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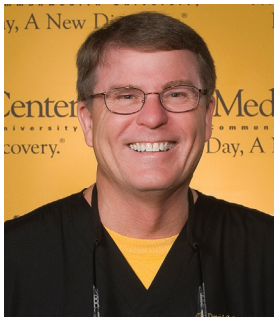

Millions of resin restorations and light-cured sealants are placed each year and curing lights are essential for those procedures. But how can you be certain that your curing light delivers the correct irradiance, exposure patterns and spectral emission to safely cure a resin-based restoration so that it performs as the manufacturer intended? To address these common concerns, this issue features "Effective Use of Dental Curing Lights: A Guide for the Dental Practitioner," a series of short articles by several key opinion leaders. Whether you've used curing lights for more than two decades as I have, or you're fresh out of dental school, the articles can help you optimize your light-curing technique. You may be surprised that such a common technique as light-curing of resin materials can be so negatively affected by very common issues.

Besides curing lights, high-speed dental handpieces are another staple for most dental practices. The Review published laboratory evaluations of several brands in the past, but handpiece manufacturers continue to refine their products, making modifications and improvements to address dentists' needs and preferences.

For this issue, the ADA Laboratories evaluated two disposable handpieces—the Azenic DHP from Azenic, Inc., (Kalamazoo, MI), and the Hi-Speed Turbine Handpiece for Single Use-GSY Series from NPH USA, Inc. (Orlando, FL). If you're wondering who would use a disposable handpiece, consider that these devices may be useful in clinical settings that present unusual operating conditions or challenging infection control situations where sterilization is not practical or cost-effective, such as remote or mobile clinics, medical missions or military field installations, or perhaps in a busy practice as a backup if no sterile reusable handpiece is available.

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Effective Use of Dental Curing Lights: A Guide for the Dental Practitioner

(Editor's Note: These articles are intended to be a resource and the views expressed are those of the authors and do not necessarily reflect the opinion or official policy of the ADA or its subsidiaries. The articles' contents are not a substitute for the dentist's own judgment.)

Abstract

Light-cured resin-based restorations will only function as the manufacturer intends when they have received the required amount of energy at very specific wavelengths. This means that the correct irradiance, exposure duration, and spectral emission must be delivered from the light curing unit (LCU). Unfortunately, every survey of LCUs used in dental offices has shown that many of these LCUs do not provide sufficient irradiance, and the light curing techniques used by many clinicians may be ineffective. In this review article, key opinion leaders present a wide breadth of international scientific expertise in the field of light curing. Clinically relevant guidelines are provided to help clinicians optimize their light-curing technique.

The American Dental Association 2005/6 Survey of Dental Services estimates that 146 million resin restorations and sealants are placed annually.[1] Almost all of these restorations use light-cured resin-based composites, hereafter referred to as RBCs. Thus, it follows that the light-curing unit (LCU) has become an indispensable piece of equipment in dental offices. While the focus of most research and education has been on choosing the appropriate RBC or LCU and on the proper handling of the restorative materials, little research has been published on the light-curing technique itself. Perhaps because light curing is perceived to be an uncomplicated procedure, the critical role of the LCU and the importance of using the proper light-curing technique are often not emphasized when teaching how to deliver successful RBC restorations. Many LCU's in dental offices deliver an inadequate output, therefore it is very likely that many RBCs placed in dental offices are undercured[2-7] and will never reach their manufacturers' intended properties.

A 2010 study using contemporary, properly functioning LCUs demonstrated that the clinician's technique when using the LCU can make a considerable difference to the amount of energy delivered to a restoration.[2] The research examined the ability of 10 dentists and 10 dental students to deliver an acceptable amount of energy (10 J/cm^2) to simulated restorations in a dental mannequin. Using the same LCU for the same exposure time, there was a large variation in energy delivery among the operators: 27% delivered less than 10 J/cm^2 of energy to the same Class I preparation and 82% delivered less than 10 J/cm^2 to a posterior Class V preparation. If we extrapolate this scenario to a wider group, the fact that so little energy was delivered, even when using correctly functioning LCUs, may explain why posterior resin-based restorations last only a median of 5 to 7 years,[8,9] when they could last 15 years or more.[10]

In the following sections, key opinion leaders present a wide breadth of international scientific expertise in the field of light curing. These short summaries reinforce the critical role of light curing in today's dental practice. Clinically relevant guidelines are provided to help clinicians optimize their light-curing technique so that they can safely deliver sufficient energy to their restorations. This should improve the likelihood that the RBC will achieve the manufacturer's intended properties, and thereby improve the long-term clinical success of photo-cured RBC restorations.

Why Delivering Sufficient Energy to RBCs Is Important

Jack L. Ferracane, *Professor and Chair, Restorative Dentistry Division Director, Biomaterials and Biomechanics, Oregon Health & Science University in Portland, Oregon*

Almost every day, dentists see RBC restorations that have signs of margin chipping or breakdown, bulk fracture, bulk and marginal discoloration, loss of anatomical form, lack of retention, or secondary caries. There is considerable evidence that delivering inadequate energy to the restoration will result in a restoration that has less than optimal properties and poor clinical performance. Thus, it is important to keep a few basic facts in mind:

Why RBC restorations fail and the relationship between light energy delivered and RBC properties

The most common reasons cited for replacement of light-activated RBC restorations are secondary caries and restoration fracture.[9-12] Other reasons include marginal breakdown and staining, wear, discoloration, pulpal death, and tooth fracture. It is well established that reduced levels of resin polymerization caused by delivering an inadequate amount of light, or light at the wrong wavelengths, will adversely affect many RBC properties.[13-26] The margin at the base (closest to apex of

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the tooth) of the proximal box in Class II RBC restorations is where secondary caries is most often found. In addition to being at risk because it is usually in dentin, this region is also the furthest from the LCU and often in the shadow of the matrix band or remaining tooth structure. Consequently, the resin at the base of the box will receive less light and energy than at the occlusal surface. To overcome this problem and ensure optimal resin polymerization, it is recommended to increase the exposure time when curing the initial layers of the RBC.[27] This may help to mitigate the following outcomes that have been reported when insufficient energy is delivered: reduced mechanical properties such as strength, stiffness, and hardness;[13,14] reduced wear resistance;[15-17] weaker bonding to the tooth;[28,29] increased "washout" of the RBC at the gingival margin;[25] increased bacterial colonization of the resin;[25] reduced color stability;[18,19] greater release of elutable substances (including bisphenol A[26,30]); and increased cytotoxicity.[20-24]

Relationship between laboratory results and clinical observations

Based on the abundance of in vitro scientific evidence, it is very possible that the poor clinical performance of many RBC restorations seen often by dentists is caused by the initial failure to adequately light cure the RBC restoration. This is supported by a clinical study in patients who had RBC restorations placed in the teeth of their dentures. The restorations had received variable amounts of light exposure times.[17] This study showed that after only two years of function, RBC restorations placed with a lower degree of cure showed significantly greater and clinically unacceptable occlusal wear (Figure 1).

