Surface roughness evaluation of polished composite using three-dimension profilometry

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Purpose: This study evaluated the surface roughness of two composite materials using a three-dimension (3D) profilometer following four clinically-acceptable finishing techniques.
Materials and Methods: Disk specimens (9x3 mm) made of two composite materials, Filtek Z250 and Pertac II Aplitip, (n=30) were prepared. Each material group was further subdivided into five additional groups (n=6). This provided a control group (unpolished) and four polishing technique groups described as follows: Arkansas stone, aluminum oxide disks (Sof-Lex), diamond point, or silicone points. A 3D profilometer was employed to measure the surface roughness parameters Sa, Ssk, Sku, Sz, Sdc, Spk, Sk, and Svk for each specimen. A diamond stylus tip with a 5 µm radius was used at a tracing speed of 0.3 mm/s. The measured area was 0.948 mm^2. The results were expressed in µm and analyzed by analysis of variance (ANOVA).
Results: Scratches and striations were microscopically observed in polished specimens and the filler resin was clearly evident in the control. The results of ANOVA revealed that the polishing techniques had a statistically significant effect on Sa, Ssk, Sdc, Sk, and Svk, but not on Sku and Spk. The type of composite had a significant effect on Ssk, Sku, Sz and Spk, but not on Sa, Sdc, Sk, and Svk ($P<0.01$). Considering only the specimens grouped according to the polishing techniques, optimum smoothness was realized with diamond points and aluminum oxide disks, and the most surface irregularities were measured with for control and specimens polished with the silicone point. The mean value of roughness parameters of Pertac was lower than those recorded for Z250.
Conclusion: The diamond point provided the lowest roughness parameters whereas the silicone points and control recorded the highest roughness parameters. **(Int Chin J Dent 2004; 4: 85-91.)**

Clinical Significance: Fine diamond point and aluminum oxide were shown most suitable for polishing disc-shaped specimens of Z250 and Pertac composite because lower 3D roughness parameters were recorded. The Arkansas stone and silicone points appear less suitable for polishing of the composite materials tested.
Key Words: composite, polish, roughness, surface.

Introduction

Proper finishing and polishing are important steps that enhance both esthetics and longevity of restored teeth.[1,2] Various techniques have been studied to produce a smooth composite surface.[3-9] Berastegui and Tjan stated microfilled composites provide smooth surfaces after polishing with an aluminum oxide polishing system, and produce less roughness after polishing with diamond, carbide, and Arkansas rotary instruments.[10,11]

Characterization of the surface texture of composites has become increasingly important because it is recognized as a key factor affecting function in clinical service. Measurement and analysis of the surface of composites provide an excellent diagnostic tool for comparing both various proprietary composites materials and the process that produces the polished surface. There is a desire to understand the three-dimensional (3D) surface structure of an observed material because of the 3D nature of the surface and its interactions in vivo. Currently refined measurement and analysis techniques have provided tools and approaches required to carry out sophisticated analysis of surface topography.[12-14] This study investigated the surface roughness, using 3D profilometry, of two composite restorations using four clinically-acceptable finishing techniques.

Materials and Methods

Two commercially-available composite restorative materials were used: a micro-fine hybrid composite (Filtek Z250, 3M Dental Products, St. Paul, MN, USA) and a radiopaque, quartz-based, fine-particle hybrid composite (Pertac II Aplitip, ESPE Dental AG, Seefeld, Germany). The Z250 composite consists of zirconia/silica (60 vol%, 0.01-3.5 µm, adduct of bisphenol A and glycidyl methacrylate (Bis-GMA), urethane dimethacrylate (UDMA), and adduct of bisphenol A and polyetheylene glycol monomethacrylate (Bis-EMA). The Pertac II composite contains quartz inorganic filler (54 vol%, 0.5-3.0 µm) and hydrophobic bifunctional methacrylates. A total of 60 specimens were prepared in a poly(tetrafluoroethylene) (PTFE) split-mold (9x3 mm, n=30 for each material). The composite material was dispensed into the mold. Each specimen was polymerized for 50 s with a visible light-polymerizing unit (Degulux, Degussa Hüls, Frankfurt, Germany).

