Original Research

Novel Water-blasting Machine for Removal of Refractory Investment and Metal Oxides

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Clinical significance

A custom-built device was produced that can remove investment material from cast metal or polymerized denture base resin, or can remove the oxide film on a metal surface. This machine uses a high-speed jet of either water or abrasives and has the advantages of low production and maintenance costs.

ABSTRACT

Purpose : A new device was made that can produce a high-speed jet of either water (water jet) or abrasives mixed with water (abrasive jet). This paper reports on the ability of this device to remove investment and metal oxides from cast alloy surfaces.

Materials and Methods : Two gypsum blocks, three investment blocks before and after heating, and three cast metal plates were tested with the newly produced device. The pressure of the jet was 4 or 8 MPa, and two types of abrasives (# 400 and # 1500 SiC and glass beads) were used. After treatment, the surface quality was observed with a charge coupled device camera. The concave depths of the investments were measured with a laser displacement meter and the alloy surfaces evaluated with a surface texture measuring apparatus. The concave depths of the investments and the surface roughness (Ra) were statistically analyzed with two-way ANOVA and Tukey's test using data from ten points.

Results : After heating, the investment was removed by a 4 MPa water jet ; the concave depth of the investments was from 0.7 to 8.2 mm. The gypsum was removed by the abrasive jet. The oxide films were removed by the 4 MPa abrasive jet using the abrasive agents.

Conclusion : This study examined the potential use of a new laboratory tool. It demonstrated that a water jet could remove investment after heating. Gypsum, adhered investment, and metal oxide were removed with an abrasive jet. This new device can be used effectively as a laboratory tool for removal of unwanted surface materials.

Key words

water jet, refractory investment, metal oxide

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INTRODUCTION

In the laboratory, it is often necessary to remove investment after casting a metal or polymerizing a denture base resin, or to remove the oxide film on a metal surface. Sandblasters or steam cleaners are currently used, or removal is done by hand using rotary grinding tools. When using a sandblaster, frequent stops are necessary to check positioning or to confirm the degree of polish, since dust obscures the operator's vision. However, harmful exposure to dust has also been associated with the long-term use of sandblasters. Research into barrel finishing¹⁾ and centrifugal shooting-type polishing systems^{2,3)} has been carried out in order to find a less harmful alternative to sandblasting. Barrel finishing provides uniform polishing and leaves a smooth surface. However, this method has some disadvantages; it cannot be used for partial polishing. It is necessary to remove phosphate-bonded investment with a sandblaster beforehand, and polishing takes a long time⁴⁾. Although the centrifugal shooting-type polishing system using abrasives in an elastic core is suitable for partial polishing, it is still necessary in some cases to first remove phosphate-bonded investment with a sandblaster, and deformation of the metal may be caused by heating for a long time⁵⁾.

We have produced a new device that uses a water jet to replace such equipment. Because the workpieces being polished are always in contact with the water, there is no risk of heating, and very little dust from the abrasives is produced. This device can produce a high-speed jet of either water (water jet) or abrasives mixed with water (abrasive jet). Polishing can thus be carried out on a wide range of materials, from soft to hard. The advantages of the device include low production and maintenance costs,

and efficient surface treatment by adjusting the water pressure. This paper evaluates the ability of this device to remove investment and metal oxides from cast alloy surfaces.

MATERIALS AND METHODS

The experimental device consists of a pump (HD 525 S, Kärcher Japan, Miyagi, Japan), tank, and the main controls (Fig. 1). A valve (Valve 1) switches between the water and abrasive jets. The pressure of the jet can be regulated from 4 to 8 MPa by another valve (Valve 2). It is possible to use the water jet either manually or in a fixed position; this function is controlled by a single screw. In contrast, the abrasive jet is used only in the fixed position (Fig. 2). In this study, the application nozzle diameter was 0.8 mm.

As shown in Table 1, gypsum blocks (a dental plaster and a dental stone), investment blocks (three phosphate-bonded investments and a dental plaster used for flasking), and cast metal plates (Au-Ag-Pd alloy, Co-Cr alloy, and Ni-Cr alloy) were used for testing. The mixing conditions for the investments and gypsums are shown in Table 2. The gypsums and investments were poured into plastic boxes (20×20×20 mm) with the vibrator to form blocks that were then kept in air at room temperature. The gypsum blocks and half of the investment blocks stored at room temperature for 24 hours were tested using the water jet (before heating). The remainder of the investment blocks was heated under the conditions shown in Table 2 and also tested using the water jet (after heating).

