

A Comparison and Evaluation of Electric Motor Dental Handpieces
and
Air Turbine Dental Handpieces

By

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Performed under protocol 451: Development of Lightweight, Low Cube, Portable
Dental Field Equipment.

Purpose: Determine if, for operative dental procedures, electric motor dental
handpieces are a suitable replacement for air turbine handpieces in military field
dental equipment sets.

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I. INTRODUCTION

One mission of the United States Army Dental Research Detachment is to develop a new generation of lightweight, low cube, dental field equipment.

Portable dental field operating and treatment units are used by the U.S. Army Forward Dental Treatment Teams (FDTTs) to provide dental treatment to U.S. Military Personnel and other authorized individuals in field Dental Treatment Facilities (DTFs). These FDTTs provide unit, hospital, and area dental support.

Unit dental support is located in the medical companies of U.S. Army divisions, separate brigades, armored cavalry regiments, and the medical elements of the Special Forces groups. An oral surgeon and comprehensive general dentist provide hospital dental support in the Combat Support Hospitals. Their primary mission is the treatment of oral and maxillofacial injuries. When workload permits they provide dental care to the hospital staff and patients.¹

Area dental support in Medical Force (MF) 2000 is provided by the medical company (dental service). This company has six FDTTs organized into one forward dental treatment section (FDTS). Each FDTT is an independent DTF with organic transportation and power consisting of one M998 (HUMVEE) and one diesel five-kilowatt generator mounted on a trailer. There are also two “heavy treatment sections” in the medical company (dental service). These two heavy sections support nine additional dentists, four hygienists and their equipment sets. The Medical Re-engineering Initiative (MRI) area dental support unit has eighteen FDTTs organized into three forward dental treatment section (FDTS). The MRI FDTT has the same equipment has

the MF2000 team. The MRI company also has one “heavy section” that supports five dentists, four hygienists and their equipment sets.

Current portable dental field operating and treatment units utilize air turbine handpieces. The compressed air needs of this sixty-seven pound treatment unit are provided by a 120-pound “portable” air compressor. This air compressor is 5.1 cubic feet and utilizes approximately 19 amperes of power. The air compressor is the major consumer of generated power in the FDTT. The unit support FDTT is the major consumer of power generated by ten-kilowatt medical company generator. The area dental support FDTT requires a five-kilowatt diesel generator mounted in a towed trailer. The “heavy team” requires two fifteen kilowatt towed generators.

In an effort to reduce the size and weight of the field DTF the USADRD developed a prototype Dental Field Operating and Treatment System (DeFTOS) that incorporated an electric motor dental handpiece. The principle advantage of the electric motor handpiece over the conventional air turbine is that compressed air and power requirements are significantly reduced. Not only is the prototype equipment smaller and lighter than current equipment, but also by significantly reducing the generated power requirements, the need for a large electrical generator is eliminated. By eliminating the five-kilowatt diesel generator and trailer, utilization of the DeFTOS could reduce the weight of each FDTT by 2700 pounds. This results in a total savings of 16,200 pounds for the MF2000 unit and 48,600 pounds for the MRI unit. Using the USADRD prototype, an FDTT can operate from a military two-kilowatt generator (the approximate size and weight of the current dental compressor), rechargeable battery packs, or the 24-volt current available through the outlet of any NATO vehicle.

Electric handpieces are rarely used in the United States for operative dental procedures and there is little published information comparing the performance characteristics of electric motor handpieces to the conventional air turbine handpieces.² Before proceeding with the fabrication of a lightweight, low cube, portable treatment and operating system, the USADRD wanted to verify that the performance of the electric motor handpiece was equal to or greater than the performance of the air turbine handpiece.

II. ELECTRIC MOTOR DENTAL HANDPIECES

There are several companies that manufacture electric dental handpiece motors. All of these motors have similar characteristics. The motor speed is adjustable from a minimum of 1000 rpms to a maximum of 40,000 rpms. Many electric motor systems have a digital display on the control panel that will indicate the motor speed. The operator can precisely control the speed by one of two methods. Some systems have a speed control adjustment switch located on the control panel; others have a foot pedal with a lever that moves horizontally to set the speed. Depressing the footswitch activates the handpiece.

Several electric motor handpieces in the commercial market have built in fiberoptics and internal air-water coolant lines. These electric motors accept a standard ISO “E” type attachment. This standard permits the motors and attachments of several manufacturers to be used interchangeably.

The surface of the motors can be disinfected. Most of the motors cannot be autoclaved, however several brands of electric motors have a removable outer sleeve that can be sterilized. The electric motors require virtually no maintenance except to change the carbon brushes approximately every two years. Brushless dental motors are now available. The brushless motor handpieces can be fabricated from autoclavable materials, but require a more complex controller and are slightly more expensive. One manufacturer sells the brushless motors with a five-year guarantee.

There three O-rings where the electric motor inserts into the handpiece attachment. These O-rings keep air and water from leaking between the motor and attachment. The O-rings last approximately nine months. They should be replaced, as needed, when they are worn. A worn O-ring will cause a water and/or air leak from between the motor and attachment. Dental personnel can change both the O-rings and brushes easily.

There are many attachments that can be utilized with the electric motor handpiece. These attachments can be autoclaved. Speed increasing contra-angle attachments with 1:4 and 1:5 ratios are available. These attachments can increase the bur speed to a maximum of 200,000 rpms. These contra-angles have a push button chuck mechanism and accept conventional friction grip burs. Various speed decreasing contra-angle attachments with ratios of 2.5:1 to 74:1 are available. They can produce bur speeds ranging from 14 to 16,000 rpms. These attachments are available with a push button chuck that will accept friction grip burs, a push button chuck that will accept latch type burs, micro size heads, and prophylactic universal heads. Straight nose cone attachments that accept larger diameter surgical and laboratory burs area are also available.

III. PURPOSE

The purpose of this study was to compare the performance of electric motor and air turbine handpieces. A testing protocol was developed based on the comprehensive performance evaluation of air turbine dental handpieces conducted by the U.S. Air Force Dental Investigative Service (USAF DIS).³

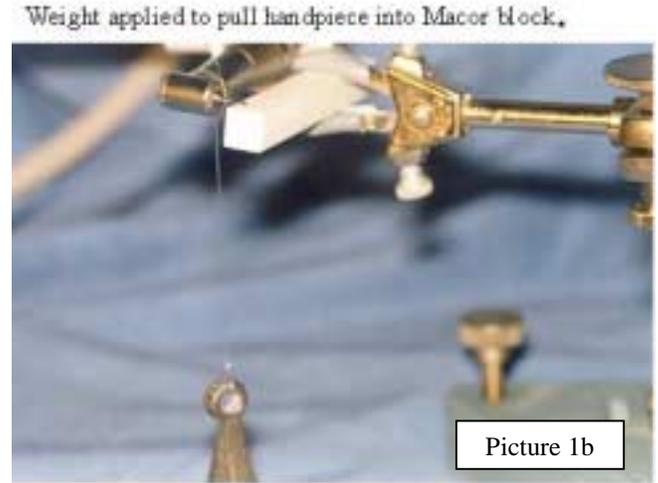
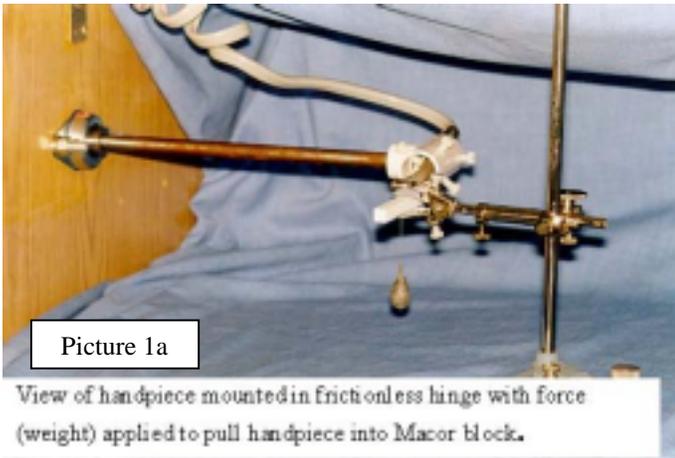
Two types of electric motor handpieces and speed increasing attachments were used in the USADRD study. The KaVo INTRAmatic LUX with the INTRA LUX 2 1:5 speed increasing contra-angle (KaVo of America, Lake Zurich, IL) and the Bien-Air MC3LK Micromotor and the CA1442 1:4 speed increasing contra-angle (Bien-Air USA Inc. Irvine CA) were selected for the study. Although the attachments are interchangeable, for this study a motor and attachment were paired and used together for the duration of the study. The Midwest Quiet–Air L (Midwest Dental Products, Des Plaines, IL) which was rated as “acceptable” in a USAF DIS test evaluation and was used as the control in this study.⁴

The USADRD examined twelve clinical parameters related to the clinical performance of electric motor and air turbine handpieces. Longevity, power (expressed as cutting efficiency), effect on pulpal thermal states, air exhaust, aerosol production, noise production, speed (in revolutions per minute), fiberoptic transmission, dependability of chuck mechanisms, static parameters (size and weight), price, and clinician acceptance were tested at baseline, 250, 500, 750, and 1000 simulated clinical uses. Each handpiece had a sample size of six. Unless otherwise specified for the electric dental motor, the term handpiece will refer to the motor and speed increasing attachment.

IV. LITERATURE REVIEW

The USAF DIS handpiece performance study controlled many variables that had not been controlled in previous handpiece performance studies.^{5,6} After measuring handpiece baseline values, the USAF DIS fabricated a custom made handpiece wear tester. The tester applied four ounces of side load force for four minutes of simulated clinical use. After four simulated clinical uses the handpieces were sterilized four times. This cycle was repeated and the handpieces were tested after baseline, 250, 500, 750 and 1000 simulated use cycles. Using this technique the USAF DIS was able to simulate two years of clinical use in a controlled environment. The USAF DIS evaluation was a comprehensive study on the effects of clinical use and sterilization on the longevity, speed, power, eccentricity, noise level and fiberoptic light intensity of nine commercially available air turbine handpieces.⁷

In the USADR study, simulated clinical use was accomplished by placing the handpieces in a custom cutting assembly. The handpieces were secured in identical “frictionless” bearings that were mounted to a vertical wall (See Pictures 1a and 1b below). Although “frictionless” may be an inaccurate claim, the amount of friction was assumed to be constant for each bearing. The air turbine handpiece operated at a regulated pressure of 30 pounds per square inch and a coolant water spray of 20 milliliters/minute. The electric motor handpieces were operated at 100% power and a coolant water spray of 20 ml/min. A new 1158 bur (Midwest Dental Products, Des Plaines, IL) was used to cut the Macor for two simulated clinical uses and then it was discarded. The 1158 is a round end plain fissure taper bur, 1.2 mm in diameter with a cutting length of 4.0 mm.



A cutting force was achieved by attaching a 115-gram weight to the head of the handpieces. Macor (Corning Glass Works, Corning NY) was used as the cutting substrate. Macor is a machineable glass-ceramic with a density of 2.52 g/cm³, modulus of rupture at 94 MPa, comparable hardness at 250 KHN, Young's elastic modulus (66.9 Gpa), and thermal properties similar to enamel.⁸ The Macor used for this study was supplied in 3/8x 1 x 3 inch pieces.

The simulated clinical conditions consisted of the following steps.

- a. The handpiece was started and allowed 2 seconds to attain maximum speed.
- b. The weight was applied and the bur cut through a 1-inch length of Macor for 30 seconds.
- c. The handpiece was stopped for twenty seconds and the Macor was repositioned.
- d. Steps a, b and c were repeated for a total of eight cycles. This constituted one simulated clinical use.
- e. After four simulated clinical uses, the handpieces were sterilized in an autoclave (Tuttnauer 2540M Autoclave. Tuttnauer USA Co LTD. Ronkonkoma, NY).
- f. Step e was repeated three times for a total of four sterilization cycles.

- g. The process started again with step a. All handpieces were subjected to 1000 clinical simulations. Assuming a handpiece is used twice a day, 250 days a year, 1000 clinical simulations correspond to two years of clinical use.

The electric motor handpiece attachments and the air turbine handpieces were lubricated in accordance with manufacturers' instructions. The handpieces were placed in sterilization bags. The handpieces were then placed in the sterilizer with the head elevated at a 45-degree angle to minimize moisture retention. In the case of the electric motors, for the purposes of sterilization, the term "handpiece" refers to the 1:4 speed increasing contra-angle. Heat sterilization is not recommended for the motors. The external surface can be disinfected or the removable outer sleeve of the motor can be heat sterilized.

V. CLINICAL PARAMETERS

A. Handpiece Longevity

Purpose

The purpose of investigating this clinical parameter was to determine if there was a difference in the clinical longevity between air turbine and electric motor handpieces.

Literature Review

The ADA stated in 1992 that every instrument that enters the mouth, including the handpiece, be sterilized between patients. The ADA also stated that heat sterilization with an autoclave or chemical vapor sterilizer was effective method of sterilization between patients to ensure internal as well as external sterilization.⁹ Several studies have suggested that heat sterilization is detrimental to the working lifespan of dental handpieces.