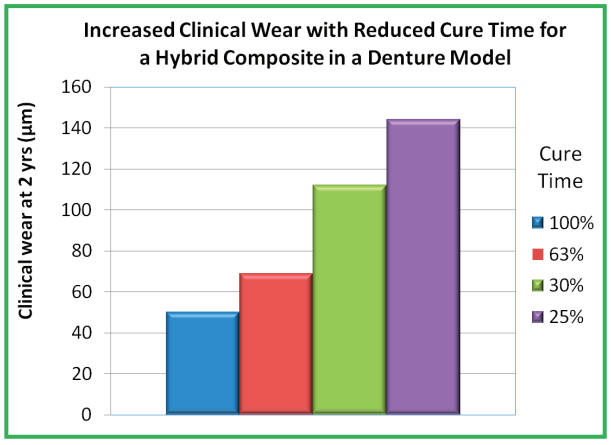

Figure 1. Increased clinical wear with a reduced cure time for a hybrid RBC in a denture model (adapted from Ferracane et al. 1997[17]).

Clinical Pearl: Based on many scientific publications, light-cured RBCs must receive adequate light energy to achieve their intended physical, chemical, and optical properties.

Matching Curing Lights to Resins

David C. Watts, *Professor of Biomaterials Science, Head of Research Group: Adhesive Biomaterials & Biomechanics, School of Dentistry, University of Manchester, Manchester, England*

To ensure that the RBC is optimally cured, dentists have a clinical responsibility to select and use RBCs and LCUs that are optimally matched.[31] However, with the wide range of RBCs and LCUs currently available, this is not an easy task. The irradiance from an LCU, also referred to as light intensity or power density, is usually expressed in units of mW/cm^2. The radiant exposure or energy density (E) received by the restoration is expressed in J/cm^2 and it is the mathematical product of the curing light irradiance (I in mW/cm^2) and the exposure time (t in seconds): E = I x t. Manufacturer-recommended exposure times are often understated because they are determined under ideal laboratory conditions.[32-35] However, the recommendations may not be clinically relevant because the amount of energy received by the RBC is greatly affected by the operator technique and the location of the restoration in the mouth.[2]

Ensuring that light wavelength output matches the restorative material's wavelength requirements

Currently, the most reliable types of LCU are the LED (light-emitting diode) units, but even these can vary considerably in their light output (irradiance) and they can deliver very different emission spectra.[36] There is also considerable variation in the chemical formulation, shades, filler types, and light-transmission characteristics of RBCs.[37-42] These differences mean that the light energy requirements and wavelengths necessary to activate the photoinitiators within different RBCs can, and do, vary significantly.[31, 32, 40, 42-45] Unfortunately, many dental RBC manufacturers do not indicate what specific wavelengths are required for optimal polymerization of their materials. General statements, such as the LCU should "deliver light in the 400 to 500 nm range of wavelengths," are not sufficiently specific because even small differences in the spectral emission from LCUs can affect their ability to polymerize RBCs.[36, 40, 41, 44, 46]

Since dental radiometers do not provide a readout of the spectral emission from the curing light, and few clinicians possess a laboratory grade spectroradiometer, clinicians can only know the spectral emission from their LCU based upon the limited information provided by the manufacturer.

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This lack of spectral information can make it very difficult for the clinician to match the LCU and exposure times to the RBC they are using. If the LCU is a quartz-tungsten-halogen unit (QTH), the range of wavelengths is sufficiently broad to adequately polymerize any dental RBC material. However, most LED or laser LCUs produce a very narrow spectral emission and are usually optimized to cure the commonly used camphorquinone photoinitiator that is most reactive to light at ~468nm.[36] Since some RBCs use alternative photoinitiators that require very different wavelengths (~410nm), it is possible to use an LED or laser unit that is not ideally matched to the RBC, and in some cases the RBC will not cure at all. Broadband LED units have been introduced that use two or more different colors of LED, meaning that their spectral output includes both blue (~460nm) and violet wavelengths (~410nm) of light. These broadband "polywave" LED units are designed for polymerizing RBCs containing both conventional and alternative photoinitiators.[40,43,44] If the dentist is using an RBC that does not include these alternative photoinitiators, a broadband LED unit is not needed, because light emitted at these lower wavelengths is less efficient in polymerizing resins that use camphorquinone. Since manufacturers are not currently required to indicate what specific wavelengths are necessary to optimally polymerize their materials, the clinician must make an educated guess to decide whether or not they should use a broadband LCU. If a resin manufacturer sells a polywave LED-LCU (emitting both blue and violet light), it is very likely that at least some of their products require a broadband LCU to optimally polymerize.

Light Curing Instructions

Some companies, e.g., Dentsply, provide extensive light curing charts indicating how long their LCU should be used to optimally polymerize their products. In one such chart, the same Dentsply LCU needs to be used for only five seconds (delivering 6 J/cm^2) with one type and shade of Dentsply RBC, whereas the same LCU must be used for 40 seconds (delivering 48 J/cm^2) with a different type and shade of RBC.[47] This range of 6 to 48 J/cm^2 in the energy required by different RBCs from just one company complicates light-curing for the clinician. Considerable variation can also be seen between nominally "equivalent" products from different manufacturers; an A2 shade from one manufacturer may require very different wavelengths and amount of energy compared to an A2 shade of another RBC.[33, 34, 37, 41, 48]

Clinical Pearl: Since light-cured RBC materials require the correct type (wavelength) and amount of light energy (J/ cm^2) to achieve their intended physical, chemical, and optical properties, resin manufacturers should indicate the parameters necessary to adequately polymerize their resins. Dentists can then match the LCU and the exposure time to the RBC they are using.

Ensure That Your LCU Is In Good Working Order

Nasser Barghi, *Professor, Department of Comprehensive Dentistry, University of Texas, School of Dentistry, University of Texas Health Science Center at San Antonio*
Claus-Peter Ernst, *Professor, Operative Dentistry, Johannes Gutenberg University, Mainz, Germany*

One potential reason why many RBC restorations are under-cured may be that the LCUs used in many dental offices worldwide do not deliver an adequate irradiance[34, 49] of at least 300 to 400 mW/cm^2.

Curing light surveys

In 1994, a survey was published on the irradiance values recorded from 209 LCUs in use in private practices in three North American metropolitan areas.[3] Thirty percent of the lights delivered irradiance values less than 199 mW/cm^2, and 16% provided irradiance values between 200 and 349 mW/cm^2. Only 54% of the LCUs delivered irradiance greater than 350 mW/cm^2. This study was repeated a decade later when a total of 161 LCUs in 65 dental offices located in two metropolitan areas of Texas were examined.[50] This time, nearly 10% of LCUs tested delivered an irradiance less than 250 mW/cm^2 and 77% of the LCUs had debris on the tip surfaces. These two studies show an overall improvement in irradiance between the two measurement times, but still, some lights demonstrated very low irradiance values, and a high proportion had resin debris on the tip end of the LCU.