Each set of specific material specimens was further divided into five groups, each receiving a different finishing regimen (n=6). Where specific finishing and polishing devices were used, a new device was used for each specimen. Group A was finished with bullet-shaped Arkansas FG stone points (Meissinger, Düsseldorf, Germany) using high-speed handpiece for 30 s. Group B was finished with aluminum oxide disks (Sof-Lex, 3M Dental Products), in four textures: coarse, medium, fine, and extra-fine with 150, 360, 600, and 1,200 grit sizes. These specimens were sequentially processed using water irrigation and a low-speed handpiece for 30 s, except for the extra-fine that was used for 10 s. Group C was finished with flame-shaped fine-grit diamond points (Edenta, AG, CH9434 AU/SG, Switzerland) using high-speed handpiece for 15 s. Group D was finished with cone-shaped fine grit silicone polisher points (Kenda, AG, Vaduz, Liechtenstein) using a low-speed handpiece for 30 s. The control group E remained unfinished. The specimens were rinsed with water and dried for 24 hours before surface roughness measurements. Selected photographs were taken using a light microscope.

To measure surface roughness, a portable face texture-measuring instrument was fabricated to develop an automatic 3D surface roughness scanning system. The system collects surface topography data from parallel profiles taken from areas up to 12.5x50 mm. The system consisted of a personal computer, an A/D converter, a conventional profilometer (Handysurf E-10A, Advanced Metrology Systems Ltd., Leicester, UK), and a precision table of a measure scope (Measurescope-10, Nikon Corp., Tokyo, Japan) derived by a stepper motor and its controller to provide the X-Y motion of the precision table with an accuracy of 1 µm (Fig. 1).

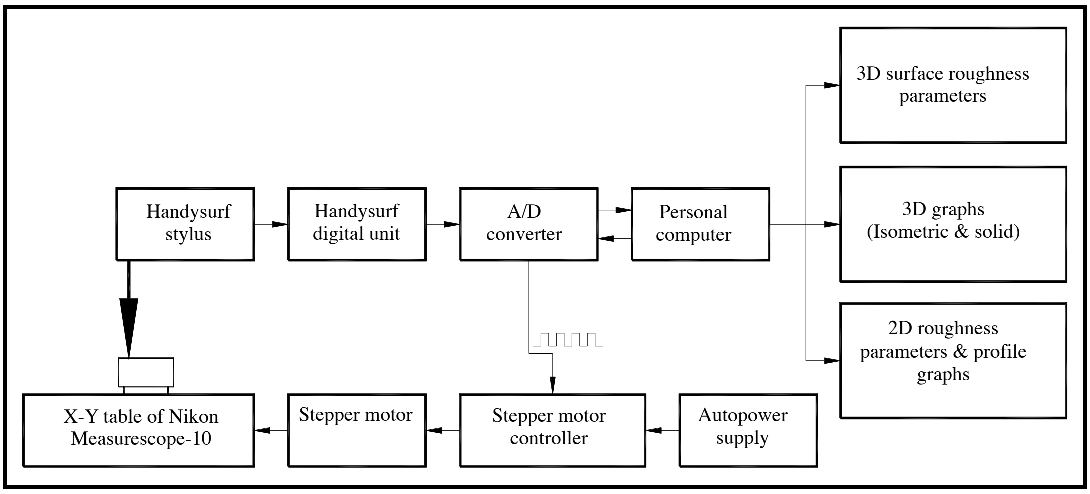

Fig. 1. Illustration of components of 3D profilometer.

A special software program was developed to control the precision table movements and the measurements of surface heights. In addition, another software program was produced for calculating 3D surface roughness parameters. The surface heights were sampled as digital data and saved to a file on the computer. The data was used for the computation of 2D and 3D roughness parameters, for contour mapping, and for isometric plots. The following 3D roughness parameters were measured for the 60 specimens: (1) Sa=arithmetic mean deviation of the surface in µm; (2) Ssk=skewness of the surface height distribution; (3) Sku=kurtosis of the surface height distribution; (4) Sz=ten-point height of the surface in µm; (5) Sdc=material volume between 10% and 50% in µm; (6) Spk=reduced summit height in µm; (7) Sk=core roughness depth in µm; and (8) Svk=reduced valley depth in µm (Table 1). The measured area was 0.948 mm^2. Tracing speed using a diamond tip with a 5 µm stylus was 0.3 mm/s. The pickup transducer employed was a displacement/inductance transducer. A statistical analysis of recordings was computed by analysis of variance (ANOVA) test (P<0.01).