Methods and Materials

Handpiece longevity was determined by recording how many successful clinical simulations were performed by a handpiece before it failed. Failure of the handpiece was determined to have occurred when it became non-operational or when the handpiece stalled on the substrate when the cutting force was applied. When a handpiece stalled, a slight digital rotation was used to restart it. If the handpiece did not operate after two attempts it was considered non-operational.

Results

The failures for each model are shown in Table 1. Neither the Kavo nor the Bien-Air electric motor handpieces had an operating failure after 1000 uses. The Midwest had a failure rate of 50% after 1000 uses. Midwest handpiece failures occurred after 260, 805, and 821 clinical

simulations. The Midwest handpieces were returned to the study after the turbines were replaced. The handpiece that failed at 260 simulations, failed again at 830. This was not counted as an additional failure.

Table 1. Handpiece Longevity (Percentage Operational). Each handpiece had a sample size of six.

Clinical Simulations/ Handpiece	0	252	500	752	1000	Subset
KaVo	100	100	100	100	100	A
Bien-Air	100	100	100	100	100	A
Quiet-Air	100	100	83	83	50	B

Discussion

Longevity is considered to be the most important factor when evaluating a handpiece.¹⁰ All twelve electric motor dental handpieces were operational after 1000 simulations. Three of the six air turbine handpieces had turbine-bearing failures. When considering the purchase of a dental handpiece, longevity is an important factor. Handpiece longevity has a direct effect on the frequency and cost of repairs. Handpiece repair cost and “down-time” are two of the factors used to determine life cycle costs.

Conclusion

The longevity of the electric motor dental handpiece is significantly better than the longevity of the air turbine handpiece.

V. CLINICAL PARAMETERS

B. Power/Cutting Efficiency

Purpose

The purpose of investigating this clinical parameter was to determine if there was a difference in the power or cutting efficiency between air turbine and electric motor handpieces.

Literature review

Power is the measure of a handpiece's capability to remove tooth structure. Power, expressed in watts, is calculated by multiplying torque (Newton meter), rotation (revolutions per minute), and a mathematical constant.¹¹ To obtain power data it is necessary to measure torque and speed simultaneously. Speed is easily measured with a tachometer and torque with a dynamometer. However, attempts to measure the torque of the electric motor at the maximum bur speed of 200,000 were unsuccessful. At this speed the electric motor handpieces consistently "over torqued" the dynamometer (Kerfoot Dynamometer. KMS Design, Altamonte Springs, FL) and a repeatable measurement of torque could not be obtained.

The USAF DIS successfully measured the torque of the KaVo electric motor with a 1:1 straight nose cone attachment. At approximately 25,000 rpms the KaVo had a stall torque of 1.933 in-ounces and a maximum power is 35.7 watts. For comparison, using the same dynamometer, the Midwest shorty generated a maximum power of 17.4 watts at 15,000 rpm. The stall torque was 2.598 in-ounces at 500 rpm. This demonstrates how the torque measurement can be a misleading indicator of power.¹²

According to data from Bien-Air, their motor has a torque of 2.9 Newton Centimeter (Ncm) (4.113 in-ounces) at 40,000 rpms. KaVo states that their motor has a minimum torque of 2.7 Ncm (3.830 in-ounces). The USAF DIS has published torque values for air turbine handpieces. However, data from various sources cannot be compared because of the wide variety of torque measuring methods and apparatus that were used.

Several recent studies have compared the cutting efficiencies of burs by placing a known force on a high-speed handpiece and measuring the amount of material removed in a certain period of time.^{13,14} The purpose of these studies was to compare various types of burs, not dental handpieces.

The force applied by a dentist with a handpiece and revolving bur on a tooth varies according to a number of factors such as operator experience, tactile sense, the type of bur, tooth density, restorative material, handpiece torque, and bur speed. Most studies estimate this force at 50- 150 grams.^{15,16,17} In these studies a handpiece was placed in a “frictionless” bearing and a known weight placed on the neck of the handpiece. This weight and the fulcrum position of the handpiece resulted in a known force applied by the bur to the surface to be cut. Since identical handpieces were used, the size and weight was constant, and therefore the resulting force was constant.

Cutting efficiency (CE) was determined to be the amount (volume) of substrate cut by a handpiece, divided by the time required to cut the substrate. If the variables of applied force and the type of bur are held constant then the CE would be a useful method of comparing the power of various handpieces.

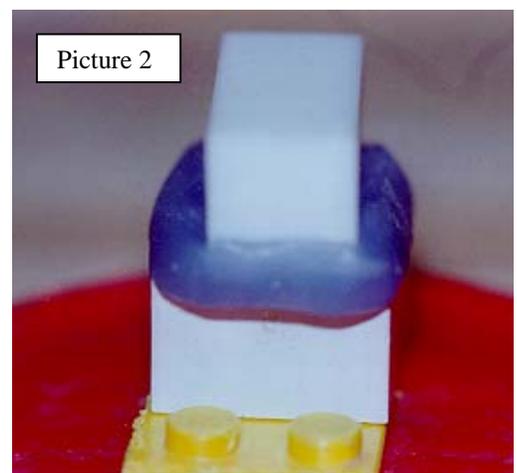
$$\text{Cutting Efficiency mm}^3/\text{sec} = \frac{\text{Volume of material removed (mm}^3\text{)}}{\text{Time to remove material (seconds)}}$$

Methods and Materials

Material selection is an important feature of a cutting efficiency study. Ideally tooth structure should be used, but inconsistencies in morphology would introduce uncontrolled variables.¹⁸ Many dental bur-cutting studies have taken advantage of the consistent density and availability of glass ceramic materials.^{19,20,21} Macor (Corning Glass Works, Corning NY) was used to simulated enamel and provide a constant material density during the tests. The Macor used for this study was supplied in 3/8x 3/8 x 5/8 inch pieces.

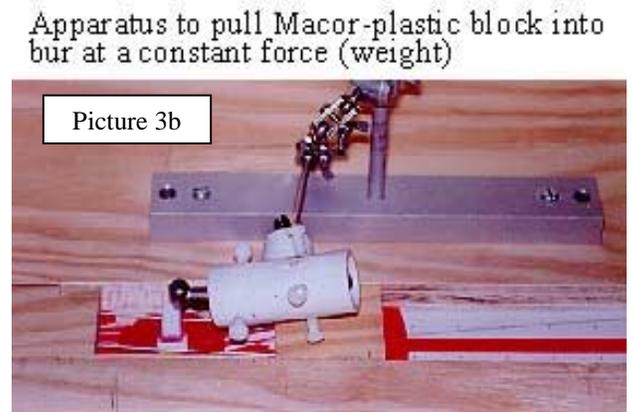
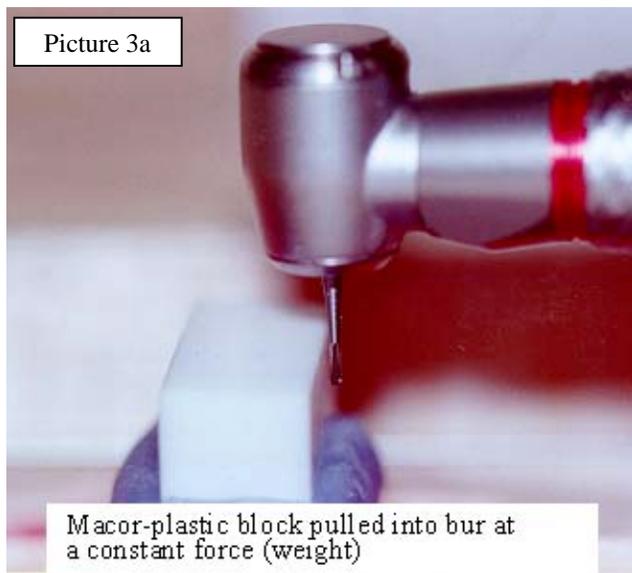
Because different handpieces were to be tested, it was necessary to build a device that would move the Macor into the bur at a reproducible force. A table was built that would create a “frictionless” surface, and it had perforations that allowed for the passage of pressurized air, similar to an air hockey table. The pressurized air would allow a disc to glide across the table surface when a weight was applied. .

The Macor was placed on a 1 x 1 inch, 1.4mm thick piece of plastic building block material and stabilized by a stent made of light cured dental acrylic (Triad, Caulk Dentsply, York PA) (See Picture 2). These Macor building blocks weighed 8.560 grams (+/- 0.1 grams) and they could be securely attached and easily removed from a second thin



Macor attached to plastic block via Triad.
Macor-plastic block attached to disc

building block that was glued to a plastic disc. The plastic disc was placed on a table with a perforated surface. Two ¼ inch diameter 18 gauge wires were mounted to prevent the disc from rising more than 1.5 mm from the surface. A cutting force of either 100 grams or 150 grams was applied by attaching a 100-gram or 150-gram weight to a piece of 25 pound test monofilament line. The line passed over a wheel at the edge of the table and the weight would move down by the force of gravity, pulling the Macor into the bur. These weights were selected to approximate the force a dentist would use. The bur depth and angle were set by a series of adjustment screws. Each cut was 3.8 mm deep through the 3/8-inch (0.9525 cm) width of Macor (See Pictures 3a and 3b).

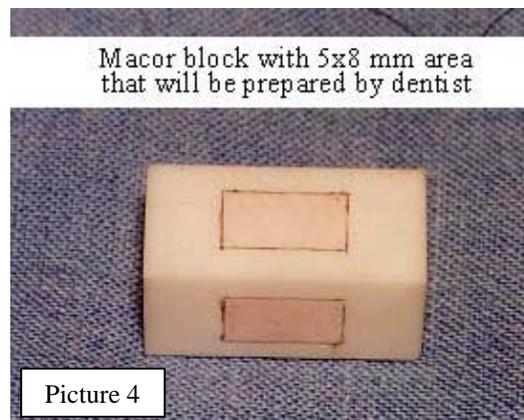


These cutting efficiency tests were conducted after the handpieces had been subjected to 204 clinical simulations. Before each series of cuts the handpieces were lubricated and sterilized according to manufacture specifications. Before testing the handpieces were run for 120 seconds without load. An 1158 bur (Midwest Dental Products, Des Plaines, IL) was used to cut the Macor two times before being discarded.

The time required for the bur to cut through the Macor was recorded. After each cut, the Macor was removed from the disc, cleaned with compressed air for fifteen seconds and then weighed to determine the amount of material that was removed. Mass was measured using a balance (AT261 Delta Range. Mettler. Toledo, OH). The mass was divided by the known density, in order to reveal the volume of Macor removed. Cutting efficiency was then determined by dividing the volume of substrate removed divided by the time (+/-0.1 second) required to complete the cut.

$$\text{Volume (mm}^3\text{)} = \text{Mass (mg)} / \text{Density (2.52 mg/mm}^3\text{)}$$

During preliminary testing, a constant force of 150 grams resulted in the air turbine handpiece occasionally “stalling” against the surface of the Macor. If the air turbine appeared to stall, the force would be momentarily stopped to permit the air turbine to regain full speed. The air turbine handpiece cut the Macor without “stalling” when a constant force of 100 was applied. The Electric motor handpiece did not “stall” at either applied force.



To determine a clinical relevance to the cutting efficiency, five dentists were asked to make preparation on Macor. A stent was used to mark an 8 x 5 mm area on four sides of a 3/8 x 3/8 x 3/4 piece of Macor (See Picture 4). The dentists were instructed to make the preparation to the depth of the fissures on a 330 carbide bur.

Each dentist was given the opportunity to use the electric handpiece on extracted teeth and Macor, to ensure familiarity with the electric handpiece. Use of the air turbine and electric handpieces were randomized. Each dentist prepared four areas with the air turbine handpiece and four areas with the electric motor handpiece. The time required by the dentist to prepare the Macor was measured. The mass of Macor removed was measured. The volume of Macor removed and CE were calculated.

Results

The volume of Macor removed with each cut was calculated by determining the weight before cutting and the weight after cutting. The volume was divided by the amount of time required for the handpiece to cut through the 3/8-inch width of Macor. This was recorded as volume removed per second. The averages for these values are recorded in Table 2.

Table 2. Cutting efficiency with identical force.

Handpiece	Force (grams)	Mean Volume removed (cubic mm)	Mean Time To complete Removal	Mean Cutting Efficiency mm ³ /sec	Std. Deviation
Electric Motor	100	45.73	14.8	3.09	.3214
Air Turbine	100	46.95	22.9	2.05	.2346
Electric Motor	150	46.03	8.4	5.67	.8052
Air Turbine	150	46.94	48.9	0.96	.1879

The time required by the dentists to make similar preparations was evaluated and “clinical cutting efficiency” was determined. These preparations are only considered similar

because the volume of material removed was not reproducible and the dentists applied variable amounts of force during the preparations. This data is listed in Table 3.