A similar situation was reported in a 2006 study from Germany. The irradiance levels of 659 LCUs from 301 dental offices in the Rhine-Main-area were measured using laboratory grade equipment.[4] Seven percent of all LCUs emitted less than 200 mW/cm^2 and 26% delivered less than 400 mW/cm^2. Bonding agent or RBC contaminated 37% of the light guides, 5% of the tips showed damage, and 6% showed damage as well as contamination with resin (Figure 2). In England, 28% of the LCU's examined delivered less than 300 mW/cm^2, 47% of the LCUs were found to be damaged, and 35% of the LCUs had varying amounts of material adherent to the light guide.[5] Forty-eight percent of the LCUs tested in

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Brazil[6] delivered less than 200 mW/cm^2, while in Canada[7] 12% of 214 LCUs emitted less than 300 mW/cm^2. The results from Saudi Arabia found that the recorded mean irradiance values from QTH and LED devices were 260 mW/cm^2 and 598 mW/cm^2, respectively. The percentage of QTH devices and LED devices considered unsatisfactory was 67.5% and 15.6%, respectively.[51]

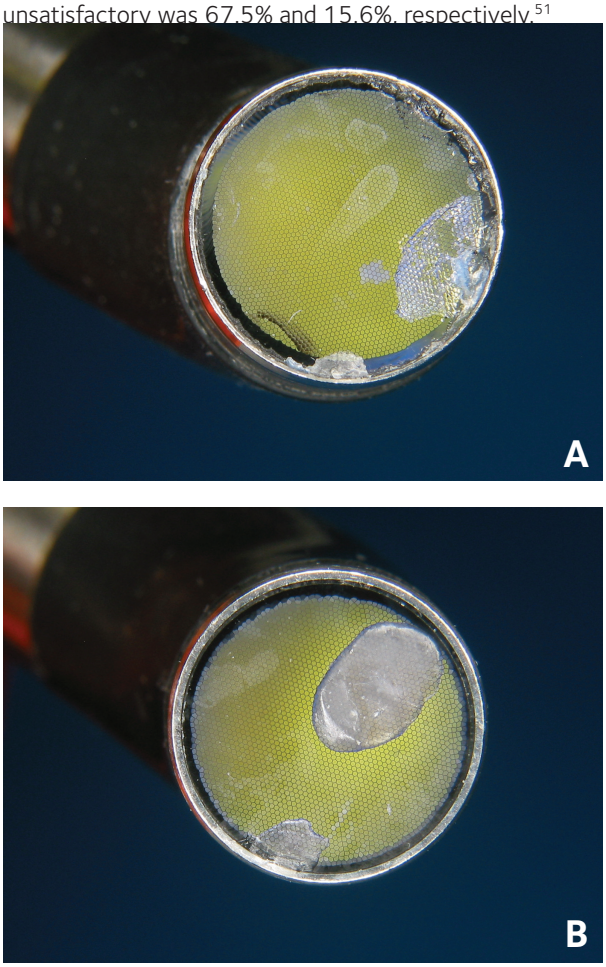

Figure 2. Examples of a damaged light guide (A), and one with resin-based composite adhering to the tip (B).

Clinical Pearl: Clinicians should monitor the output from their LCUs using a radiometer on a regular basis to ensure that the LCU is functioning optimally, and take appropriate steps to remove adherent resin from tip-end-surfaces.

Potential Health Problems Related to Light Curing

Frederick A. Rueggeberg, *Professor and Section Director of Dental Materials, Department of Oral Rehabilitation, College of Dental Medicine, Georgia Regents University, Augusta, Georgia*

Light curing generates heat.[52-55] In 2012, three clinical cases were reported where one brand of LED curing light may have caused burns to the lips.[56] The authors recommended that no soft tissue should be near the tip of the curing light. It was also reported that even when covered by a rubber dam, this offered no significant protection to soft tissue. They recommended that the LCU should be activated over the RBC material only and to place gauze under the rubber dam to reduce heating the soft tissues underneath. The potential for causing a soft tissue burn may be exacerbated if clinicians arbitrarily use exposure durations in excess of those recommended by the manufacturer in an attempt to ensure that their RBC restoration has received sufficient light energy. Although this effort is well intended and hopes to achieve optimal properties in the RBC restoration, it can also cause an excessive increase in intrapulpal temperature, because of the extra energy delivered to the tooth. Clinicians are taught to prepare vital teeth using adequate water coolant thus avoiding unnecessary thermal trauma to the pulp that can cause post-operative sensitivity or pulpal pathosis. For the same reason, they must also take steps to avoid overheating the tooth when using the curing light.

What is an unacceptable temperature increase?

Based on animal experiments, one study reported that an increase of 5.5° C in intrapulpal temperature resulted in a 15% increase in pulpal necrosis of Rhesus monkey teeth.[57] The potential for temperature increase is related to the photo-thermal heat generation that occurs when a material absorbs photons of light, the total energy delivered, and to the exothermic polymerization reaction as the resin cures.[58]

Can curing lights cause an unacceptable temperature increase?

Many publications show that this potential is very real.[44,52-54,59-65] The greater the irradiance of the LCU and the longer the exposure duration, the greater the potential for temperature rise within the pulp and adjacent soft tissues. Increased temperature is of concern especially in a deep preparation, where there is a minimal

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insulating effect from the overlying dentin.[52-55,59] When the first generation of LED-LCUs was introduced, it was often claimed that they did not produce any temperature rise in the pulp;[53,66,67] a marketing benefit over other LCUs. However, this lack of temperature increase occurred because of the very low irradiance from these early LED units. The irradiance from LED units has now surpassed that from plasma arc (PAC) units, so the potential for generating damaging temperatures in pulpal and gingival tissues has also increased and is once again a topic of concern.[52,56,63,64]

Testing for temperature increase

Patients, who are often anaesthetized, cannot be relied upon to indicate if their tissues are getting too hot. Currently there is no practical method of monitoring the temperature rise caused by the LCU in the mouth. However, dentists can shine the LCU on the back of their own hand for the same exposure times they use on their patients. This will provide some idea of the potential for temperature rise in the mouth from their LCU.

A solution for preventing undesirable temperature increases

Directing a stream of air across the tooth immediately before, during, and after light exposure, will minimize intrapulpal temperature rise.[60] The air stream can be generated using an air-water syringe, or from a high speed suction tip held close to the coronal part of the tooth.