Table 1. Surface roughness parameters and indications.

Parameters	Observations
Sa	Smaller values indicate smoother surfaces.
Ssk	Smaller values (negative values) indicate good food retention and good bearing area.
Sku	Higher values indicate better and smoother surfaces.
Sz	Higher values indicate good food retention and staining.
Sdc	Smaller values indicate good food retention and staining.
Spk	Higher values indicate initial higher stresses.
Sk	Higher values indicate stable load distribution after a period of mastication.
Svk	Smaller values indicate good food retention.

Results

Fig. 2 shows optical micrographs of composites. The unpolished control groups revealed high concentrations of organic matrix in the composite surface. The polished surfaces showed the prints of abrasive material in the composites. Fillers were not evident in the surface of the polished Z250 composite, but a few were evident in the Pertac composite. Fig. 3 show 3D topography of the composite surfaces. Polished and control groups presented the differences of roughness profile related to finishing instrument types.

Tables 2 represents the results of the arithmetic mean and standard deviation (SD) of roughness parameters of Sa, Ssk, Sku, Sz, Sdc10%-50%, Spk, Sk, and Svk of Z250 and Pertac composites. The minimal value of Sa was recorded for diamond and silicone while the maximal value (poorest) was recorded for the control. The maximal values of Ssk were recorded for Sof-Lex and diamond in Z250 and for diamond and silicone in Pertac, and the minimum value was observed with the control group. The maximum values of Sku were observed with Sof-Lex and diamond for Z250 and with silicone and diamond for Pertac. The extreme minimal values of Sz, Sdc, Sk, and Svk were seen for the diamond abrasion finishing, whereas the extreme maximal values were recorded for the control. Low level of Spk was seen with the silicon and diamond abrasive finished surfaces, while high level of Spk was recorded for both the control and Sof-Lex finished surfaces.

The polishing methods revealed a statistically significant effect on Sa, Ssk, Sdc, Sk, and Svk, but lack of statistically significant differences for Sku and Spk (P<0.01). The comparison of the two composite resins also revealed a statistically significant effect for Ssk, Sku, Sz, and Spk, but no statistically significant difference for