Table 3. Clinical cutting efficiency of five dentists making similar preparations.

Handpiece Dentist	Electric		Air Turbine		Highest Cutting Efficiency
	Mean	Std.Dev	Mean	Std.Dev	
1	1.99	.469	1.34	.349	Electric
2	1.52	.237	1.72	.097	Electric
3	1.39	.128	1.06	.407	Electric
4	1.20	.125	1.55	.225	Air Turbine
5	0.81	.050	1.29	.683	Air Turbine

Discussion

Power is the measure of a handpiece’s ability to remove tooth structure. Power in air turbine handpieces is usually measured by determining torque. However, even among air turbine testing, standardized regimens are difficult to achieve.²²

This study involved a reproducible test to evaluate the cutting efficiency of the KaVo electric motor dental handpiece compared to an air turbine handpiece rated “acceptable” by a government testing organization. The results show that with equal amounts of applied force (100 and 150 grams), the electric motor handpiece cut a glass ceramic material significantly more effectively (volume per second) than the air turbine handpiece. The cutting efficiency of the air turbine handpiece significantly decreased with the greater force. This was due to the fact the air turbine handpiece had insufficient torque to operate effectively at the greater force.

There may be concern that this more rapid removal of tooth structure may have an adverse effect on the pulpal temperature. Data listed later in this report show no significant

difference in the pulpal temperature increase between the air turbine and electric motor handpiece despite the more rapid removal of tooth structure with the same applied force.

It was attempted to determine if the greater CE of the electric motor handpiece in laboratory studies was repeated in a clinical setting. For the group of five dentists, three dentists achieved significantly higher cutting efficiency with the electric motor handpiece. Two of the dentists achieved significantly higher cutting efficiency with the air turbine handpiece. Overall, there was no significant difference in the clinical cutting efficiency of the air turbine and electric motor handpieces in this study.

Conclusion

Laboratory tests indicate that the electric motor dental handpiece has a higher cutting efficiency than the air turbine handpiece. This may not be clinically significant. It is possible that the dentists have learned to remove tooth structure at a certain “speed” and some dentists are not taking full advantage of the increased torque of the electric motor. Further studies may be needed to determine if dentists will take advantage of the increased torque as they become accustomed to the electric motor handpiece.

V. CLINICAL PARAMETERS

C. Pulpal Temperature

Purpose

The purpose of investigating this clinical parameter was to determine if there was a difference in the effect on pulpal temperature between air turbine and electric motor handpieces.

Literature review

Early studies indicated that the heat generated by operative procedures was a major cause of pulpal injury.^{23,24} A recent study isolated the effect of heat from other potentially harmful factors and concluded that average increases in pulpal temperature of 11.2° Celsius does not damage the pulp. The study also concluded that heat plays a secondary role to bacterial intrusion and chemical irritation.²⁵

Other studies measured the temperature changes in the pulp chamber when teeth were subjected to a bur on a highspeed handpiece. In some of these studies pulpal temperature decreased when air-water spray coolant was employed.^{26,27} In other studies the pulpal temperature increased.²⁸

USADRDR replicated the testing techniques used in several studies that measured pulpal temperature changes by using a thermocouple temperature probe inserted into a pulp chamber that was filled with a heat conducting compound.^{29,30,31,32}

Methods and Materials

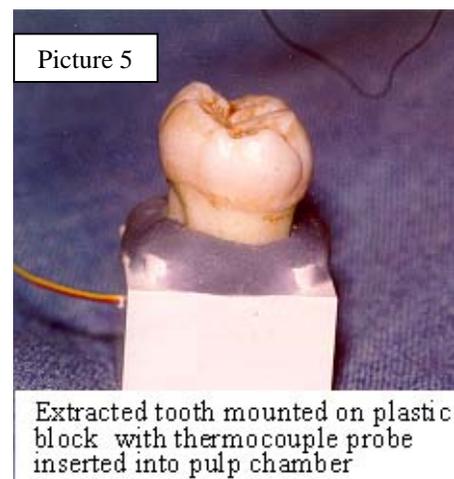
The electric motor and air turbine handpiece are significantly different in respect to size and weight. However, it was desired to maintain a constant, repeatable cutting force for each

handpiece. It was therefore necessary to construct a testing regimen that would move the tooth into the bur, of both types of handpieces, at a constant force.

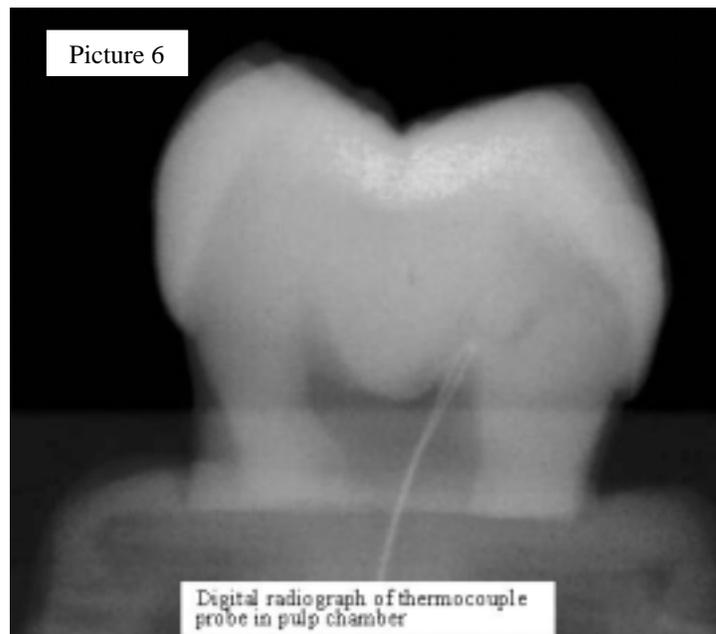
The teeth of 18-24 year old patients who had bilateral extraction of mandibular third molars were examined. Five pairs of caries free mandibular third molars were utilized in the study. The mesial-distal length of each pair was approximately the same (+/- 5%). Immediately after extraction the teeth were stored in physiologic saline solution with 10% formalin solution to prevent dehydration. The teeth were stored under 100% humidity except when used for testing. Five pairs of teeth were selected.

The root portion was sectioned with a carborundum disk perpendicular to the long axis of the tooth, approximately 3 mm below the Cemento-Enamel Junction (CEJ). The pulp chamber was cleaned of remnant pulpal tissue by spoon excavator and irrigated with 10 cc of 5.25% sodium hypochlorite.

The teeth were affixed with acrylic to a 1.6 x 1.6 cm x 1.6 cm plastic building block. The plastic block had a hole drilled in the middle of the top surface with a 2 round bur, which has a 1.0 mm diameter. The tooth was positioned with the chamber centered over the hole in the plastic block. The acrylic was applied in varying amounts so that each paired tooth-plastic block unit weighed approximately the same (+/- 0.1 gram). A 1.4mm thick piece building block was glued to a plastic disc (See Picture 5).



A silicon heat transfer compound (Z9, GC Thorsen, Inc. Rockford, IL) was injected into the pulp chamber to facilitate heat transfer and simulate pulpal tissue. A thermocouple probe (Type K, Omega Engineering, Stamford, CT) was inserted through a small hole in the side of the plastic building block, through the top of the block, into the tooth. Sticky wax (Moyco, Philadelphia, PA) was used to fix the probe in the proper location against the pulp chamber roof. Probe placement was confirmed by digital radiography and positions were corrected as needed (See Picture 6). The probe was then connected to an electronic digital thermometer (DP41-TC, Omega Engineering).



A 25-pound test monofilament line was used to affix the weight to the plastic block. The line passed over a wheel at the edge of the table, and the weight would move down by the force of gravity, pulling the Macor into the bur. The tooth-plastic block unit could easily be attached and removed from the disc. The disc was placed on a table with a perforated surface. The perforations allowed for the passage of pressurized air. The pressurized air caused the disc to glide with minimal friction across the table surface when the weight was applied. Two 18 gauge

orthodontic wires were mounted to prevent the disc from rising more than 1.5 mm from the surface of the table (See Picture 7).

Apparatus to pull Macor-plastic block into bur at a constant force (weight) with thermocouple probe and digital thermometer in place .

Picture 7



Although it was planned to apply identical force to each of the handpieces, clinical studies indicated that some dentists applied a greater amount force with the electric motor handpiece than with the air turbine. To simulate this clinical difference, a cutting force of 100 grams was applied to the air turbine handpiece and a cutting force of 135 grams was applied to the electric motor handpiece.

Two handpieces, a KaVo and a Midwest, were selected for the test. These handpieces had been subjected to 100 clinical simulations. Before each series of cuts the handpieces were lubricated and sterilized according to manufacture specifications. Before testing they were run for 120 seconds without load. A new 1558 round end taper bur was used to prepare each tooth. The bur depth and angle were set by a series of adjustment screws. Three preparation cuts, parallel to the sagital plane, were made in a mesial distal direction on the occlusal surface. Each cut was set to a depth of 2.5 mm. The bur was discarded after the three cuts were made.

The left mandibular third molars were prepared with an air turbine handpiece. The right mandibular third molar prepared with an electric motor handpiece. The tooth and bur were aligned so that the bur would enter and exit the tooth at a depth of two millimeters.

The temperature of the coolant water was maintained at a constant temperature by a water bath (23.0 °C). The water coolant was set to flow at 20 ml/min for both handpieces. Several previous studies documented pulpal temperature changes when the initial pulpal temperature was approximating body temperature at 37 °C. Since the purpose of this study was simply to compare heat generation from air turbine and electric motor handpieces, the teeth were tested at room temperature.

The temperatures in the pulp were automatically recorded every second. The time required for each preparation was also recorded in order to determine any correlation between the cutting speed and maximum pulpal temperature. After the teeth were prepared, they were sectioned to determine residual dentine thickness. Teeth with a residual thickness of less than 1.25 mm from the floor of the preparation to the roof of the pulpal chamber were to be removed from the study. All teeth had a residual thickness greater than 2.0 mm.

Results

Table 4 shows the average pulpal temperature and average pulpal temperature increase generated by the two handpieces. The average time that the handpiece was in contact with the tooth is also listed. Paired sample statistics for the maximum pulpal temperature and adjusted temperature increase from the baseline.

Table 4. Pulpal temperature changes and preparation time with air and electric handpieces.

	Electric Handpiece	Air Turbine
Mean preparation time (secs)	29.13	35.52
Std. deviation	1.405	0.405
Mean Maximum Temperature increase (⁰ C)	3.76	3.86
Std. deviation	0.09	0.10

On average the relative temperature within the pulp chamber increased by 3.48 degrees Celsius for the electric motor and 3.62 degrees Celsius for the air turbine. The electric motor preparations were accomplished 4.2 seconds quicker (SD 6.76) than the air turbine preparations.

Discussion

The testing regimen in this study may be unorthodox, but this test was designed to be simple, reproducible, and provide for control of the variables. Because the teeth were tested at a controlled room temperature, the amount of thermal change in this study may have been different than if a simulated body temperature had been utilized. However, the amount of heat generated by the handpieces, measured by pulpal temperature changes, is statistically similar. This finding is remarkable because the electric motor handpiece removed tooth structure significantly faster (approximately 20%) than the air turbine handpiece

Conclusion

The electric motor handpiece with its increased cutting efficiency and ability to cut tooth structure at a greater applied force than the air turbine handpiece does not create an increased thermal hazard to the pulp than the air turbine handpiece.

V. CLINICAL PARAMETERS

D. Air Exhaust

Purpose

The purpose of investigating this clinical parameter was to measure the volume of air that was exhausted from the head of the air turbine and electric motor handpieces.

Literature review

Most of the compressed air driving the air turbine handpiece is vented to the rear of the handpiece. However, a cooling stream of air from the drill head enters the mouth.³³ Although air turbine handpieces are contraindicated for dental alveolar surgical procedures, since the introduction of the air turbine handpiece, the incidence of iatrogenic subcutaneous emphysema has increased.³⁴

The compressed air requirements for the brush type electric motor handpieces are significantly less than the requirements for the air turbine. An electric motor is responsible for rotating the bur, not air. In addition to the air-water coolant spray, the electric motor handpiece requires a stream of compressed air to cool the motor. Without this cooling air the motor will become hot to the touch and eventually stall.

Methods and Materials

An air turbine handpiece (Midwest) and an electric motor handpiece with the speed increasing attachments (KaVo) were used to determine the amount of air exhausted from the handpiece head into the oral cavity. These handpieces had undergone approximately 200 clinical simulations before testing. A ½ inch diameter rubber hose was connected to a 1-inch diameter

hose that was placed over the handpiece head and fastened to the body of the handpiece. The hose exited into a graduated 1000ml cylinder. The cylinder was filled with water, inverted, and then placed in a four-liter pan filled with water. For each handpiece tested the coolant spray was set at 20 ml/min of water. The amount of air that exited the handpiece was determined by measuring the time required to displace water from the graduated cylinder (See Picture 8). This test was performed ten times for each handpiece to obtain an average volume of air exhaust coming from the head of the handpiece. The air water coolant spray was then switched off and the same technique was used to measure the amount of air that exited the head of the handpieces. This measurement was also repeated ten times for each handpiece.