Protect your eyes from the blue light hazard

The light from LCUs can be very dangerous to your eyes.[68-70] The most damaging wavelength for the retina is blue light, near 440 nm, which is within the spectral emission from dental LCUs.[71,72] Blue light is transmitted through the ocular media and absorbed by the retina. While high levels cause immediate and irreversible retinal burning, chronic exposure to low levels of blue light causes retinal aging and degeneration.[68] This chronic photochemical injury to the retinal pigmented epithelium and choroid may accelerate age-related macular degeneration (ARMD).[72-74] To minimize ocular health risks, the operator should wear protective glasses, the so-called "blue-blockers." These glasses can significantly reduce the transmission of light below 500 nm to less than 1%.[75-77] This level of filtering allows the operators to safely watch what they are doing when light curing and helps clinicians ensure that their light-curing technique is optimal.[2,78,79]

Clinical Pearl: Light emitted from dental LCUs may result in potentially harmful increases in intrapulpal or soft tissue temperatures. Measures should be taken to reduce this hazard. Clinicians should also take precautions to protect the eyes of the patient, operator, and assistant from potential permanent ocular damage from the LCU.

Selecting and Using a Light Curing Unit (LCU)

Adrian Shortall, *Reader in Restorative Dentistry, School of Dentistry, University of Birmingham, St. Chad's Queensway, Birmingham, England*

Choosing a new LCU for the dental office is a challenge. Dental manufacturers currently market a plethora of sophisticated devices delivering increasingly higher irradiance values and having multiple light exposure options (e.g., soft start, pulsed, low, high, and turbo modes). The following are some of the factors that should be considered when selecting a new LCU that will adequately cure the RBC in the shortest time, while minimizing shrinkage stress and optimizing the clinical longevity of the restoration.

Is fast curing or "soft-start" essential?

Some manufacturers market very powerful LCUs that claim adequate curing after only a 5- or even a 1-second[80] exposure, but longer exposure times may be more realistic.[48,65,81-83] When manufacturers recommend exposure times, their values are often based on laboratory testing under ideal circumstances with the LCU in very close proximity to the RBC being polymerized. Clinically, these conditions may not be possible. Therefore, to be confident that they are delivering the required amount of energy, dentists must know the irradiance of the LCU at the distance between the LCU and the RBC they are attempting to light-cure. In addition, dentists need to consider the clinical relevance of the evidence claiming that soft-start, stepped, ramped, or pulse-delay light-curing techniques will reduce polymerization stress or improve clinical performance.[83-90] Current information indicates that any benefit from using these alternative exposure modes is highly dependent on the specific RBC used, the LCU, and the clinical situation.[91-97]

Size and location of the intended polymerization area

Turbo light guides may deliver more irradiance at the light tip, but the dispersion of light emitted from these guides is greater than that from standard light guides.[31,98-101] Often a standard light guide will provide significantly greater irradiance and, consequently, better resin curing[14,91,100,103] at clinically relevant distances than a turbo tip.[102] Also, the dentist should ensure that the light tip delivers a sufficiently wide beam to cover all of the intended polymerization area with light at the required wavelengths. This is especially relevant when using broadband 'polywave' LED curing lights that deliver

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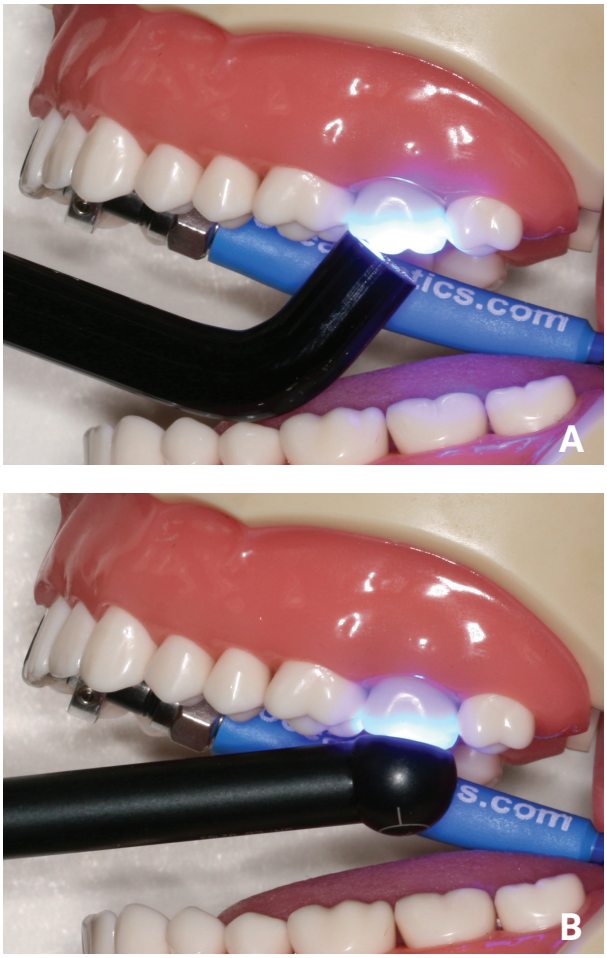
a spatially and spectrally inhomogeneous light output across the light tip.[99,104] Such light beam inhomogeneity has been reported to result in inhomogeneous resin polymerization.[101] When a small turbo tip is used to boost irradiance values, it may be necessary to use multiple exposures, whereas using a light tip large enough in diameter to cover the whole restoration may require only one slightly longer exposure. With these broad requirements, dentists can choose between different LCUs by considering some of the following factors.

Irradiance over distance

In some LCUs, the irradiance may be high close to the tip, but it declines very rapidly as the distance from the tip increases,[31,81,98,100, 101,103,105,106] potentially adversely affecting the resin polymerization[14,91,100,103] and other properties previously discussed.[13-17,19-24, 26,28-30] This is clinically relevant because the distance between the cusp tip and the base of the interproximal box can often exceed 7 mm.[98,107] To help the practitioner determine the ability of their LCU to cure their RBC at clinically relevant distances, Rueggeberg et al. have described a simple modification of the depth-of-cure "scrape" test.[32] Cutting off the end of a resin compule and light curing the resin at a typical operating distance from the surface of the resin allows the clinician to determine the depth of cure achieved by their light source and radiation protocol.[32]



Figures 3: A and B. The tip in Fig. A does not allow straight-line access of the light guide to the restoration area, especially where mouth opening is limited. The tip in Fig. B allows a light straight-line access, and is thus potentially much more effective.

Intraoral ergonomics

Light does not bend around corners. The clinician needs to check whether the LCU tip can effectively reach the more difficult locations in the mouth, especially for patients with limited mouth opening or those who cannot keep still (e.g., children or elderly), and that the light tip has a straight-line access to the RBC surface. Figure 3 illustrates how a commercial photocuring training/measuring device (MARC™, Managing Accurate Resin Curing; BlueLight Analytics Inc., Halifax, Nova Scotia, Canada)[108] can be used to measure the irradiance and energy density delivered by different LCU tip designs to a simulated restoration. Here the effect of light-guide positioning and accessibility to the operative area on the energy delivered is measured using a clinically relevant simulation.