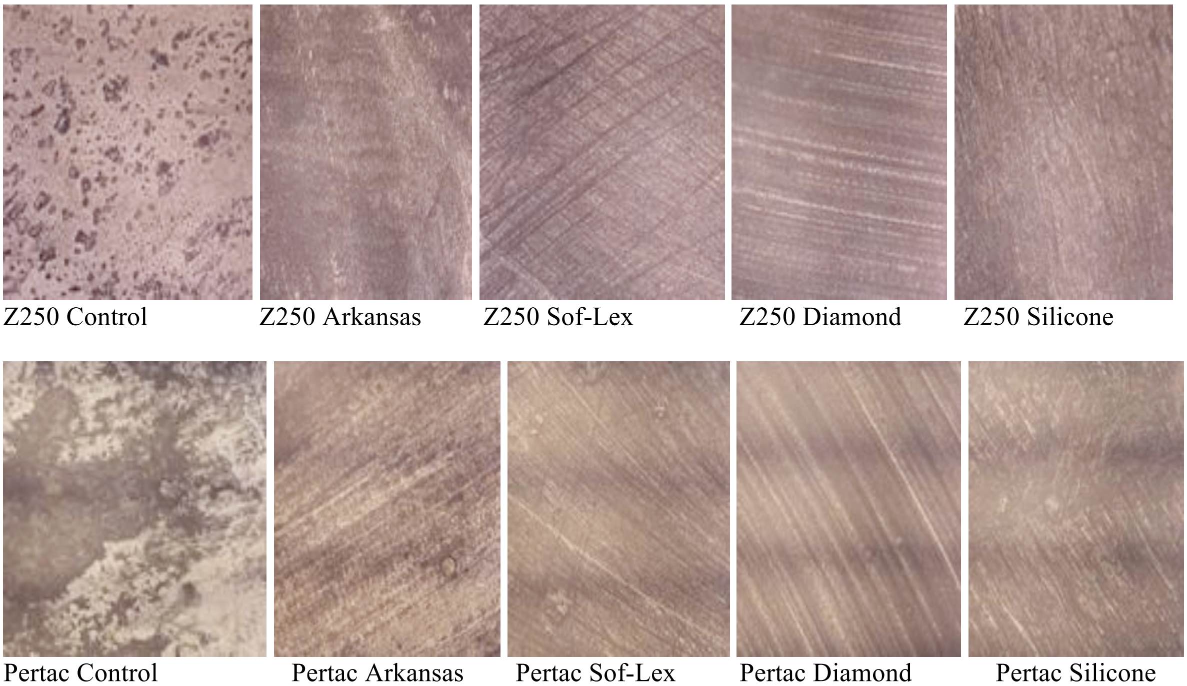

Fig. 2. Optical micrographs of composites.

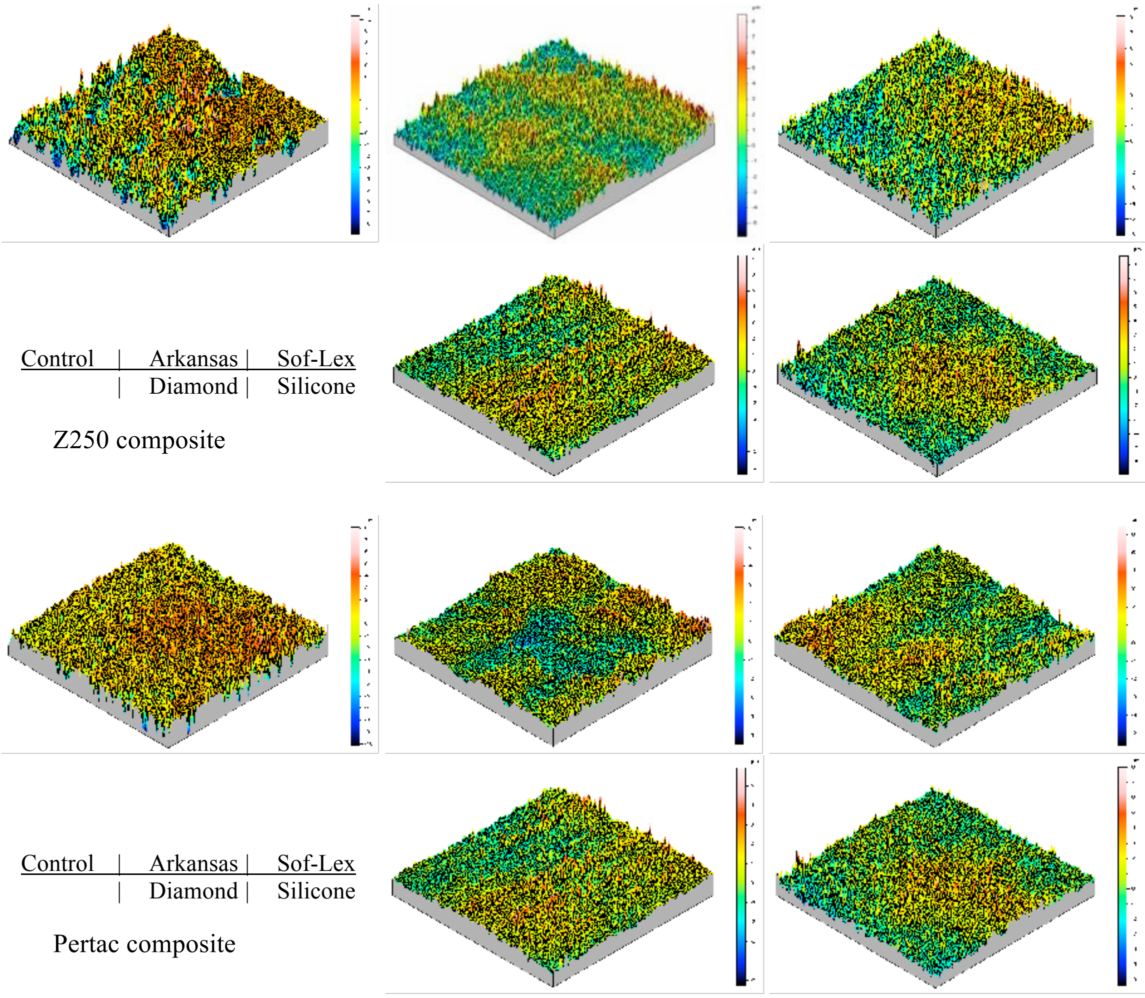

Fig. 3. Selected 3D topographies of the composite materials.