The air-water coolant spray and the motor coolant air were turned-off, and the amount of air exhaust from the electric motor handpiece head was measured as described above. When the motor coolant air is off, the motor may overheat resulting in damage or performance changes.³⁵ Because of this risk, measurements of the air exhaust without a motor coolant spray were

conducted at the end of the 1000 clinical simulation study. A 10 ml vessel was substituted for the 1000 ml cylinder because a large volume of air exhaust was not generated.

Results

The amount of time required for the handpiece to release 1000 cubic centimeters of air at 1 atmosphere was recorded. Table 5 lists the average volume of air exiting from the handpiece heads. The table also lists the amount of air exhaust measured when the coolant air to the motor was turn-off.

Table 5. Volume of air (mm³/min) exiting handpiece head.

		Mean Volume Air(mm ³ /min)	Std. dev	
Without Air-water spray	KaVo	16.99	0.290	A
	Bien-Air	20.69	0.167	B
	Air Turbine	59.55	1.867	C
With Air-water spray	KaVo	39.87	1.654	I
	Bien-Air	46.94	0.790	II
	Air Turbine	112.89	9.018	III
Without motor air coolant	KaVo	0.11	0.03	
	Bien-Air	0.13	0.06	

Discussion

When the air-water coolant spray is set for 20 ml/min of water the air turbine handpiece emits significantly more air from the handpiece head than either electric motor handpiece. The Bien-Air electric handpiece emitted significantly more air than the KaVo.

When the air-water coolant spray is turned-off, the air turbine handpiece emits significantly more air from the handpiece head than either electric motor handpiece. The Bien-Air electric handpiece emitted significantly more air than the KaVo.

For each handpiece, the level of air emitted without the air-water coolant spray is approximately 50% of the amount air of exhaust when the air-water spray is operational.

Some practitioners use air turbine high-speed handpieces during periodontal surgery involving boney re-contouring. These results suggest that if used for dental alveolar or periodontal surgery either type of handpiece (air turbine or electric) could cause an air emboli in the tissues of the patient, even if a separate irrigation syringe is used instead of the air-water spray.

In the electric motor handpieces studied, the air exhaust measured when the air-water coolant spray was turned-off could be the result of the motor coolant air migrating through the contra-angle attachment. Depending on the electric motor handpiece delivery system, this motor coolant air can be turned-off. When the motor coolant air is not activated the measured air exhaust is reduced to less than 1.0 mm³/min. Because of the significant air exhaust reduction, the electric motor handpiece may be better suited for these periodontal procedures because of the probable reduced risk of air emboli. However this procedure can reduce the life of the handpiece. With continued use the handpiece will become hot to the touch and eventually overheat. Manufacturers claim that the newer, brushless electric motor handpieces do not require this motor coolant air and will not produce an air exhaust without the air-water coolant spray.

Conclusion

This data suggests that the electric motor exhausts less compressed air into the patient's mouth than an air turbine handpiece. This data also suggests that the electric motor handpiece with a contra-angle attachment may be suitable for dental-alveolar surgical procedures if the

motor coolant air is turned-off and a separate irrigation syringe used. It may be possible to substitute this handpiece for a surgical Hall or Stryker drill.

V. CLINICAL PARAMETERS

E. Aerosol Production

Purpose

The purpose of investigating this clinical parameter was to measure the amount of aerosol generated by the air turbine and electric motor handpieces.

Literature Review

Microorganisms in saliva and plaque are present in the aerosol created when a dental handpiece is used in an operative procedure.³⁶ Bacteria and other microorganisms in the oral cavity can be transmitted to dental personnel by aerosols generated during dental procedures.³⁷

Fine aerosols generated by highspeed dental equipment consist of moisture droplets and contaminants that are less than 5 microns in diameter.³⁸ Particles in the 0.5-10 micron range are carried for hours at great distances and the size of these particles allow them to remain airborne for hours and travel deep into the respiratory tract.³⁹

Micik suggested that the bulk of the aerosol production was from the spray action, not the cutting operation.⁴⁰ Another study determined that the bacteria in aerosol were generated mostly by the actual cutting.⁴¹

Methods and Materials

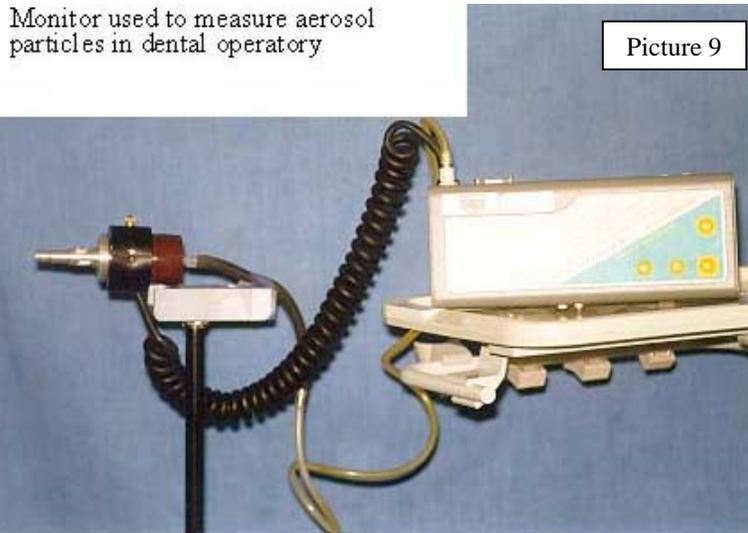
Part I

In vitro testing was conducted utilizing extracted teeth, a clean room, and a HazDust II Aerosol Monitor (Environmental Devices Corp, Haverhill, MA). The monitor, with the inhalable sampler, detects particles in the 0.1-10 micron range with an air sample flow rate of 2.0 liters per minute. The monitor allows the calculation of minimum particle concentration; time weighted average particulate concentration over a period of time (TWA); and short-term exposure level (STEL), the maximum concentration of particulates over a period of time. The unit was maintained and calibrated in accordance with manufacturer's instructions. Sensor optics on the HazDust were cleaned daily.

Three hundred non-carious extracted third molars were obtained for the study. Immediately after extraction the teeth were stored in physiologic saline solution with 10% formalin solution to prevent dehydration. The teeth were stored under 100% humidity, except when used for testing.

A clinical day was simulated in the following manner. A dental operatory (12 x 12 foot) located in the US Army Dental Research Institute was chosen for the study. No other procedures were performed in this operatory for the duration of the study. The teeth were mounted in an acrylic base that could be mounted on a lab bench. Every thirty minutes a 4 x 8 mm class V preparation was made to the depth of a 330 carbide bur (0.8 mm diameter, 1.2mm long). High velocity suction was used.

An air turbine handpiece (Midwest) and an electric motor dental handpiece (KaVo) were each used for ten days. These handpieces had undergone approximately 200 clinical simulations before this testing. The air-water coolant spray was set at 20 ml/min for both handpieces. The monitor was placed on a tripod three feet away from the operative field at the same height (See Picture 9). The amount of aerosol produced during a simulated clinical day was recorded.



Part II

To determine if the HazDust findings were clinically significant, clinical testing was conducted. Volunteers were recruited from active duty military personnel who had at least two carious lesions. Patients were excluded if they had active systemic infections, cold or flu symptoms within seven days, HIV positive, or any other conditions that contraindicate restorative dental treatment. Patients were treated in a 16 x 12 foot operatory with 9.5-foot high ceilings at the Great Lakes Naval Hospital Dental Clinic.

The patients were scheduled for two appointments in a dental operatory exclusively reserved for this study. During one appointment, a tooth was prepared with an air turbine handpiece. During the other appointment, the tooth was prepared with an electric motor dental

handpiece. The treatment was completed before the clinic opened for the general patient population. Any treatment not completed during these two appointments was scheduled for a later date.

A Burkard Model PASA Portable Air Sampler for Agar Plates (Spiral Biotech Company, Bethesda, MD) was used to collect aerosolized bacteria and particle matter onto sheep's blood agar medium in a 9 cm diameter petri dish. Sheep blood agar was selected because it is a good growth medium for oral bacteria. It had been used in the majority of the past studies found in the literature. The air sampler passed air over the petri dish at a flow rate of 20 liters per minute.

The air sampler was located three feet from the patient's mouth, at waist level, on the patient's right side. Air samples were collected by exposing the petri dish for a three-minute period of time. A baseline air sample was collected five minutes before the patient was seated in the operatory. A second baseline air sample was collected after the patient was seated in the chair. Starting at the time that the dental bur was first applied to the tooth, a third air sample was collected. This air sample measured the bacterial levels in the aerosol produced during dental treatment. A fourth air sample was collected one hour after the treatment had started.

The petri dishes were incubated at 37 degrees Celsius in an atmosphere of 5% carbon dioxide for 48 hours. Following incubation, all bacterial colonies were enumerated by counting a 10 cm section grid. Data was to be reported as total colony forming units per sample.

Part III

Clinical and laboratory testing revealed contradictory information. The air sampler was used in a clean room (Airo Clean Model 823, Extron PA) in USADRD facilities. Dimensions of the clean room were 8.5 x 22.5 foot with an 8.25-foot high ceiling. The atmosphere displacement was approximately 700 cubic feet per minute (CFM).

An *in vitro* carious lesion model was used to assess the rates of bacterial aerosolization. A series of 3/8" x 3/8" x 3" Macor blocks were sterilized and aseptically embedded into 10 ml of Todd Hewitt Agar (1.50% w/v) in a 9 cm petri dish. Cultures of *Streptococcus mutans* 25175 were grown to mid-logarithmic phase ($A_{660nm} = 0.20$) in Todd Hewitt (TH) broth; 300 μ l of this culture was used to inoculate 15 ml aliquots of 0.75% TH top agar at 37°C. After the primary agar layer had solidified around the base of the Macor blocks, the *S. mutans* dosed top agar was poured into the dish, encasing the remainder of the exposed Macor sample. Plates were incubated 48 hours to permit proliferation of the cariogenic organism throughout the top agar-Macor matrix. At the completion of the incubation period, extensive bacterial growth was easily evident.

The air turbine handpiece (Midwest) and the electric motor handpiece (KaVo) were set to have a 20 ml/min air-water coolant spray. The air sampler was placed 24 inches from the work site at the same horizontal level. Air samples were collected by exposing the blood agar petri dish for three minutes with air passing over the dish at 20 liters per minute. Ten minutes before the cutting procedure, a baseline air sample was collected. Another baseline air sample was collected five minutes before the cutting procedure.

Three 8 x 5 mm, 1.2 mm deep spaces were prepared in the Macor. As soon as the cutting procedure started, an air sample was taken to measure the aerosol created by the cutting procedure. Only one Macor sample was tested each day to assure that residual aerosol contamination had been cleared. Ten minutes after the preparation was completed another air sample was collected.

Each blood agar plate was incubated at 37 degrees Celsius in an atmosphere of 5% carbon dioxide for 48 hours. Following incubation, individual plates were enumerated by counting total colony forming units.

Results

Part I

The results from the HazDust monitoring are listed in table 6. The results indicate that in an isolated operatory the electric motor handpiece produces significantly less aerosol than the air turbine handpiece.

Table 6. Aerosol (particles per cubic meter) produced by handpieces, measured by HazDust monitor.

	Air Turbine	Electric Motor
Maximum aerosol Concentration	3.59	1.38
TWA. Time weighted Average	2.13	0.66
STEL. Short term exposure level	2.97	1.17

Part II

The results from the air sampler in the hospital dental clinic are listed in Table 7. The air sampler attempted to measure the amount of aerosol produced as a function of CFUs counted on the petri dishes. Since the two initial (baseline) measurements, taken each morning, are

statistically similar, they are grouped together as “pre-operative” CFU level. There is no significant difference between the electric motor and air turbine handpieces in the number of colony forming units that were collected on the petri dishes.

Table 7. Average CFUs detected in clinical study.

CFU levels	Handpiece	Mean CFUs	Standard deviation	Std error mean
Pre-operative	Electric Motor	3.21	1.31	0.350
	Air Turbine	3.43	1.22	0.327
Operative	Electric Motor	6.79	4.74	1.267
	Air Turbine	6.29	3.29	0.880
Post-operative	Electric Motor	4.50	2.74	0.732
	Air Turbine	4.00	1.96	0.524

Part III

The results from the air sampler in the laboratory clean room are listed in Table 8. The air sampler attempted to measure the amount of aerosol produced as a function of CFUs counted on the petri dishes. Since the two initial (baseline) measurements are statistically similar, they are grouped together as “pre-operative” CFU level.

Table 8. Average CFUs detected in clean room study.