Infection control method

The best practice from a cross-infection viewpoint is met by LCUs that feature removable, autoclavable light guides and easily disinfected surfaces. However, autoclaving light guides may produce "boiler scale" over the tip that reduces light output. This scale can be removed by polishing the tip end. Some current disinfection solutions may harm the light-transmitting ability of glass-fibered light guides.[109] Other surface disinfectants may degrade the LCU's plastic case, lenses, reflectors, fiberoptic light guide, and electronics over time,[110] so care should be taken to use the appropriate disinfectant. Textured, non-watertight (non-blistered) activation buttons are particularly difficult to clean, and can absorb fluids and retain microbes between the button and the LCU body. To prevent cross-infection, a barrier can be used to cover the entire LCU. Several manufacturers provide disposable, plastic infection control barriers as an effective means of protection for both the unit as well as the light guide. Although these barriers do not significantly affect spectral distribution, the irradiance is reduced,[111,112] especially if the seam of the barrier lies across the light tip.

Maintenance of output over time (robustness)

While it is well recognized that the output from quartz-tungsten-halogen units changes as the light source and filter age, the output from LED units may also decline with age or misuse. Although hand-held dental radiometers are inaccurate,[113-117] and do not report the spectral emission from the LCU, they can be of practical benefit when used to monitor the relative performance of the same LCU/light guide combination over time. Dentists should maintain a logbook for each LCU from the date of purchase so that they can monitor its relative

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performance over time. Exposure durations can be adjusted to accommodate for a decrease in output to deliver similar energy levels as when the LCU was new. This information, coordinated with in-office performed depth-of-cure scrape tests using light and dark shades of the dentist's favorite RBC light cured at clinically relevant distances, will help ensure optimal and predictable light-curing results. A hand-held radiometer can also be used to test the extent to which an infection control barrier reduces the output from the LCU, and adjustments to the exposure time can be made accordingly.[111,112,118]

Clinical Pearls: Clinicians should be aware that the claimed benefits of the various light exposure modes have yet to be proven clinically. Routinely recording the irradiance values can help identify any degradation in light output from the LCU. If a barrier is used, irradiance measurements should be taken with the barrier in place. This will enable the clinician to calculate the longer exposure durations required to compensate for any decrease in irradiance.

MARC and the four CORE variables

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Clinicians routinely transfer preclinical motor skills that they have learned on a dental mannequin to the patient. Consequently, a preclinical light-curing simulator, MARC (Managing Accurate Resin Curing) was developed. MARC is a patient simulator that uses a laboratory-grade, fiber-optic spectroradiometer contained in a dental mannequin head that can be attached to a dental chair. MARC measures the irradiance, radiant exposure, and wavelengths delivered to simulated restorations under clinical conditions. This information cannot be obtained from dental radiometers that only provide a generally inaccurate irradiance value.[113-117] The amount of energy delivered is often far less than the clinician assumes, and much less than the restoration requires.[2,79] With use of the MARC device, clinicians and dental educators can easily measure the actual radiant exposure delivered as well as clearly see how small changes in chairside light-curing techniques can have a significant impact on the potential for the clinician to adequately light-cure the RBC. In one study, dental students were divided into two groups to learn how to use a curing light. One group received light-curing instruction using MARC; the other group received training using a conventional mannequin. When tested four months later, the students who had received light curing instruction on the MARC device delivered more energy to the simulated restoration than their classmates who were not trained using MARC.[119]

A simple acronym, CORE (Curing light, Operator technique, Restoration characteristics, and Energy requirement), helps clinicians understand the variables that govern successful light-curing of RBCs.[120] Each of these variables needs to be managed and mastered for clinicians to have the confidence that the properties of each RBC they place reach those intended by the manufacturer. The variables include the following factors:

Curing light

As previously discussed,[80] there is a remarkably wide range of irradiance values emitted from contemporary new LCUs: from 400 to 5,840+ mW/cm^2. Clinicians must know the irradiance and spectral emission range produced by their LCUs so that they can match the LCU and the exposure time to the RBC they are using.

Operator technique

Dentists would never prepare a tooth without looking at what they are doing, but Figure 4 illustrates what

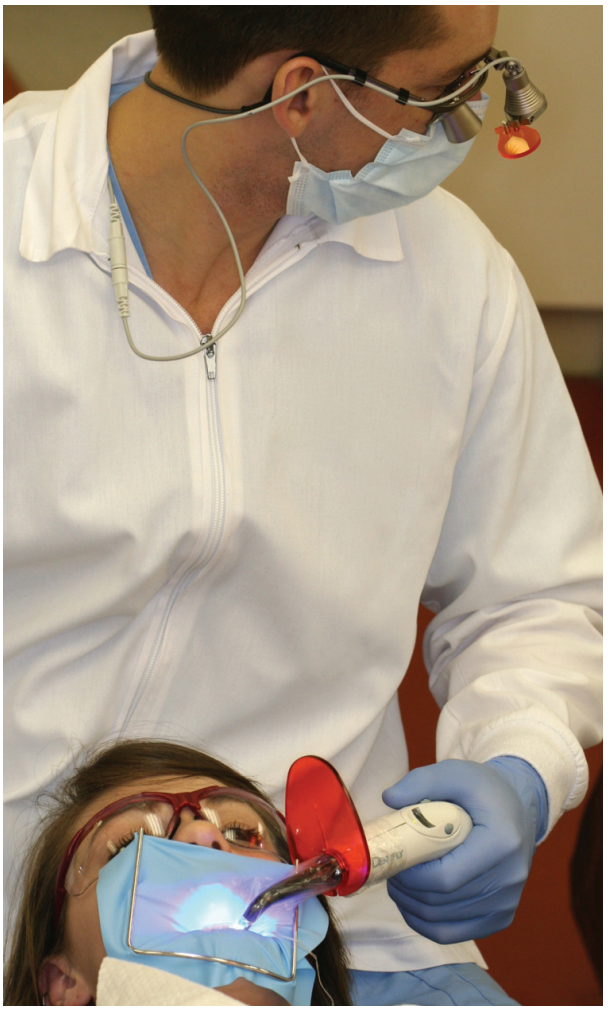

Figure 4. Typical light curing—the clinician looks away.

