different factors were significant. The only common characteristic in the analysis result was time squared, indicating that the color change–time relationship was not linear but rather accelerating. Ra had a positive linear relationship with color change for three of the composite materials tested: Supreme, Z250, and P60. The smaller the Ra was (the smoother the surface was), the smaller the discoloration (the more resistance to stain) of the material was. But for A110 with up to Ra = 0.07 μm, the stain resistance was not affected by Ra. This result might be due not only to the difference in particle size, but also to differences in the resin matrix and inorganic fillers used in the material (A110), which has a different resin matrix system than the other three materials and uses different inorganic fillers as well (see Table 1). Based on the data of this study, it appears that not only the size of the primary filler particles influenced stain resistance, but the chemical characteristics of the resin matrix and the filler affected stain resistance also. As resin matrix and the filler compositions were different for different composites, they might interact differently with certain stains (such as coffee), and this may be related to the chemical composition of the staining substance itself. When considering the fact that coffee was consumed warm (at temperature higher than 37°C in this study), the higher temperature might accelerate the discoloration process.[12]

One purpose of this study was to detect a surface roughness limit for the composites. An Ra value of 0.07 μm might be a polishing limit for A110, whereas no Ra limit was found for the other three composites in the Ra range tested. The first null hypothesis that surface roughness did not influence the stain resistance of the composite when it was < 0.1 μm (a surface roughness limit existed) was partly accepted as no surface roughness limit was detected for Supreme, Z250, and P60. The discoloration of these three composites increased as the Ra increased. The second hypothesis that different types of dental resin composites did not influence stain resistance was rejected because the type of composite did influence the discoloration.

When the composites tested are used clinically, more attention should be paid to polishing Supreme, Z250, and P60 restorations as increased Ra had a significant influence on discoloration. A110 might be a better choice for restoration of anterior teeth as it allows for more tolerance of Ra in terms of discoloration. Patients should also be advised and educated that consuming foods and drinks such as coffee increases discoloration of the restoration when compared with water. In addition, the discoloration is additive over time.

The specimen with Mylar surface (no polishing) was not tested owing to the fact that restorations usually need to go through the finishing and polishing procedures in clinical situations. A grinder-polisher was used to polish specimens instead of polishing manually to reduce surface variation caused by a nonuniform polishing force. The Ra values used are in a similar range to that produced by different finishing and polishing systems used clinically.[5] The sandpaper used in this study contained very fine abrasives to obtain those Ra values. Although Ra is the most commonly used parameter to describe surface roughness, more parameters are needed to fully define the profile of a surface.[13] The surface profiles formed by sandpaper and polishing cups and disks might still be different even if they have the same Ra value, and this could limit the direct application of the results to a clinical situation.

CONCLUSIONS

Significant linear relationships between Ra and gloss existed for the four resin composites in the range tested. Coffee had a significant influence on the discoloration of the dental resin composite materials tested. Different materials behaved differently in the coffee solution. Discoloration increased as Ra increased for the materials tested, except with Filtek A110. For A110, 0.07 μm might be a polishing limit below which no further increase in stain resistance is found. The color change of the specimens in coffee solution was accelerated with time.

DISCLOSURE

The authors do not have any financial interest in the companies whose materials are discussed in this article.

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COMMENTARY

EFFECT OF SURFACE ROUGHNESS ON STAIN RESISTANCE OF DENTAL RESIN COMPOSITES

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Surface roughness (Ra) of restorations can be related to plaque accumulation and periodontal health as well as stain resistance, which affects esthetics. The authors designed this study to investigate the relationship between Ra and stain resistance for four composite resins with different structural and chemical compositions.

The basis for this study and its design are certainly plausible for the properties investigated are clinically relevant and significant. The methodology is well thought out and executed as planned. However, clinical observations suggest that discoloration is more frequently associated with the cavosurface margin area than with the center "flat surface" of the restoration. Certainly, there may be other factors such as weak bonds in certain areas of the restoration, tissue characteristics, and polymerization shrinkage leading to or contributing to more frequent stain in the marginal area, but this study did not specify where the Ra evaluation was conducted. Were these readings obtained from different areas of the sample and then averaged? Did the readings include the areas of the cavosurface margin or the boundary of the sample? It must be added that if the Ra was measured in all samples in the same area, then the polishing methodology and the material properties and composition would be more significant variables than where the measurements were taken.

The authors also investigated gloss of the materials. It certainly can be appreciated that the Ra and gloss are directly related, although the degree may be different as influenced by filler particles and the amount. Gloss is a unique property that is directly related to the reflective index and refractive index values of the materials. In the case of the composite resins, those would be the properties of the filler particles as well as the resin matrix. The amount and size of the filler particles is important, but so are the intrinsic properties of the materials. Discussion of these critical properties and their potential influence would certainly have enhanced the article's comprehensive inclusion and clinical implications. Perhaps the parameters of this study are not all inclusive, and further investigation is necessary.

Color change as affected by coffee (and other darkly stained food items) and Ra certainly are clinically important. This interaction, as influenced by the composition of the materials, is well analyzed and described. These effects could have been elaborated further if the effect of different temperatures had been included in the studied, even if the temperature variation was investigated for three different temperatures. Additionally, the effect of pH, if any (as in the pH of coffee), could have been discussed in greater detail. This might have offered clinicians a better understanding and thus more valuable information for the patients.

Overall, this is a well-designed study with specific parameters and their clinical implications. *No single study can be all inclusive.* As a reviewer, one can certainly be critical and make many comments—"Monday morning quarter-backing." That, however, is not my intention; I have simply raised some additional questions that perhaps merit further investigation and clarification.

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