As for the alloys, a wax pattern (10×20×0.5 mm) was made with sheet wax (#22, Casting Wax Sheets, Kerr, Orange, CA, USA). After the gypsum-bonded casting investment (Cristobalite Micro, GC, Tokyo, Japan) was heated at 600° C, Au-Ag-Pd alloy (CA) was cast using a conventional centrifugal casting machine

Fig. 1 Diagram of the custom-built surface cleaning device

Fig. 2 Schematic representation of the nozzle ; a) Manually operated water jet, b) Fixed water jet, c) Fixed abrasive jet

(CM-30, Morita, Tokyo, Japan). After the phosphate-bonded investment (S) was heated at 700° C, Co-Cr alloy (CO) and Ni-Cr alloy (NI) were cast using a high-frequency automatic centrifugal casting machine (Acetoron Automatic AA-2000, Sankin, Tokyo, Japan). The casting temperatures were 1,395° C for CO and 1,290° C for NI. After casting, the metal surfaces were washed to remove adherent investment.

For removal of investment using the device being tested, the distance between the test specimen and the application nozzle was fixed at 20 mm, and the high-speed water jet lasted for 3 seconds. Gypsum test specimens that could not be cleaned with the water jet were cleaned using the abrasive jet at 4 MPa and 8 MPa. Alloy specimens were treated using the abrasive jet at 4 MPa. The abrasive materials included silicon

Table 1 Materials used in this investigation

Code	Materials	Manufacturer	Type of material
T	Taivest	GC, Tokyo, Japan	Casting investment
S	Snow White	Shofu, Kyoto, Japan	Casting investment
C	Ceravest	GC, Tokyo, Japan	Casting investment
A	Advastone	GC, Tokyo, Japan	Plaster for flasking
P	Plastone	GC, Tokyo, Japan	Dental stone
D	Dental Plaster	Noritake, Aichi, Japan	Dental plaster
CA	Castwell MC	GC, Tokyo, Japan	Au-Ag-Pd alloy
CO	Cobaltan	Sankin, Tokyo, Japan	Co-Cr alloy
NI	Neo Nicromebond	Shofu, Kyoto, Japan	Ni-Cr alloy

Table 2 Conditions for preparation of test specimens

Code	P/L ratio	Mixing condition	Heating condition
T	0.15	60 sec/vacuum	RT → 800°C, 800°C/120 min
S	0.18	30 sec/vacuum	RT → 800°C, 800°C/90 min
C	0.24	60 sec/vacuum	RT → 800°C, 800°C/30 min
A	0.38	60 sec/vacuum	RT → 100°C, 100°C/60 min
P	0.28	60 sec/vacuum	—
D	0.42	30 sec/vacuum	—

RT : Room temperature

carbide powder (SiC) (# 400 and # 1500, Maruto, Tokyo, Japan) and glass beads for a pencil blaster (particle size $<100 \mu\text{m}$, Daiei, Osaka, Japan) suspended in water (50 g/1,500 ml).

After treatment, the surface quality was observed with a charge coupled device camera (P-4500, Nikon, Tokyo, Japan). The concave depth of the investments was measured with a laser displacement meter (L-4000, Keyence, Osaka, Japan). Measurement was done with the stage set at a speed of 0.5 mm/sec, and the data were processed by analytical software (LE Shape Analysis, Version 1.02, Keyence). The alloy surfaces were characterized with a surface texture measuring apparatus (Surfcom 130 A, Tokyo Seimitsu, Ibaraki, Japan). The measuring conditions were as follows : measuring distance of 5 mm, movement rate of 0.6 mm/s, and cutoff wavelength of 0.8 mm.

The concave depth of the investments and the surface roughness (R_a : arithmetic mean value) were statistically analyzed with a two-

Table 3 Concave depth (mm) of investments after heating treated by the water jet

Code	4 MPa	8 MPa
T	4.2 (0.3)	8.0 (0.9)
S	3.5 (0.3)	5.0 (0.6)
C	0.7 (0.1)	1.8 (0.1)

() : Standard deviation

way ANOVA and Tukey's test (5% significance level) using ten data points ($n=10$).

RESULTS

After heating, the investments (T, S, and C) were easily removed by the water jet at 4 MPa (Fig. 3). The concave depths of T, S, and C are shown in Table 3. A two-way ANOVA showed interaction between the water pressure and the kind of investment ($p<0.05$). The concave depths of T, S and C treated by 8 MPa water jet were significantly greater compared with the 4

MPa water jet ($p < 0.05$). This finding indicates that the concave depth can be adjusted by controlling the water pressure. Statistically significant differences were found among the concave depth of T, S, and C ($p < 0.05$).

Although the plaster used for flasking (A)

Fig. 3 Three phosphate-bonded investments and a dental plaster for flasking treated with the water jet

was removed by the 8 MPa water jet, the removal was not efficient (Fig. 3). The water jet failed to remove dental stone (P) or the dental plaster (D); however, both of them could be removed by the abrasive jet at 4 MPa and 8 MPa (Fig. 4).