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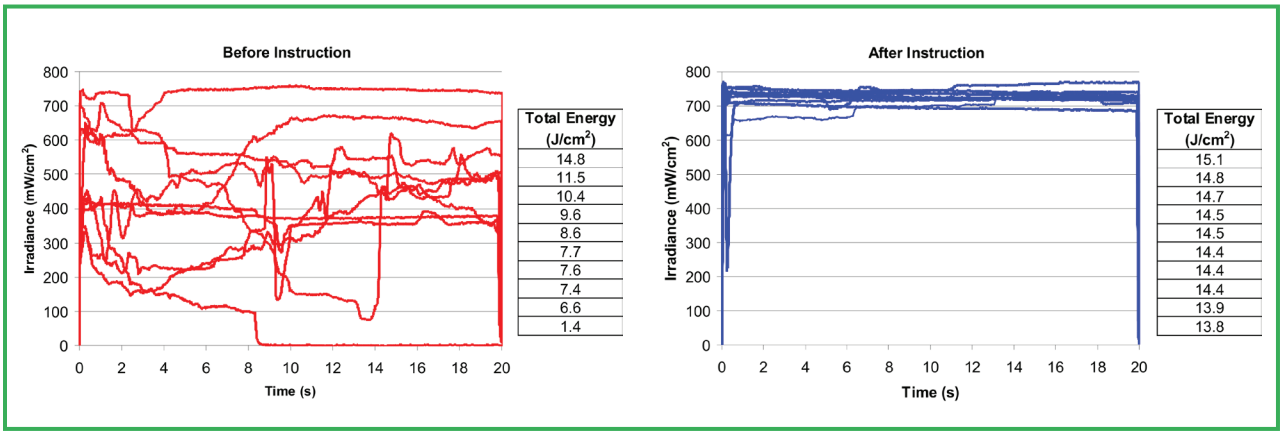

Figure 5. Examples of variations in irradiance (the height of line at each time point) and energy density (the total area under each irradiance line from start to end of exposure) delivered by dentists to a simulated restoration in MARC before (left, red traces) and after (right, blue traces) receiving instruction using MARC.

often happens when light-curing an RBC restoration; the clinician looks away so that the bright light does not damage their eyes. MARC shows there can easily be a 10-fold variation in energy density delivered by different clinicians, even when using their same LCU, for the same exposure duration, on the same tooth.

Figure 5 illustrates the irradiance and energy density delivered by 10 dentists using the same LCU, on the same tooth, for the same exposure time. When first tested, the irradiance delivered by the dentists was extremely variable, resulting in a 10-fold range in energy density delivered.[2] After instruction with immediate feedback using MARC, there was less variability in the irradiance and more energy was delivered.

Restoration characteristics

As previously discussed, it is important to take the restoration characteristics into account when determining the exposure time. The light guide must have direct access to the preparation so that the tip is as close as possible with the beam at 90° to the RBC surface.

Energy requirement

The operator must be aware of the energy and wavelengths required to adequately cure the RBC being used. As previously described, clinicians should not assume that all shades and types of RBCs require the same exposure time. Clinicians must follow the manufacturer's instructions for their brand and shade of RBC as there can be an eight-fold difference in the amount of energy recommended by the manufacturer to effectively light cure different shades and types of their RBC.[47]

Clinical Pearl: MARC is a laboratory grade, energy measurement tool that helps clinicians manage the four CORE variables. Now that clinicians can measure the energy delivered to simulated RBC restorations, they can manage their light-curing technique to ensure optimal resin polymerization and improve long-term restoration success.

Clinical Tips for Better Results

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The evidence presented in this paper can be used to develop practical tips and guidelines that clinicians can use to ensure that their light-cured resin restorations are adequately polymerized:

- Protect the eyes of everyone in the operatory who could be directly exposed to the bright blue light, using appropriate orange (blue-light blocking) safety glasses.
- Position the patient so that the person using the LCU can see the restoration and so that the LCU can access the restoration.
- Prior to use, examine the tip of the LCU for damage or for remnants of previously cured RBCs. Clean or replace as necessary.
- Choose the appropriate LCU, output mode, and exposure time to provide the appropriate wavelengths and amount of energy as recommended by the resin manufacturer.
- Place the central axis of the tip of the LCU directly over and perpendicular to the RBC surface; the emitting end should be parallel to the RBC surface being light cured.
- Watch the operative area through the orange (blue-light blocking) glasses, or shield when light curing.
- Stabilize the LCU and begin light curing with the tip about 1 mm away from the RBC. Then after 1 second, when the top surface of the RBC is hard, move the tip of the LCU as close as possible to the surface of the RBC. This method helps prevent uncured resin from

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adhering to the tip of the LCU, especially with longer exposure times.

- Where undercuts exist, preventing direct straight-line access to the RBC, move the LCU tip around and use supplementary bucco-lingual light exposures.
- Beware of overheating the tooth when light curing with a high power LCU, especially with longer exposure times.
- Depending on the heat generation capacity of the LCU, direct a stream of air over the tooth, or wait several seconds between each light exposure cycle.

Clinical Pearl: Clinicians should not take for granted what appears to be the easy task of light curing.

Conclusions

Light-cured RBCs will attain the manufacturer-intended properties when they have received the required amount of energy at very specific wavelengths. This means that the irradiance, exposure duration, and spectral emission delivered from the LCU must be matched to the requirements of the RBC. Many LCUs in dental offices worldwide do not provide sufficient irradiance, and the light curing techniques used by many clinicians may be highly ineffective. With today's high output LCUs, clinicians need to control the heat generated and take precautions to protect eyes. Criteria have been provided for selecting an LCU that best suits individual practice needs. Lastly, the four CORE variables that need to be managed chairside have been outlined, together with some simple steps to assist clinicians provide safer, long-lasting RBC restorations.

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Disposable Handpieces: A Laboratory Evaluation of Two New Products

High-speed dental handpieces are a staple in the practicing dentist's array of operatory equipment. While reusable air-driven handpieces are the most common type in use, manufacturers continue to refine their products, making modifications and improvements to address dentists' needs and preferences. As a result, reusable electric handpieces and, more recently, "hybrid" air-electric reusable handpieces have entered the market. Some manufacturers have even introduced new models of pre-sterilized disposable high-speed air-driven dental handpieces intended for single use on one patient, and two newer market entries are the subject of this evaluation.

Pre-sterilized disposable handpieces may be useful in clinical settings presenting unusual operating conditions or challenging infection control situations where sterilization is not practical or cost-effective. Examples are remote or mobile clinics, medical missions or military field installations, or perhaps in a busy practice as a backup if a sterile reusable handpiece is unavailable.

The ADA Laboratories evaluated two disposable air turbine dental handpieces available in the U.S. market: Azenic DHP from Azenic, Inc., (Kalamazoo, MI) and Hi-Speed Turbine Handpiece for Single Use-GSY Series from NPH USA, Inc. (Orlando, FL) (Table 1). Both products are sold pre-sterilized in individually sealed packets ready for clinical use and labeled with an expiration date.

The ADA Laboratories evaluated the products' performance characteristics using standard test methods, modifications of standardized methods, methods reported in the literature, and methods developed in the laboratory.

Handpiece Weight and Balance

A handpiece's weight and how it balances in the hand during clinical use are important considerations. A handpiece may cause discomfort if it is too large or too small for one's hand, too heavy or too light, has an awkward balance point that interferes with proper finger rest leverage, or it creates an unusual pull on the hand due to the feeder hose position.