CFU levels	Handpiece	Mean CFUs	Standard deviation	Std error mean
Pre-operative	Electric Motor	0.00		
	Air Turbine	0.00		
Operative	Electric Motor	6.64	4.11	1.0975
	Air Turbine	7.79	2.19	0.5853
Post-operative	Electric Motor	3.71	2.09	0.5589
	Air Turbine	4.07	1.90	0.5078

Discussion

Because of the significantly less air is emitted from the head of the electric motor handpiece than from the air turbine handpiece, it was anticipated that the electric motor

handpieces would produce less aerosol than the air turbine handpiece. However, the various testing methods provide conflicting results.

The results of the HazDust Monitor in an isolated dental operatory reveals that use of the electric motor handpiece results in significantly less aerosol production than the air turbine handpiece. This is believed to be a result of the smaller amount of compressed air entering the patient's mouth from the handpiece head.

The results of the dental clinic survey indicate that there is no significant difference in the amount of aerosol created by the electric motor and air turbine dental handpieces. These non-significant differences in the hospital dental clinic may have been the result of "background" contamination. The findings suggested that ambient room air in the operatory/clinic contained residual levels of aerosolized organisms. There are eight other operatories in the dental clinic, which is located on the seventh floor of an eleven-story building. This finding may have practical applications for large dental clinics. Although an electric handpiece may produce fewer aerosols than an air turbine, in a large dental clinic with both electric motor and air turbine handpieces, the amount of aerosol in the clinic may not be significantly altered.

The results of the aerosol study, conducted in a clean room using a glass ceramic material imbedded in a *S. mutans* agar, indicate that there is no significant difference in the amount of aerosol created by the electric motor and air turbine dental handpieces.

Conclusion

Final analysis of the data indicates:

1. Without an air-water coolant spray, the electric motor places significantly less compressed air into the patient's mouth than the air turbine handpiece.
2. With an air-water coolant spray, the electric motor handpiece and the air turbine handpiece produce statistically similar levels of aerosol contamination.

V. CLINICAL PARAMETERS

F. Noise

Literature review

Noise is defined by its sound level and frequency. Since noise includes frequencies throughout the audible range, sound measurements are adjusted to account for frequency dependent human hearing. This measurement is called A-weighted (dBA).

Many studies have indicated that there is a risk of noise induced hearing loss (NIHL) resulting from dental practice. A 1985 literature review 11 of 19 studies indicated that dental drills cause NIHL.⁴² A Scandinavian study followed a group of dentists for seventeen years and concluded that dental drills are not a risk to dentist's hearing.⁴³ A study published in 1990 concluded that dentists received, on average, only 8-12% of their 24-hour noise exposure from their dental practice.⁴⁴ However, these studies did not test multiple dentist clinics and recorded exposure to dental drill noise as little as 15-30 minutes per 8-hour day. A dental school study concluded that in a large preclinical lab personal protective devices might be indicated. The study also demonstrated that personnel who spend time in "noisy" dental labs might be at risk for hearing problems.⁴⁵

Although noise levels of dental handpieces may not cause hearing loss, noise can interfere with communication, cause an increase in blood pressure, quicken the pulse, and constrict blood vessels.^{46,47}

There is a high level of noise in the field DTF. The air turbine handpiece and the required air compressor are the principle contributors to this high noise level. The U.S. Military has

written essential characteristics for dental field units.⁴⁸ One essential characteristic is that noise levels shall not exceed 75dBA at a distance of one meter from the compressor. An electric motor handpiece field dental treatment unit should meet or surpass this essential characteristic.

Methods and Materials

Part I

The noise level of one brand of air turbine handpieces and two brands of electric motor handpieces were measured in a 12x12 dental operatory located in the U.S. Army Dental Research Institute. The sample size for each handpiece was six. The air compressor was remotely located so that the background sound level was not affected by the air compressor operation. The handpieces were the only source of noise in the operatory. The noise levels were recorded when the handpieces were operating at the maximum rpm. In order to simulate intraoral conditions, the sound levels were recorded while the handpieces were operating inside the mouth of a dental mannequin.

An Extech Noise Dosimeter RS-232 (Extech Instruments. Waltham MA) was used to measure the one minute average decibel level of the handpieces. The microphone was mounted on a tripod fourteen inches above the handpiece.

After 208 simulated clinical uses, the noise level of the handpieces was measured while cutting blocks of Macor, a glass ceramic material. The Macor was mounted in the area of the lower right molar. Since dental handpieces are almost always used with the air-water spray, the spray was utilized during testing and set at 20 ml/min. Suction was not employed. The water accumulated, via a drain tube, in a basin at the base of the chair. Background noise level was

recorded. Five seconds after the handpiece was started, a dentist made a rectangular shaped preparation (4 x 6 x 2 mm deep) in the Macor. The noise level was recorded for one minute. The noise level of each handpiece was measured five times. The handpieces were not sterilized or lubricated during this time. Each handpiece used a new 1558 carbide bur for the five noise level measurements.

The test was repeated after 232 clinical simulations, with one modification. In order to measure the noise level of the handpieces when the burs were “free-running”, or not cutting substrate, the noise level of the handpieces was measured while the handpieces were held approximately 10 mm above the Macor. The same 1558 bur was used for each measurement.

The use of the handpieces during the noise level tests was not recorded as a clinical simulation for purposes of the associated longevity study.

Part II

The second part of the study measured the noise levels produced by a U.S. Army Forward Dental Treatment Team (FDTT). A FDTT consists of one dentist, one assistant, dental supplies and equipment working in a canvas tent approximately sixteen feet in diameter.

During one two day period the FDTT utilized the currently issued “Dental Operating and Treatment Unit Field” (ADEC, Newberg, OR) and the “Compressor-Dehydrator Dental Equipment” (Air Techniques, Hicksville, NY). The treatment unit was placed just behind the dentist. The compressor was outside of the tent, approximately twelve feet from the noise dosimeter, behind a wall of sandbags (30 inches high, 30 inches wide, and 12 inches thick).

During a second two-day period, the FDTT utilized the USADRD DEFTOS. The DEFTOS was placed immediately to the left of the patient chair.

Dentaforms with Macor mounted inside the mouth were utilized to simulate patients for this study. A four minute simulated operative procedure was performed utilizing a handpiece and high velocity suction. Fourteen simulated procedures were performed each day, for a total of twenty-eight procedures with each system.

The noise dosimeter was mounted on a tripod and located approximately fourteen inches above the mouth of the dentaform. The dosimeter measured the noise level (dBA), exposure time, dose value, the eight-hour time weighted average (TWA), average noise dosimeter level (dBA), and background noise levels in the FDTT that utilized.

Results

The average decibel levels for the handpieces, with the bur “free-running” and with the bur cutting Macor are recorded on Table 9. Table 10 records the noise level data for the current air turbine based dental field treatment unit and the USADRD electric motor DEFTOS prototype.

Table 9. Average noise level (dBA) of handpieces. Average background noise was 62 dBA. Each group had a sample size of six handpieces.

	KaVo	Bien-Air	Air Turbine
Average Noise level (dBA) while cutting	77.00	77.33	83.33
Standard deviation	1.54	1.75	1.86
Standard error	0.632	0.715	0.760
95% confidence, lower bound	75.37	75.50	81.38
95% confidence, upper bound	78.63	79.17	85.28
Average Noise level (dBA)	75.00	75.33	81.66

with “free-running” bur			
Standard deviation	2.61	1.37	2.88
Standard error	1.064	0.558	1.174
95% confidence, lower bound	72.26	73.90	78.65
95% confidence, upper bound	77.74	76.77	84.68

Table 10. Noise comparison of current “Dental Operating and Treatment Unit Field” and the DEFTOS. Average background noise 67dBA.

	Field unit with air turbine handpiece	DEFTOS prototype field unit with electric motor handpiece
Average exposure time	4 min	4 min
Noise dose level	0.21	0.08
T.W.A.	45.43	38.70
Noise average (dBA)	79.2	69.0

Discussion

In a clinical setting, the electric motor handpieces produce significantly less noise than the air turbine handpieces in both the cutting and “free-running” decibel measurements. However, the testing also indicated that all of the handpieces produce noise levels well below the OSHA eight-hour limit of 85 dBA for noise induced hearing loss (NIHL).

The clinical setting results also indicate that there is no significant difference in the noise levels between a bur cutting a substrate and a bur that is “free-running”. This finding disagrees with those of Bahannan⁴⁹, and Setcos.⁵⁰ Bahannan determined that a cutting handpiece created more noise than a free running handpiece. Setcos determined that a free running handpiece created more noise than a cutting handpiece.

The clinical setting only recorded the noise from one operating handpiece. In a large multi-operatory setting there may be a risk for noise induced hearing loss. Multiple handpieces and high velocity evacuators (HVE) in one area may combine to produce noise levels above the OSHA eight-hour limit.

In a field environment DTF, the results in Table 10 indicate that a portable field treatment system and operating system, utilizing an electric motor handpiece, produces significantly less noise than the present “Dental Operating and Treatment Unit Field” that utilizes an air turbine handpiece.

Conclusion

The electric motor dental handpiece is significantly quieter than the air turbine handpiece. The reduced noise of the electric motor handpiece may minimize the NIHL risk in a clinical setting.

In all field environments where the air turbine and electric motor portable dental treatment systems were tested the treatment systems utilizing the electric motor dental handpiece was significantly quieter than the current air turbine systems.

V. CLINICAL PARAMETERS

G. Speed

Literature Review

The electric motor handpiece is capable of well-controlled bur speeds of 5-200,000 rpms depending on the type of attachment placed on the motor. The maximum air turbine bur speed is

significantly greater; most ball-bearing air turbine handpieces operate at a maximum bur speed of 350,000- 400,000 rpms. However, the bur speed of the air turbine cannot be precisely controlled and the speed for any air turbine will dramatically decrease as load is increased.⁵¹

The USAF DIS found that for air turbine handpieces there was no correlation between baseline rpm and handpiece longevity.⁵² According to the formula $\text{Power} = \text{Torque} \times \text{Speed} \times \text{Constant}$, a reduction in handpiece speed over a period of time will result in a decrease in power. It has also been reported that changes in free running speeds are primarily related to bearing deterioration.⁵³ The purpose of this test was not to compare the handpieces to each other, but to determine if clinical use and sterilization adversely affected the tested handpieces.

Methods and Materials

The speed in revolutions per minute (rpms) was measured with a Tach-4AR tachometer with Remote Optical Sensor (Monarch Instruments, Amherst, NH). Bur speed of the air turbine and the two different electric motor handpieces was measured at initial baseline and after 252, 500, 752 and 1000 clinical simulations. Each group consisted of six handpieces.

It was desired to determine if any speed change in the electric motor handpieces was related to the motor or to the attachment. In order to measure motor speed a 10CN Intra 1:1 straight nose cone attachment (KaVo of America, Lake Zurich, IL), with a 703 surgical bur, was placed on the motor. In order to provide a constant, the same attachment and bur was used on all the electric motors at baseline determination and after 1000 clinical simulations. This attachment was not subjected to sterilization procedures.

Results

Mean speed values, in revolutions per minute (rpms), for each handpiece group is shown in Table 11. When a handpiece failed it was no longer included in calculating the mean for the group. Midwest handpieces failed at 260, 805, and 821 clinical simulations. Table 12 records the average speed of the electric motors.

Table 11. Mean Handpiece speed in rpms over use.

Handpiece	KaVo Motor and attachment	Bien-Air Motor and attachment	Midwest Quiet-Air
Number of clinical simulations			
Baseline (0)	190,067 (n=6)	157,173 (n=6)	370,308 (n=6)
Std deviation	696.18	1,199.11	6,808.99
252	190,242 (n=6)	156,633 (n=6)	362,348 (n=6)
Std deviation	1,195.16	1,049.13	9,218.98
500	189,423 (n=6)	155,447 (n=6)	365,804 (n=5)
Std deviation	991.50	787.06	9,979.80
752	189,095 (n=6)	154,593 (n=6)	363,370 (n=5)
Std deviation	1,118.81	1,241.48	6,355.63
1000	189,173 (n=6)	155,768 (n=6)	355,347 (n=3)
Std deviation	840.83	1,603.24	9,079.85
Mean loss from 0 to 1000 uses	894	1,405	14,961
% Mean loss from 0-1000 uses	0.4	0.9	4.0

Table 12. Mean electric handpiece motor speed (in rpms) with 1:1 straight nose cone attachment.

	KaVo E.M With 1:1	S.D.	Bien-Air With 1:1	S.D.
Baseline 0 simulations	38,177 (n=6)	360.37	37,517 (n=6)	359.81
1000 clinical simulations	38,112 (n=6)	396.66	37,012 (n=6)	430.18
% change in motor speed (rpms)	-0.14		-1.34	

Discussion

It is unclear if decreasing handpiece speed indicates a gradual failing of handpiece. USAF DIS data indicates that handpieces fail abruptly and that decreased speed may indicate improper maintenance and lubrication.⁵⁴ However, in this study, manufacturer's instructions were closely followed during this study.