The oxide films on the cast alloy surfaces were removed by the 4 MPa abrasive jet using all three abrasives (Fig. 5). The polishing marks left by the # 1500 SiC were faint, but were more defined for # 400 SiC. The polishing marks from the glass beads were narrow and bright. The surface roughness (R_a) of CA, CO and NI is

Fig. 4 Dental plaster and dental stone treated with the water jet

Fig. 5 Au-Ag-Pd alloy, Ni-Cr alloy and Co-Cr alloy plates treated with the abrasive jet and three types of abrasives

Table 4 Surface roughness ($R_a : \mu\text{m}$) of three alloys before and after treatment by the abrasive jet

Code	As cast	# 1500	# 400	Glass beads
CA	0.65 (0.11)	0.43 (0.05)	0.45 (0.05)	0.28 (0.03)
CO	4.23 (0.73)	1.36 (0.09)	1.80 (0.20)	1.06 (0.15)
NI	1.56 (0.22)	1.22 (0.09)	1.29 (0.07)	0.71 (0.06)

() : Standard deviation

shown in Table 4. There was an interaction between the abrasive and the kind of alloy by two-way ANOVA ($p < 0.05$). The R_a for the glass beads was significantly smoother than for # 400 SiC ($p < 0.05$). In CO and NI, the R_a for # 1500 SiC was significantly different from the R_a for the glass beads ($p < 0.05$). Fig. 5 and Table 4 show that the glass beads efficiently removed the adhered investment and oxide film, and left a smooth polished surface.

DISCUSSION

Previous studies^{6,7)} examined only the removal of investment and oxide films by using a high-speed water jet. Although the polishing efficiency of a water jet is inferior to that of an abrasive jet, the operating costs of the water jet are low; it uses only water and electricity. Devices using high-pressure water are usually quite large, and consequently, the production costs of the equipment are high. Our device includes a commercial high-pressure washer for the pump, which considerably reduces production costs, and the resulting device is compact. This device can be produced inexpensively, as it simply requires a nozzle and a locking device for the application mechanism. The water jet is used first to remove investment and metal oxides; anything that cannot be removed with the water jet can then be removed with the abrasive jet. The abrasives used can be either a suspension or a powder. Moreover, the abrasives can be recycled to reduce operating costs.

It is generally said that it is difficult to remove a cast piece from a phosphate-bonded investment after casting. The results in Fig. 3 indicate that it was easier to remove the investment after heating than before heating, and that this device can be used for this purpose. The cohesive strength of a phosphate-bonded investment and a gypsum-bonded investment decreases after cooling. Therefore, the concave depth of the investment after heating was deep, which shows that this device can perform selective removal by utilizing the strength difference.

This study examined the ability of the device to remove phosphate-bonded investment, which is relatively difficult to eliminate. After heating, the investment was removed efficiently using only the water jet. Furthermore, the T and S investments could be eliminated using the water jet at 8 MPa without heating.

In this new device, the concave width could be adjusted by changing the diameter of the application nozzle. Furthermore, the concave depth could be adjusted by changing the water pressure with a simple adjustment of a valve (Valve 2 in Fig. 1). The width and depth could be adjusted simultaneously by changing the distance between the application nozzle tip and the object.

Generally, it is difficult to clean away the gypsum that adheres to dental instruments and tools without damaging the matrix. Although the water jet could not remove solid dental plaster or dental stone, they were easily removed using the abrasive jet, demonstrating that our

device can be used to clean gypsum from dental instruments and tools. To get rid of the investment, #1500 SiC powder was best in the present study because in most cases, it did not affect the metal matrix. To remove metal oxides, #400 or coarser SiC powder should be used, while glass beads should be used if a smooth metal surface is desired.

In general, the steps taking place in a dental laboratory consist of casting, removing the investment, removing the metal oxide with a sandblaster, grinding, and polishing. Mechanical grinding with dental burs or disks heats the metal and produces a burr or Beilby layer. Further testing of surface cleaning methods using abrasives and water pressure is necessary, so that the disadvantages of mechanical polishing can be overcome by using the abrasive jet instead.

Yamanaka et al.⁸⁾ produced a wet-blasting polishing device that employed an abrasive jet, and reported that this device could be applied for dental purposes. However, their device used only an abrasive jet, whereas our device uses either a water jet or an abrasive jet.

The custom-built device in this study has some advantages : 1) the production and maintenance costs are low, 2) there is no risk of heating because the workpieces are always in contact with water, 3) dust is not created and dispersed in the air, and 4) the water jet and the abrasive jet can polish soft or hard workpieces without a sandblaster. Shimizu⁹⁾ indicated four desirable properties of a polishing apparatus : 1) operation is simple to carry out ; 2) the environment is not contaminated ; 3) the polishing time is short ; and 4) skill is not required. This new device satisfies these four conditions ; if partial

polishing is a disadvantage, this machine has at least this one disadvantage.

This study examined the potential use of a new laboratory tool. We demonstrated that the device could remove investment (after heating) with a water jet, and could remove gypsum, investment, and metal oxide with an abrasive jet. This new device can be used effectively as a laboratory tool.

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