To quantify how the handpiece might feel, we measured the weight both with and without a two-foot length of handpiece tubing attached, and the balance point with a two-foot length of handpiece tubing attached. We determined the balance point (the center of gravity along the handpiece's main axis) by moving the handpiece assembly with the attached length of tubing along a balancing rod until it balanced without falling backward or forward when released (Figure 1A on page 15).

When we determined and marked the approximate balance point, the handpiece assembly with the tubing was aligned on the center of a laboratory scale and weighed (Figure 1B on page 15).

For comparison, Table 2 (page 15) provides the weights and balance points for the devices evaluated in this study along with some values from two previous ADA Professional Product Review handpiece evaluations.

The balance point of the Azenic handpiece is on the dental tubing (Figure 2 on page 16). This may result in a "pulling" force towards the dental unit depending on the position of the handpiece in the practitioner's hand, the tubing configuration (e.g. coiled versus straight), the tubing control system (e.g. retractable versus hanging), and/or the weight of the tubing.

Although these measurements attempt to quantify how the handpiece will feel when held during clinical use, comfort and fatigue are subjective and cannot be determined exclusively through measurements in the laboratory. Practitioners should ultimately make a determination of comfort during use under the conditions present in their own treatment operatory.

Handpiece Dimensions

A handpiece's overall dimensions affect both access to and visibility of the operative site. To provide a sense of how well the handpiece can afford access to different areas in the mouth, we measured the following: The maximum diameter of the handpiece head (Dmax), the maximum length of the non-rotating component of the handpiece head (Lmax), the distance a 19-mm-long test mandrel extends from the handpiece head (lp), the overall head height of the handpiece with the test mandrel in place (H), and the visibility angle (α), (Figures 3A and 3B on page 16). We also measured the overall length of each handpiece (L).

The visibility angle (α) affects how the handpiece fits in the mouth during use and where it may contact the dentition (Figure 3A).

Note that the length the bur extends from the handpiece head (lp) is inversely related to the visibility angle, while the maximum diameter of the handpiece head (Dmax) is directly related. Therefore, a relatively large head diameter with a relatively small projection length may make it more difficult to see the operative site.

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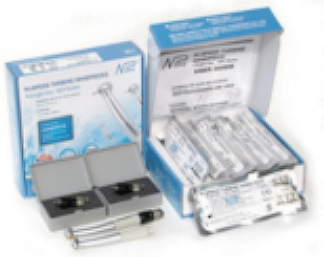
Table 1. Features of Disposable High-speed Handpiece

Disposable Highspeed Handpiece	Azenic DHP	Hi-Speed Turbine Handpiece for Single Use-GSY Series
		
Manufacturer	Azenic, Inc. 888-347-7576 www.azenic.com	NPH USA, Inc. 407-615-3898 www.nph-usa.com
Packaging	Box of 12 sterile individually-wrapped units	Box of 10 sterile individually wrapped units; reusable coupler sold separately
Connecter Type	Standard ISO 9168 type B, 4 holes	Standard ISO 9168, 2 and 4 holes
Recommended drive air pressure at dental unit	40 psi	(245 kPa) 35.5 psi
Water pressure and flow rate	5 psi to obtain 35 mL/min	Water pressure and flow rate not specified. The pressure difference between air and water should not differ by more than 50kPa (7.25 psi)
Operating speed (no load)	325,000-375,000 rpm	280,000 rpm or greater
Light source requirements to operate light	2.5 watts	No light
Stated Weight	17.3 grams	25-32 grams without coupler
Recommended burs	Use burs with shanks that comply with ISO 1791-1	Use burs with head diameter of 1.59-1.60 mm, total length not to exceed 26 mm
Duration of Use (minutes of cutting on a single patient)	16 minutes of cutting (on a single patient)	3-4 hours
Number of burs that can be used during a single treatment	5	Up to 100 burs
Shelf-life	2 years	2 years
Available Models	No additional models sold	**Push Button Auto Chuck Models:** GSY03D super torque model (tested) (large head) GSY03B (small head) Height: 13 mm Head diameter: 10.5 mm **Manual Chuck Models:** GSY05D (large head) GSY05B (small head)
Recommendations for Disposal	Recycling Program available. Otherwise, dispose as Medical Waste§	Dispose as Medical (Biohazard) Waste
Other Notes/Special Instructions		NPH instructs purified or distilled water to be used, and compressed air to be filtered and oil-free. Coupler is not sterilizable, but can be wiped down with a chemical disinfectant (not bleach) and protected with a barrier sleeve. The coupler should be discarded after 10 uses, or when practitioner observes air leaking at coupler-handpiece connection; whichever comes first.¥
Procedures recommended for use with this handpiece	Any use where a friction grip, high-speed reusable handpiece can be used	Any use where a friction grip, high-speed reusable handpiece can be used
Warranty	Not applicable for a disposable device	12 months
Cost	$23 per handpiece	$15 per handpiece; $15 per coupler

The product features and technical information contained in this table were obtained from manufacturer's technical table, MSDS, and/or instructions for use. Cost information is approximate at time of publication and may vary by distributor.

¥ Verbal/written communication from manufacturer.

§ The Centers for Disease Control and Prevention Guidelines for Infection Control in Dental Health Care Settings broadly recommend disposal of single-use items "appropriately". While they only have specific recommendations for sterilizable handpieces, any item that might be contaminated with potentially-infectious patient material should be disposed of in a biohazard bag. Disposal into a sharps container is not required.

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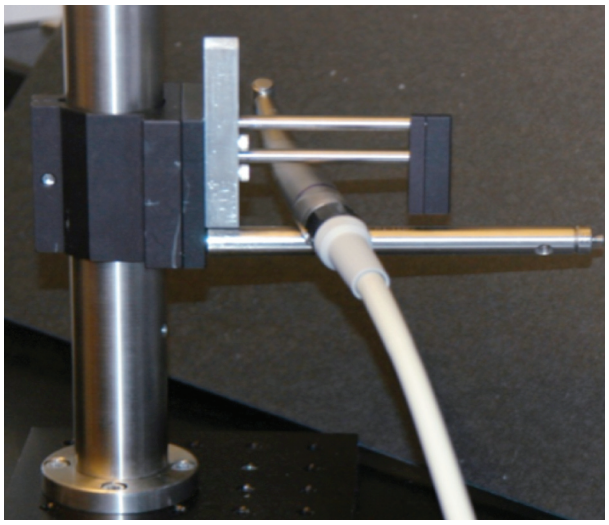

Figure 1A. Depiction of balance point test set-up for determination of balance point of a handpiece along its main axis. Note: an electric handpiece is shown here.

Table 3 (on page 16) shows that the two disposable handpieces had the same maximum head diameter; however, the Azenic has a smaller projection length resulting in the largest visibility angle of any of the handpieces in the table, which, with all other variables being equal, makes visibility of the operative site more difficult.

For any handpiece, a large overall head height (H) may present a challenge when trying to access posterior teeth, as the handpiece head may touch the opposing dentition. Table 3 shows that the overall head height (H) of both disposable handpieces is within the range of previously tested conventional high-speed air-turbine and electric handpieces.