The speed of the motor with both a contra-angle speed increasing attachment and 1:1 straight nose cone was measured. This allowed separate assessments of the degradation of the attachments and motors over 1000 simulated uses. With their speed increasing contra-angles, the KaVo and Bien-Air showed no statistically significantly speed degradation over 1000 simulated clinical uses and sterilizations. The electric motors with the straight nose cone also demonstrated no statistically significantly speed degradation. In this study the air turbine handpiece showed a significant decrease over 1000 simulated clinical uses. However, a similar USAF DIS study did not detect a significant decrease in the bur speed in this brand of air turbine handpiece.

Conclusion

The speed and therefore the power of the electric motor handpieces and attachments remains constant over a period of 1000 simulated clinical uses.

V. CLINICAL PARAMETERS

H. Fiberoptic Transmission

Literature Review

The air turbine in this study had a different type of fiberoptic system than the electric motor handpieces. The air turbine had a remote light source. The light was transmitted through a fiberoptic bundle in the handpiece hose that connected to the handpiece. The electric motor handpieces have a light source in the handpiece motor. A fiberoptic rod in the handpiece attachment connects to the light source.

Light degradation may be caused by handpiece lubricants, water contaminants, or damage from the material that is cut. The purpose of this study was not to compare the fiberoptic delivery system but to determine the affect of 1000 simulated clinical uses and sterilizations on the fiberoptic light transmission capability within the air turbine handpiece and electric motor attachments.

Methods and Materials

The fiberoptic light transmission was determined by measuring the light that was emitted from the handpiece. The photometer, AEMC Light Meter, Model 814 (AEMC Corporation, Boston, MA) was placed at the tip of an 1158 bur that was fully seated in the chuck. The angle of the photometer to the handpiece head was adjusted so that the greatest reading was recorded. Measurements at baseline, 252, 500, 752, and 1000 simulations were used to determine changes in the light transmission intensity for each handpiece. After 1000 simulated uses, a very fine rubber abrasive point, Shofu super-greenie gold polishing point (Shofu Dental Corp, Menlo Park, CA) was used to polish the fiberoptic lens and remove any contaminants or scratches. The

polishing was accomplished with an electric handpiece at 5000 rpms. The illumination measurements were then recorded.

Although different light sources were used for each of the three brands of handpiece, the source for each group remained constant. The fiberoptic system was not active during the 1000 simulations. This reduced the chances of light source failure affecting the light intensity measurements.

Results

The fiberoptic intensity measurements for each handpiece are shown in Table 13. Handpieces that failed the longevity test were included in the fiberoptic transmission test. It was theorized that the handpiece repair would not affect the fiberoptic transmission capability of the handpiece.

Table 13. Mean Fiberoptic Transmission Test (n=6).

	KaVo	Bien-Air	Air Turbine
Initial baseline illumination reading (LUX)	45,142	45,382	36,560
Standard deviation	66.76	80.35	845.00
Illumination reading (LUX) after 1000 simulated uses	33,125	34,407	24,967
Standard deviation	1,658.21	1,440.45	1,139.66
Percent decrease from baseline	73.4	75.8	70.5
Illumination reading (LUX) after 1000 simulated uses and polishing	42,075	41,958	29,048
Standard deviation	1,010.40	1,153.82	1,679.66
Percent decrease from baseline	93.2	92.5	82.1

Discussion

All of the handpieces had a decreased fiberoptic output after 1000 simulated clinical uses. In a clinical setting it is possible that light transmission intensity would decrease as a result of the light source bulb and/or damage to the fiber bundle in the handpiece hose. In this study, testing took place in the controlled environment of a research operatory, and there was no damage to the air turbine handpiece hose. The light source bulb was only utilized at baseline measurements and after 100 simulated uses.

Polishing of the fiberoptic lens was done to eliminate external sources of light degradation such as lubricants, minerals from water, and scratches caused by the substrate. It is assumed that the light transmission data recorded after polishing of the lens is the best indicator of light transmission degradation. Polishing may cause the degradation of epoxy resin bundles because water and other contaminants may enter the space between the bundles. Although polishing may result in a rapid degradation of fiberoptic transmission, no further measurements were recorded.

After polishing, the electric motor handpieces had significantly less decrease in light intensity transmission than the air turbine. This is likely the result of the design of the fiberoptic rod, not a factor of the type of handpiece. There is a fiberoptic rod in the electric motor contra-angle attachment that transmits the light from the motor to the handpiece head. The fiberoptic bundle in the air turbine handpiece is held together with epoxy resin that may discolor and darken after exposure to the heat and moisture from an autoclave.⁵⁵

Conclusion

The ability of the fiberoptic rod in the electric motor handpieces to transmit light after 1000 clinical uses is significantly better than the ability of the tested air turbine handpiece. However, this is not a result of the handpiece type but a result of the type of fiberoptic rod in the handpiece. It must be noted that there are air turbine handpieces currently available that utilize the same type of fiberoptic rod found in these electric motor handpieces.

V. CLINICAL PARAMETERS

I. Chucking Mechanism

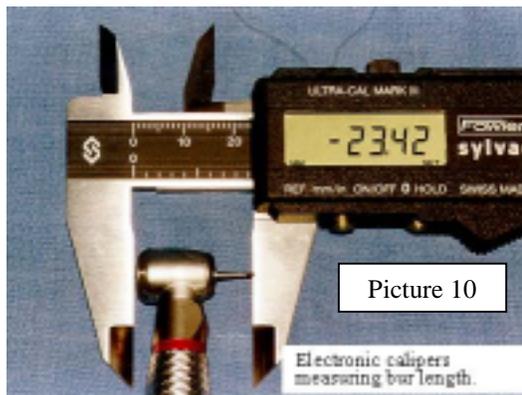
Literature Review

The USAF DIS study of air turbine handpieces indicated that all of the tested handpiece chucking mechanisms safely retained the bur in the handpiece throughout the evaluation.⁵⁶ The USAF DIS test was repeated on the electric motor handpieces to determine if the performance of the electric motor handpieces was equivalent to the performance of the air turbines. In this study both electric motor handpieces utilized a push-button type chucking mechanism. The air turbine used a latch type mechanism.

Methods and Materials

All handpieces that were being evaluated for longevity were tested for chucking mechanism effectiveness. This group initially consisted of eighteen handpieces representing three different manufacturers of handpieces. The chucking mechanism effectiveness was initially tested after twelve clinical simulations.

1. A 330-carbide bur (Midwest Dental Products, Des Plaines, IL) was placed in a handpiece



and the interocclusal distance was measured with a Digital Caliper Mark III, (Fowler Ultra-Cal, Switzerland) accurate to ± 0.01 mm (See Picture 10). This interocclusal distance is measured from the back of the

handpiece head to the tip of the bur.

2. The handpiece was subjected one clinical simulation test.

3. The interocclusal distance was re-measured. The difference, if any, between the initial measurement and post-clinical simulation measurement was recorded.
4. An increase in interocclusal distance of over 0.5mm was considered an indication of bur slippage and chuck failure.
5. The bur was reseated into the handpiece.
6. Steps 1-5 were repeated three additional times for each handpiece.
7. Steps 1-6 were repeated after 258, 512, 760, and 992 clinical simulations.
8. When a handpiece was recorded as a “failure” in the longevity study, it was deleted from further interocclusal distance measurements.

Results

All handpiece chucking mechanisms safely retained the bur in the handpiece during the evaluation. The increases in interocclusal measurement after simulated clinical use are found in table 14.

Table 14. Average amount of increase in bur length (mm) with simulated clinical use.

Handpiece Clinical Uses	KaVo (n=6)	Bien-Air (n=6)	Air turbine Non-failures
12 S.D.	.01	.03	.02 (n=6)
258 S.D.	.11	.18	.14 (n=5)
512 S.D.	.12	.35	.22 (n=5)
760 S.D.	.12	.29	.33 (n=5)
992 S.D.	.23	.30	.29 (n=3)

Discussion

None of the handpieces experienced a chuck mechanism failure. There appears to be an increase in interocclusal distance relative to the number of clinical simulations. There is no statistical difference in interocclusal distance increase among the tested handpieces. Although the bur length increased with the number of simulations, the increases were less than 0.50 mm and were not considered clinically significant.

Conclusion

There were no chucking mechanisms failures among the tested electric motor dental handpieces and the air turbine handpieces.

V. CLINICAL PARAMETERS

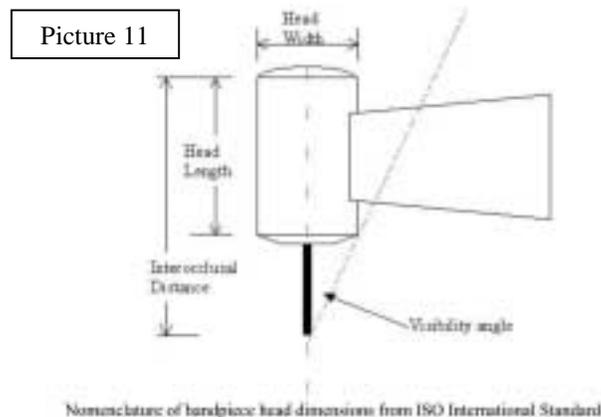
J. Static Parameters

Literature Review

There are large variations in the length, weight, and head size of various dental handpieces. Head diameter is largely determined by the handpiece rotor diameter. Head length is often cited by manufacturers, but head length size does not necessarily indicate the interocclusal clearance required to access an area of the mouth. The head length plus the length of the bur protruding from the handpiece will determine the minimum interocclusal clearance. However, visibility of the operative area is more a function of “visibility angle.”⁵⁷ The International Standards Organization (ISO) has defined measurements for the visibility angle and interocclusal clearance of dental handpieces.⁵⁸

Methods and Materials

The static parameters of the handpieces in the longevity study were measured and recorded. A digital caliper accurate to ± 0.01 mm was used to measure the head width and interocclusal clearance. The visibility angle was calculated using the ISO International Standard.⁵⁹ (See Picture 11) The handpieces were weighed on a scale accurate to 0.01 grams (AT261 Delta Range. Mettler. Toledo, OH).



Results

Table 14 lists the visibility angle, interocclusal access distances, and weight of each handpiece. The handpiece head length and width have a direct influence on visibility angle and interocclusal distance. The handpiece data from the USAF DIS study is included in order to compare the size and angle of the electric motors to a greater number of air turbine handpieces.

Table 14. Handpiece visibility angle and interocclusal distance.

	Visibility angle (degrees)	Inter-occlusal distance (mm)	Head width (mm)	Head length (mm)	Total weight (grams)
KaVo	23	23.1	9.5	16.1	172.00
Bien-Air	22	22.9	11.0	15.2	176.00
Midwest Quiet Air	21	23.8	10.5	16.5	69.68
Lares 557*	17	21.0	10.0	11.5	38.67
Lares 757*	25	21.0	12.8	13.8	42.73
Midwest Tradition*	20	22.3	10.5	12.8	54.81
KaVo640B*	25	22.8	12.4	15.1	83.90
KaVo 642B*	19	21.8	11.0	13.2	80.80
Star 430*	20	22.5	11.0	12.8	66.44

*-USAF DIS data

Discussion

It is evident from this data that the electric motor handpieces are significantly heavier than the air turbine handpieces. Visibility angles and interocclusal distances for the electric motor handpieces are greater than for the air turbines.

Conclusion

The size and weight of the electric motor handpiece are significantly greater than the size and weight of the air turbine handpieces. Results of a clinical survey, listed later in this report, indicate that the increased size and weight are not clinically significant.

V. CLINICAL PARAMETERS

K. Price

Introduction

The actual cost of a handpiece or any piece of equipment is the life cycle cost. The life cycle cost can be calculated by determining the cost of the investment phase, the cost of operations and support, and the longevity of the equipment. The investment phase consists of procurement, fielding, and support equipment. Operations and support consists of personnel labor costs, training, lubricants, and spare parts.

The electric motor and air turbine handpieces have different capabilities and delivery systems. The electric motor handpiece can replace both the air turbine highspeed and slow speed handpieces. In addition, the electric motor can also be used to replace the laboratory handpiece. Because of these facts, the price of the electric motor and attachments should be compared to the combined price of the high speed and slow speed handpieces. Although a slow speed handpiece may not be used for every patient, the comparison is based on the assumption that a dentist will need high and slow speed capabilities for each operative patient.

Methods and Materials

The manufacturer's government price (August 1999) was obtained to determine an estimate of initial handpiece costs. It must be noted that handpiece prices and availability can change without notice.

The cost to provide handpieces for one dentist was based on a requirement that each dentist will have four sets of handpieces. Four sets of handpieces permit the operative dentist to

treat a large number of patients and yet have sufficient time for a handpiece to return from sterilization. Four sets of electric motor handpieces include one motor, four high speed and four slow speed attachments. In this comparison, four sets of air turbine handpieces include four Midwest Quiet-Air high-speed handpieces, one Midwest Quiet-Air Shorty low speed handpiece, and four Midwest Quiet-Air slow speed contra-angles with latch type head (Midwest Dental Products, Des Plaines, IL).