Table 2. Roughness parameters for the Z250 and Pertac composites.

	Control		Arkansas		Sof-Lex		Diamond		Silicone	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Z250 composite										
Sa	1.70	0.56	1.23	0.12	1.17	0.14	1.11	0.09	1.10	0.18
Ssk	0.49	1.07	0.93	0.38	1.09	0.68	1.04	0.11	0.81	0.15
Sku	4.90	4.27	4.74	1.35	5.50	2.46	5.17	0.45	4.51	0.63
Sz	14.91	1.62	12.71	0.39	12.58	1.17	12.03	0.53	12.03	1.26
Sdc	2.76	0.96	2.35	0.18	2.21	0.25	2.08	0.26	2.01	0.33
Spk	2.67	0.86	2.62	0.19	2.78	0.59	2.57	0.20	2.30	0.23
Sk	4.87	1.90	3.53	0.56	3.24	0.72	3.17	0.25	3.30	0.61
Svk	1.90	1.39	0.90	0.24	0.88	0.26	0.78	0.08	0.85	0.15
Pertac composite										
Sa	1.42	0.60	1.43	0.25	1.18	0.24	1.10	0.06	1.14	0.12
Ssk	0.15	0.49	0.23	0.13	0.38	0.25	0.58	0.12	0.53	0.21
Sku	3.39	0.69	3.24	0.60	3.66	0.57	4.01	0.37	4.14	0.77
Sz	11.93	2.76	12.34	1.08	11.40	1.00	10.99	0.55	12.10	0.68
Sdc	2.39	1.17	2.45	0.55	2.03	0.48	1.89	0.18	1.95	0.27
Spk	2.04	0.94	2.17	0.22	2.07	0.34	2.18	0.18	2.17	0.15
Sk	4.20	1.80	4.47	0.97	3.59	0.78	3.33	0.18	3.49	0.44
Svk	1.57	0.90	1.44	0.27	1.21	0.24	1.03	0.05	1.11	0.12

Sa, Sdc, Sk, and Svk ($P<0.01$). Considering only the groups according to the polishing techniques, the least surface roughness was found with diamond points and Sof-Lex discs, and the greatest surface roughness was recorded with the control and silicone points.

Discussion

Composite restorations cannot be finished to an absolutely smooth surface because the cutting particles (abrasive) of the finishing material must be relatively harder than the fillers.[8,9] This study revealed that Pertac composite finished with a less rough surface than Z250 composite. This might be attributed to the inorganic macrofiller size and/or hardness in Pertac that resisted and protected the abrasion of the material. When the composite was subjected to abrasion, the matrix between and around the filler particles may be lost, leading to a protruding and eventual plucking of these particles, resulting craters, scratches, and striations from the abrasive grits.

Historically, Sa (Ra in two dimensions) is one of the first parameters used to quantify surface texture. Most surface texture specifications include Sa, either as a primary measurement, or as a reference. Unfortunately, Sa may be misleading in that many surfaces with grossly different features may have the same Sa, but may function quite differently. Sa only quantifies the “absolute” magnitude of the surface heights and is insensitive to the spatial distribution of the surface heights. Sa is also insensitive to the “polarity” of the surface texture in that a deep valley or a high peak will result in the same Sa value. Despite its shortcomings, once a process for forming a surface has been established, Sa may be used as a good monitor as to whether something may have changed during subsequent production of the surface. The best (minimum) values of Sa were observed for diamond and silicone, and the maximum (the poorest) values were recorded in case of control.

Ssk is a measure of the "skewness" or symmetry of the surface. Since the height values are "cubed" prior to the integration/averaging, the polarity of the surface is maintained. Thus a surface with predominantly deep valleys will tend to have a negative skew, whereas a surface comprised of disproportionate number of peaks will have a positive skew. Ssk may be used to quantify the symmetry of the surface as it may relate to various considerations such as particulate retention. The best (maximum) values of Ssk were recorded for Sof-Lex with Z250 and diamond points with Pertac, but the poorest (minimal) values were observed with the control.