Air Turbine Costs	=	4 highspeed handpieces	+ 1 slow speed motor	+ 4 contra-angle slow speed motors
Electric Handpiece Costs	=	1 electric motor	+ 4 speed increasing contra-angle attachments	+ 4 speed increasing contra-angle attachments

Results

The cost of the individual handpieces, handpiece motors, and attachments for the two electric motor handpieces and the air turbine control are listed in table 15. Using this data, the cost of a “four handpiece set” was also calculated. The lowest possible price for an electric system was determined by utilizing the interchangeable components from both electric motor manufacturers.

Table 15. Government price for individual dental handpiece components and of dental handpiece systems.

	KaVo	Bien-Air	Electric hybrid	Midwest
Motor/handpiece	\$600	\$650	\$600	\$560
Speed increasing contra-angle	\$649	\$432	\$432	-NA-
Slow speed motor	-NA-	-NA-	-NA-	\$829
Speed increasing contra-angle	\$606	\$489	\$489	\$226
System cost	\$5620	\$4334	\$4284	\$3973
% price difference from air turbine system	+41.5%	+9.1%	+7.8%	-NA-

Discussion

At first glance, the electric motor handpiece systems appear to be significantly more expensive than the air turbine system. However this cost is not a life cycle cost. A more accurate estimate of the cost of a dental handpiece system would be the cost per patient procedure. This would be calculated by the life cycle cost divided by the number of patients treated during the life of the system. Test results listed earlier in this study indicate that the electric motor handpieces have a significantly greater longevity than air turbine handpieces.

Conclusion

Placing electric motor handpieces in fixed facility military dental clinics for use in operative dentistry is not likely to result in a significant cost savings to the government. However, the cost of utilizing an electric motor dental handpiece instead of an air turbine handpiece in a portable field unit should significantly decrease costs to the government. Portable treatment units that utilize air turbine handpieces cost approximately the same as portable treatment units that utilize electric motor handpieces. However there will be a significant cost savings in support equipment. The electric motor unit will operate on less than 1 kilowatt of

power, eliminating the need for a five-kilowatt trailer mounted generator. This will save 2700 pounds and one vehicle per forward dental treatment team (one dentist).

Further studies should be conducted to determine if the electric motor handpiece and attachments could be substituted for the surgical handpiece.

V. CLINICAL PARAMETERS

L. Clinician survey

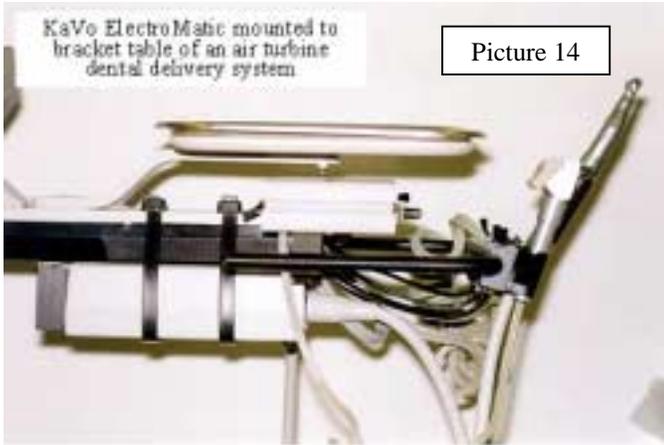
Introduction

Laboratory testing is important, but it is also important for clinicians to accept any new piece of dental equipment. Although electric motor dental handpieces have a large share of the European marketplace, there were no published reports on the acceptability of electric motor dental handpieces for operative dentistry in the U.S.

Methods and Materials

The USADRD provided electric motor handpieces and attachments to several military dental clinics. There are several systems that will convert a conventional air turbine operator into an electric dental motor operator. One of the following adapter systems were utilized for this study: KaVo Combident (KaVo of America, Lake Zurich, IL), KaVo ElectroMatic (KaVo of America, Lake Zurich, IL), ADEC Adapter (ADEC Inc. Newberg, OR) and the Bell Converter (Bell Dental Products, Denver, CO) (See Pictures 12-15). All of these systems are fiberoptic capable. Both the ADEC and Bell systems utilize the Bien-Air electric motor handpiece.





120-volt current powers the electric dental motor in these “adapter systems”. A high-speed handpiece hose is connected to the adapter to provide the cooling air and water. In the KaVo Combident, a separate electric motor rheostat controls motor speed, water spray, motor speed control, and motor on/off. The ElectroMatic and Bell Converter utilize the operator’s air rheostat to control the motor on/off, with speed controls on the converter box mounted to the bracket table. The ADEC Adapter is a separate “mobile cart” with an independent rheostat for motor on/off and the speed control located on the cart.

The dentists were asked to treat healthy adult patients with at least two carious lesions of similar size and caries classification (I, II, III, IV, or V). At least one tooth was prepared using the electric motor handpiece and at least one other tooth was prepared with the air turbine currently used by the dentist. The dentist completed a survey form after every patient treated with the electric motor handpiece. The survey collected information about the dentist such as the number of teeth prepared with an electric handpiece, specialty training, years of practice, and gender. The dentists were asked to evaluate the handpiece, not the adapter system. They evaluated the electric handpiece and their air turbine handpiece based on twelve performance characteristics. These characteristics were graded on a seven-point scale.

1. The size of the head of the handpiece related to the operator's visibility of the tooth.
2. The quality of the fiberoptic lighting.
3. The general feel (balance, length, weight) of the handpieces.
4. The amount of vibration produced by the handpiece during the procedure.
5. The ability of the practitioner to control the movement of the handpiece.
6. The quality of the coolant water spray (aim and control).
7. The level of noise produced by the handpiece.
8. The ease of changing burs in the handpiece.
9. The ease of changing handpiece attachments on the motor.
10. The cutting efficiency of the handpiece on tooth structure, amalgam, composite resin, acrylic and metal or porcelain fixed prosthetics.
11. The ability to control the handpiece to create a precise margin.
12. The overall operation of the handpiece.

After the procedure, patients were also questioned to determine if they could discern a difference between handpiece #1 and #2. If a difference was noted, the patient was asked which handpiece would be preferred if another procedure was required.

Results

The dentists used the electric motor handpieces for operative procedures between 6 and 20 times. If at any time they felt uncomfortable using the electric motor they were encouraged to stop the comparison. Table 16 plots the experience of the dentist with electric handpieces against the rating the dentist gave the air turbine handpieces. The difference between the numerical ratings for the handpieces was determined. Zero is neutral or equal ratings, a positive number

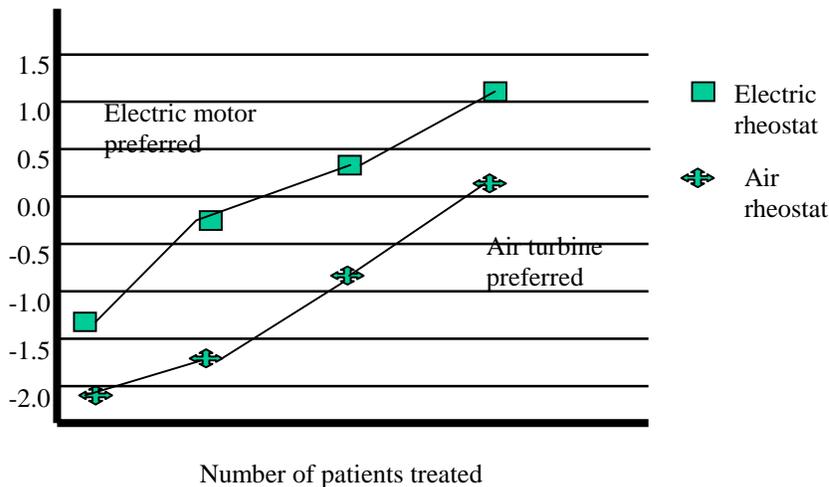
means the electric motor rated higher, and a negative number means the air turbine rated higher.

Table 17 lists several of the performance parameters and demonstrates how the ratings of certain handpiece performance parameters changed with experience.

Table 16. Clinician Evaluation of handpiece performance characteristics based on experience using electric handpieces. “E” indicates the electric motor handpiece was preferred, “A” indicates the air turbine was preferred, “-“ indicates no preference.

Number of clinical procedures performed with electric handpiece	<4	4-7	8-11	>11
Ability to control	A	A	-	A
General feel	A	A	A	-
Fiberoptic quality	E	E	E	E
Noise level	E	E	E	E
Handpiece vibration	A	-	E	E
Visibility of tooth	A	A	A	A
Water spray	E	E	E	E
Overall preference	A	A	-	E

Table 17. Handpiece Preference versus Clinical Experience with the Electric Handpiece.



Discussion

A tabulation of the surveys indicated the following:

1. Practitioner acceptance of an electric handpiece increases with an increasing level of clinical experience with the handpiece.
2. Practitioner acceptance of electric handpiece is greater when delivery system uses an electric motor rheostat instead of an air turbine rheostat.
3. There were no significant differences in clinician acceptance among the electric motor handpieces.
4. After a learning curve of eleven patients, 82.1% of the dentists rated the electric handpiece as equal to or better than their air turbine handpiece.
5. After a learning curve of eleven patients, 64.3% of the dentists utilizing the electric motor and rheostat would purchase the system if the cost per patient procedure were approximately equal to the air turbine.
6. 48% of the patients preferred the electric handpieces, 18% preferred the air turbine handpieces, and 34% had no preference.

Conclusion

Based on these results, it is anticipated that if a fiberoptic capable, internal air-water coolant spray electric motor dental handpiece were incorporated into a portable field dental treatment and operating system, that handpiece would be acceptable to military dentists.

VI. HANDPIECE STUDY CONCLUSION

This evaluation was a necessary phase of the research and development of a new lightweight field dental treatment and operating system. Before a new dental treatment system utilizing electric motor could be developed, it had to be determined that the electric dental motor with fiberoptic capability and internal air-water coolant spray was a suitable replacement for the air turbine handpiece.

Based on this evaluation, USADRDR determined that the desired characteristics of an electric motor dental handpiece are:

1. Internal air-water coolant spray line.
2. Fiberoptic capability.
3. A tachometer to display rpm speed of motor. In addition the system should be capable of providing the speed with various gear ratio attachments.
4. An audible warning that will sound when motor is placed in reverse.

To summarize the findings:

1. Longevity: The longevity of the electric motor dental handpiece is significantly better than the longevity of the air turbine handpiece.
2. Power/ cutting efficiency: Laboratory tests indicate that the electric motor dental handpiece has a higher cutting efficiency than the air turbine handpiece. This may not be clinically significant. It is possible that the dentists have learned to remove tooth structure at a certain “speed” and some dentists are not taking full advantage of the increased torque of the electric motor. Further studies may be needed to determine if dentists will

take advantage of the increased torque as they become accustomed to the electric motor handpiece.

3. Effect on pulpal thermal states: The electric motor handpiece with its increased cutting efficiency and ability to cut tooth structure at a greater applied force than the air turbine handpiece does not create an increased thermal hazard to the pulp than the air turbine handpiece.
4. Air exhaust: This data suggests that the electric motor may be suitable for dental-alveolar surgical procedures. The handpiece has sufficient torque, and the measured air exhaust is negligible. This data also suggests that the electric motor handpiece with a contra-angle attachment may be suitable for dental-alveolar surgical procedures if the air-water spray is turned-off and a separate irrigation syringe used. It may be possible to substitute this handpiece for a surgical Hall or Stryker drill in some instances.
5. Aerosol production: Final analysis of the data indicates that the electric motor handpiece does not generate more aerosol contamination than the air turbine. One test indicates that the aerosol production from the electric motor handpiece is significantly less than the production from the air turbine handpiece.
6. Noise production: The electric motor dental handpiece is significantly quieter than the air turbine handpiece. The reduced noise of the electric motor handpiece may minimize the NIHL risk in a clinical setting. In a field setting, a field treatment and operating system that combines a quieter handpiece and HVE with a reduced need for portable generator power will create a quieter work environment for the forward deployed treatment teams.
7. Speed in revolutions per minute: The electric motor handpieces did not demonstrate a significant loss in speed after 1000 simulated clinical uses and sterilizations. A significant

decrease in the bur speed of the air turbine handpiece was noted, although a similar USAF DIS study did not detect significant decrease in the bur speed for this air turbine handpiece.

8. Fiberoptic transmission: The ability of the fiberoptic rod in the electric motor handpieces to transmit light after 1000 clinical uses is significantly better than the ability of the tested air turbine handpiece. However, this is not a result of the handpiece type but a result of the type of fiberoptic rod in the handpiece. It must be noted that there are air turbine handpieces currently available that utilize the same type of rod found in these electric motor handpieces.
9. Dependability of chuck mechanisms: None of the handpieces experienced a chuck mechanism failure. There is no statistical difference in bur length among the three tested handpieces.
10. Static parameters (size and weight): The size and weight of the electric motor handpiece are significantly greater than the size and weight of the air turbine handpieces. Results of a clinical survey, listed later in this report, indicate that the increased size and weight are not clinically significant.
11. Price: Placing electric motor handpieces in military dental clinics for use in operative dentistry is not likely to result in a significant cost savings to the government. However, the cost of utilizing an electric motor dental handpiece instead of an air turbine handpiece in a portable field unit should significantly decrease costs to the government.
12. Clinician acceptance: Based on these results it is anticipated that if a fiberoptic capable, internal air-water coolant spray electric motor dental handpiece were incorporated into a portable field dental treatment and operating system, that handpiece would be acceptable to military dentists.

13. Neurological effects: As a group, dentists have a higher rate of neurological symptoms in their hands than the average population. Recent studies indicate that these symptoms are not caused by traditional vibrating handpieces, but by repetitive hand grip, abducted shoulders, flexed spine, and rotational body movements.⁶⁰ Therefore use of the electric motor instead of an air turbine motor is not expected to cause additional long-term neurological problems for the military dentist.

The electric motor performed as well as or better than the air turbine handpiece in at least ten of the twelve performance parameters.

VII. APPLICATIONS OF STUDY TO FIELD DENTISTRY

This study indicates that electric motor dental handpieces utilized in dental field treatment systems offer several advantages.

1. There is significant reduction in the need for compressed air. Compressed air needed for the electric motor coolant spray could be supplied with an external compressed air source (manual pump, electric pump, and compressed air cylinder).
2. There is less noise produced by the electric motor handpiece and the principle source of noise in the DTF, the dental compressor, is eliminated.
3. The electric motor handpiece can be used in dental-alveolar surgical procedures. This will eliminate the need to have a separate surgical handpiece with treatment team.
4. A separate slow speed handpiece is not required for the treatment system.
5. There is a significant reduction in the need for generated power, which means significantly less cube and weight requirements for each dentist. The acquisition of an electric motor handpiece portable field dental treatment system will allow the Forward Dental Treatment Teams (FDTT) to reduce their weight by 2700 pounds. This is calculated on the weight of the five-kilowatt generator and trailer. The FDTT could be powered by a two-kilowatt diesel generator that is presently in the military procurement system or by rechargeable batteries.
6. According to the Directorate of Combat Developments, the Forward Dental Treatment Sections (FDTS) will lose 50% of their transportation assets (3 of the 6 M998 vehicles and 3 of the 6 generators and trailers). This will reduce the mobility of the FDTS from 100% to 50%.⁶¹ The acquisition of an electric motor handpiece portable field dental treatment system in combination with the handheld x-ray, digital radiography laptop

computer, lightweight dental chair, lightweight operatory light may enable the FDTS to be 100% mobile with 50% of its present transportation assets.

7. The principle disadvantage of most electric motor field dental treatment and operating systems is that the compressed air capabilities will not directly support a sonic scaler. This may be a minor inconvenience, and scaling can be performed with hand instruments. However most of the patient population will be dental readiness class I and II and should not have heavy calculus deposits on their teeth. It will be possible to support a sonic scaler with an electric motor system, but the electrical requirements of the treatment system will increase.

IX. Footnotes

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- ¹ FM 8-10-19. Dental Support in a Theater of Operations. U.S. Army Academy of Health Sciences. San Antonio TX. 1995
- ² Gennaro R. Electric Motor Handpieces. Dental Products Report. Dec 97.
- ³ Longevity and Performance Evaluation of Nine Commercially-Available Dental High-Speed Handpieces. USAF Dental Investigative Service. Brooks Air Force Base. Sep 98.
- ⁴ Kuehne J. Longevity and Performance of Autoclavable High-Speed Handpieces. USAF Dental Investigative Service. Aug 1993.
- ⁵ Worthington L, Martin M. An Investigation of the Effect of Repeated Autoclaving on the Speed of Some Dental Turbines in General Dental Practice. *Journal of Dentistry*. 1998;Vol.26(1):75-77.
- ⁶ Wirthlin M, et al. The Performance of Autoclaved High-Speed Dental Handpieces. *JADA*. 1981;Vol.103:584-587.
- ⁷ Longevity and Performance Evaluation of Nine Commercially-Available Dental High-Speed Handpieces. USAF Dental Investigative Service. Brooks Air Force Base. Sep 98.
- ⁸ Accuratus Ceramic Corporation. Washington NJ
- ⁹ Special Report: Results of a Workshop on Handpieces and Other Instruments in Dentistry. *JADA* 1992;Vol 123:44-47.
- ¹⁰ Longevity and Performance Evaluation of Nine Commercially-Available Dental High-Speed Handpieces. USAF Dental Investigative Service. Brooks Air Force Base. Sep 98.
- ¹¹ Brockhurst P, Shams R. Dynamic Measurement of the Torque-Speed Characteristics of Dental High Speed Air Turbine Handpieces. *Australian Dental Journal*. 1994;Vol.39(1): 33-38.
- ¹² Leonard, Dan. Oct 1997.
- ¹³ Siegel S, von Fraunhofer J. Dental Cutting with Diamond Burs: Heavy-Handed or Light Touch. *Journal Prosthodontics*. Mar 1999;Vol. 8(1): 3-9
- ¹⁴ Siegel S, von Fraunhofer J. Assessing the Cutting Efficiency of Dental Diamond Burs: *J Am Dent Assoc* 1996; Vol. 127:763-772.
- ¹⁵ Ibid.
- ¹⁶ Eames WB, Nale J: A Comparison of Cutting Efficiency of Air Driven Fissure Burs. *J Am Dent Assoc* 1973; Vol. 86:412-415.
- ¹⁷ Semmelman J Kulp P Kurlansik L. Cutting Studies at Air Turbine Speeds. *J Dent Res* 1973; Vol. 52(5):1138-46.
- ¹⁸ Siegel S von Fraunhofer J. Assessing the Cutting Efficiency of Dental Diamond Burs: *J Am Dent Assoc* 1996; Vol. 127:763-772.
- ¹⁹ Naylor W Nova Disposable Diamond Instruments. USAF Dental Investigative Service. 1990. Project no 90-39U.
- ²⁰ Siegel S von Fraunhofer J. Assessing the Cutting Efficiency of Dental Diamond Burs: *J Am Dent Assoc* 1996; Vol. 127:763-772.
- ²¹ Gureckis K, Burgess J, Schwartz R. Cutting Effectiveness of Diamond Instruments Subjected to Cyclical Sterilization Methods. *J Prosthet Dent* 1991; Vol.66(6):721-6
- ²² Bleiholder R, Rosenstiel S, et al. A Laboratory Performance Test for Dental Rotary Instruments. *J Dent Res* 1987; Vol. 66:1746.
- ²³ Zack L, Cohen G. Thermogenesis in Operative Techniques. *J Prosth Dent*. Sep-Oct 1962; Vol.1(2):977.
- ²⁴ Bhaskar S, Lilly G. Intrapulpal Temperature Changes During Cavity Preparation. *J Dent Res* July-Aug 1965.Vol.44:644.

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- ²⁵ Baldissara, Pcatapano S, Scotti R; Clinical and Histological Evaluation of Thermal Injury Thresholds in Human Teeth: A Preliminary Study. *Journal of Oral Rehabilitation*. 1997; Vol. 24;791-801.
- ²⁶ Mahon W, Hembree J, et al. The Influence of Ultra Speed Cutting Instruments and Coolants on In Vitro Intrapulpal Temperature Changes During Cavity Preparation. *Jour of Tenn Dental Assoc*. Vol. 61(1):13-17.
- ²⁷ Vukovich, Wood, Daley. Heat Generated by Grinding Ceramic Brackets. *Am J Orthod Dentofac Orthop*. Jun 1991; Vol. 99(6).
- ²⁸ Ottl P, Lauer H. Temperature Response in the Pulpal Chamber During Ultrahigh Speed Tooth Preparation with Diamond Burs of Different Grit. *J of Prosth Dent*. July 1998;Vol. 80(1).
- ²⁹ Zack L, Cohen G. Pulp Response to Externally Applied Heat. *J Prosth Dent*. Apr 1965.Vol. 19(4):516-30.
- ³⁰ Tjan A, Grant B, Godfrey M. Temperature Rise in the Pulp Chamber During Fabrication of Provisional Crowns. *J Prosth Dent* Dec 1989, Vol. 62(6):622-626.
- ³¹ Hatton J et al. Effect of Handpiece Pressure and Speed on Intrapulpal Temperature Rise. *Amer Jour of Dent*. Apr 1994. Vol.7(2).
- ³² Kocher T, Plagmann H. Heat propagation in dentin During Instrumentation with Different Scaler Tips. *Quintessence International*. 1996. Vol. 27(4).
- ³³ Bavinger J. Subcutaneous and Retropharyngeal Emphysema Following Dental restoration. *Annals of Emergency medicine* 1982;11:7
- ³⁴ Bodai C, DiFiore P. Subcutaneous Emphysema in Dental Practice. *General Dentistry*. Jul-Aug 92.
- ³⁵ Bell Dental Products
- ³⁶ Shaw D, Krejci R, Dyer J. Airborne Contamination Produced by Electrosurgery. *General Dentistry* Jul-Aug 1994.
- ³⁷ Blount J. A Look at Aerosol Contamination During Dental Procedures. *Dentistry* Feb 1996.
- ³⁸ Blount J. A Look at Aerosol Contamination During Dental Procedures. *Dentistry* Feb 1996.
- ³⁹ Miller R, Micik R. Air Pollution and its Control in the Dental Office. *Dental Clinics of North America*. July 1978;Vol.42(3):453-76.
- ⁴⁰ Micik R, et al. Studies on Dental Aerobiology. Bacterial Aerosols Generated During Dental Procedures. *J Dent Res* 1969;48:143-8
- ⁴¹ Earnest R, Loesche W. Measuring Harmful Levels of Bacteria in Dental Aerosols. *JADA*. Dec91;Vol. 122:55-57
- ⁴² Coles R, Hoare N. Noise Induced Hearing Loss and the Dentist. *Occupational Medicine*. 1985;Vol.159:209-218.
- ⁴³ Lehto T. Dentist's Hearing and Exposure to High Speed Turbine Dental Drill Noise. *Finnish Dental Society*. 1990;Vol. 86(3-4).
- ⁴⁴ Wilson T, et al. Hearing Damage Risk and Communication Interference in Dental Practice. *J Dent Res*. Feb 90; Vol. 69(2):489-493.
- ⁴⁵ Setcos J, Mahyuddin A. Noise Levels Encounters in Dental Clinic and Laboratory practice.. *International Journal of Prosthodontics*. 1998;Vol. 11(2):150-157.
- ⁴⁶ Rapp G. Some Physiologic Response to Highspeed Handpiece Noises. *Dental Digest* 1971;137-140.
- ⁴⁷ Wilson T, et al. Hearing Damage Risk and Communication Interference in Dental Practice. *J Dent Res*. Feb 90; Vol. 69(2):489-493.
- ⁴⁸ Essential Characteristic for the Dental Field Treatment System. *Defense Service Center-Philadelphia*. June 1997.

-
- ⁴⁹ Bahanna S, El-Hamid A, Bahnassy A. Noise Level of Dental Handpiece and Laboratory Engines. *Journal of Prosthetic Dentistry*. Oct 93;Vol.70(4):356-360.
- ⁵⁰ Setcos J, Mahyuddin A. Noise Levels Encounters in Dental Clinic and Laboratory practice.. *International Journal of Prosthodontics*. 1998;Vol. 11(2):150-157.
- ⁵¹ Masayuki T, et al. Comparison of Rotational Speeds and Torque Properties Between Air-Bearing and Ball-Bearing Air Turbine Handpieces. *Dental Materials Journal*. 1989;Vol.8(1):26-34.
- ⁵² Longevity and Performance Evaluation of Nine Commercially-Available Dental High-Speed Handpieces. USAF Dental Investigative Service. Brooks Air Force Base. Sep 98.
- ⁵³ Dyson J, Darvell B. Dental Turbine Handpiece Testing. *Australian Dent Journ* 1995;40(5):330-8.
- ⁵⁴ Longevity and Performance Evaluation of Nine Commercially-Available Dental High-Speed Handpieces. USAF Dental Investigative Service. Brooks Air Force Base. Sep 98.
- ⁵⁵ Ibid.
- ⁵⁶ Ibid.
- ⁵⁷ Dyson J, Darvell B. Aspects of the Design of Modern Dental Air Turbine Handpieces. *Australian Dent Journ* 1993;Vol.38(6):446-70
- ⁵⁸ International Standard 7785-1:1992. Dental Handpieces Part 1: High-Speed Air Turbine Handpieces. Geneva:International Standards Organization1992.
- ⁵⁹ International standard-7785-1:1992. Dental Handpieces, Part 1. High Speed air turbine Handpieces. Geneva: International standards Organization, 1992.
- ⁶⁰ Ekenvall L Nilsson B, Falconer C. Sensory Perception in the Hands of Dentists. *Scandanavian Journal of Work and Environmental Health*. 1990;16:334-9.
- ⁶¹ Dental Branch Briefing. Directorate Combat Developments Division. Hospital-Integrated Concept Team Panel. San Antonio, TX. April 1998.