Sku is the degree of concentration around the mean value of an amplitude distribution curve. Sku characterizes the anomalies in the surface height distributions in that a normally (i.e. following a Gaussian or bell curve distribution) distributed surface texture would tend to have a Sku of 3. When the surface texture is composed of non-normally distributed high peaks or deep valleys, the Sku becomes very large. When the surface is composed of a gradually varyingor “rolling-hill” type texture, the Sku will be less than 3. Sku is a good indicator of when an otherwise normally distributed surface may have some defects. Sku might be used to identify the presence of surface defects and inordinate peaks or valleys. Sku is evaluated by taking the “fourth power” of the surface heights. The best results of Sku were observed with Sof-Lex and diamond surface finishes for Z250 and with silicone and diamond surface finishes for Pertac.

Sz may be used to characterize the extreme features of a surface, with Sz being a nominal measure of the “Peak-Valley” range of the surface. Typical applications for Sz may include surface nicking and staining. The best (minimum) values of Sz occurred with diamond finishing and the poorest (minimal) values were recorded for the control of Z250 and the Arkansas finished surface of Pertac.

Material volume between 10% and 50% of heights, Sdc, is typically used to study surfaces that may characterize either particulate retention or staining criteria. The optimal values of Sdc were observed for diamond and silicone finished surfaces, whereas the poorest values were recorded in the control.

A high Spk implies a surface composed of high peaks providing small initial contact area and thus high areas of stress (force/area) when the surface is contacted. Thus Spk may represent the nominal height of the material that might be postulated to be removed during abrasive masticatory function.

Sk represents the core roughness of the surface over which a load may be distributed, after a period of abrasive function. Svk is a measure of the valley depths below the core roughness and may be related to particulate retention. The optimal values of Sk and Svk occurred with diamond finished surfaces and the poorest values with the control. These parameters were investigations of surface profile, especially the average of the peaks and valleys, which are considered contributory for plaque retention and load distributions. Despite the same finishing instrument, the mean values of these parameters for Pertac were less than that for Z250, confirming that the composite structure itself was playing a major role in the polishing results. The result of ANOVA ascertained that the polishing methods had a statistically significant effect on Sa, Ssk, Sdc, Sk, and Svk without noted effect on Sku and Spk. Therefore it could be postulated that there is potential for particulate retention, bearing area, staining, and load distribution without a significant effect on smoothness of a surface and initial stresses. The two composites themselves had a statistically significant effect on Ssk, Sku, Sz, and Spk without a statistically significant effect on Sa, Sdc, Sk, and Svk. Therefore, there is potential for particulate retention, nicking, and staining criteria, but not a significant effect on smoothness of a surface and load distribution. Therefore, decreasing the size by rearranging the abrasive grits might well decrease surface roughness.

Considering only the specimens grouped according to the polishing techniques, the most desirable results were found with the diamond points and aluminum oxide abrasives, whereas the control and silicone polished groups recorded the least desirable roughness parameters. This observation coincided with studies showing that the ESPE MFS/MPS polishing kit, which includes diamond points, provided a more clinically-acceptable polished composite surface than the Enhance polishing kit, which includes aluminum oxide disks.[6,7] The Sof-Lex was better for polishing a microfiller while diamond points and Arkansas stone provides better results for hybrid composites.[15] Also, Sof-Lex provided better surface smoothness than silicone polishers.[11] Diamond polishing and the Enhance kit produced rough surfaces for composites.[7-9] The worst roughness was seen with the control because of the air-inhibited layer on the surface, surface porosity, and high filler concentration.

Conclusions

Surface roughness of two composites polished with four abrasive systems was evaluated by 3D profilometry. Within the limitation of this investigation, the following conclusions can be drawn.

1. The 3D profilometry permitted multiple descriptions of the surface roughness profile of the composite resins sampled above and beyond that possible with 2D profilometry.
2. Fine-grain diamond points and Sof-Lex disks provided the smoothest surfaces.
3. The silicone polishing point and control surfaces showed the roughest finishes.
4. The design and type of abrasive affected the criteria of roughness parameters.
5. The structure of the composite in conjunction with filler size were shown to be potentially important factors in composite surface roughness.

Acknowledgment
This work was supported in part by a Grant-in-Aid for Young Scientists (B) 16791210 (2004) from the MEXT-Japan.

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Received September 27, 2004. Revised October 12, 2004. Accepted October 18, 2004.