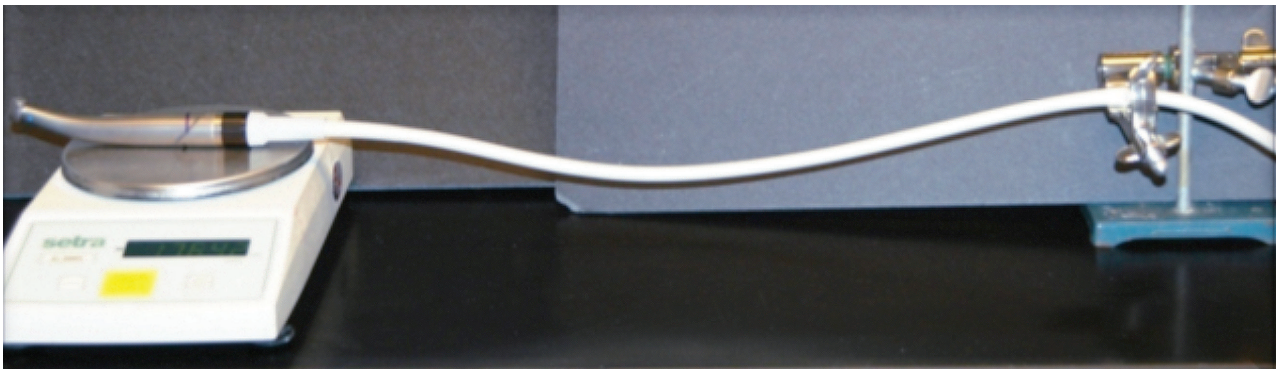

Figure 1B. Depiction of test set-up for measurement of weight of handpiece with two-feet of tubing. The balance point of the handpiece (marked with an "x") is positioned on the center of the scale, and the ring stand is adjusted to the height of the scale (note that an electric handpiece is shown in the picture).

Table 2. Handpiece Weight and Balance

Manufacturer Name	Product Name	Weight of Handpiece [grams]	Weight of Handpiece and 2-feet of tubing [grams]	Balance Point+ [mm]
Disposable High-Speed Handpieces				
Azenic, Inc.	Azenic DHP	17.2 ± 0.0	60.2 ± 0.1	165
NPH USA Inc.	GSY03D Super Torque Model	58.6* ± 0.4	103.3 ± 0.1	125
High-Speed Air Turbine Handpieces Having the Least and Greatest Weights§				
Lares Research	557 UltraLite	28.1 ± 0.1	85.4 ± 0.4	ND
BienAir	Prestige L	72.7 ± 0.2	119.6 ± 1.1	ND
Electric High-Speed Handpieces Having the Least and Greatest Weights ¥				
NSK	Ti-Max NL 400	ND	171.2 ± 0.5	120
BienAir	Micromotor MX Series	ND	244.4 ± 0.3	120

For each manufacturer, three handpieces were weighed (n=3), and the mean weight and standard error values are reported in the table.

\+ The balance point values were measured from the head of the handpiece to the balance point. For each manufacturer, the values reported in the table are from one measurement on a representative handpiece (see Figure 2).

ND Not determined.

* The reported weight for the NPH brand includes the coupler (note that in Table 1 the manufacturer reports the weight of their handpiece to be 27-32 g; however, this is the weight of the handpiece without the coupler, which is necessary for operation).

§ These values are from the "High-Speed Air Turbine Handpieces" issue of the ADA PPR (see Vol. 2, Issue 3), and are provided for reference. The values reported are for the lightest and heaviest handpieces. Note that for the values reported with 2-feet of tubing, the weight was determined with the handpiece and tubing on the scale, which is slightly different than the method described in this issue.

¥ These values are from the "Electric Handpieces" issue of the ADA PPR (see Vol. 5, Issue 3), and are provided for reference. The values reported are for the lightest and heaviest handpieces, and they were measured using the method described in this issue.

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Table 3. Handpiece Dimensions

Manf. Name	Product Name	Max. Diameter of Head ± std error [Dmax]	Projection Length of Bur from Handpiece ± std error [lp]	Maximum Length of Handpiece Head ± std error [Lmax]	Visibility Angle ± std error [ɑ]	Overall Length ± std error [L]	OverallHead Height ± std error [H]
Disposable High-Speed Handpieces							
Azenic Inc.	Azenic DHP	12.6 ± 0.0	7.0 ± 0.3	15.5 ± 0.0	30 ± 1	120.8 ± 0.2	23.0 ± 0.2
NPH USA Inc.	GSY03D Super Torque Model	12.6 ± 0.0	8.4 ± 0.0	14.7 ± 0.1	23 ± 0	118.3 ± 0.2	23.2 ± 0.1
High-Speed Air Turbine Handpieces Having the Least and Greatest Dimensions§							
Lares	557 UltraLite	10.2 ± 0.0	9.8 ± 0.5	12.4 ± 0.1	13 ± 1	126.4 ± 1.4	22.2 ± 0
Sirona	T2 Control	12.4 ± 0.0	7.0 ± 0.3	15.8 ± 0.3	26 ± 0	108.9 ± 0.2	23.2 ± 0
Electric High-Speed Handpieces Having the Least and Greatest Dimensions ¥							
Star	NuTorque	10.1 ± 0.0	9.0 ± 0.1	14.1 ± 0.1	18 ± 1	136.5 ± 0.6	23.1 ± 0.3
Sirona	SiroTorque L+	10.2 ± 0.1	6.7 ± 0.1	16.1 ± 0.3	24 ± 0	156.7 ± 0.7	22.6 ± 0.7

For each manufacturer, three handpieces were measured (n=3), and the table provides mean dimensions ± standard error given in millimeters except for visibility angle, which is given in degrees.

§ These values are from the "High-Speed Air Turbine Handpieces" issue of the ADA PPR (see Vol. 2, Issue 3), and are provided for reference. The values reported are for the handpieces with the smallest and largest visibility angles.

¥ These values are from the "Electric Handpieces" issue of the ADA PPR (see Vol. 5, Issue 3), and are provided for reference. The values reported are for the handpieces with the smallest and largest visibility angles.

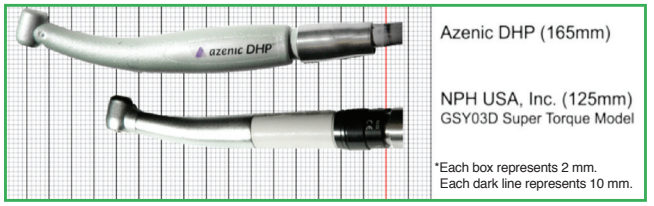

Figure 2. Representative disposable handpieces aligned at the balance point, which is represented by the red line. Each box represents 2 mm, and each dark vertical line represents 10 mm. Balance point values are reported in Table 2.

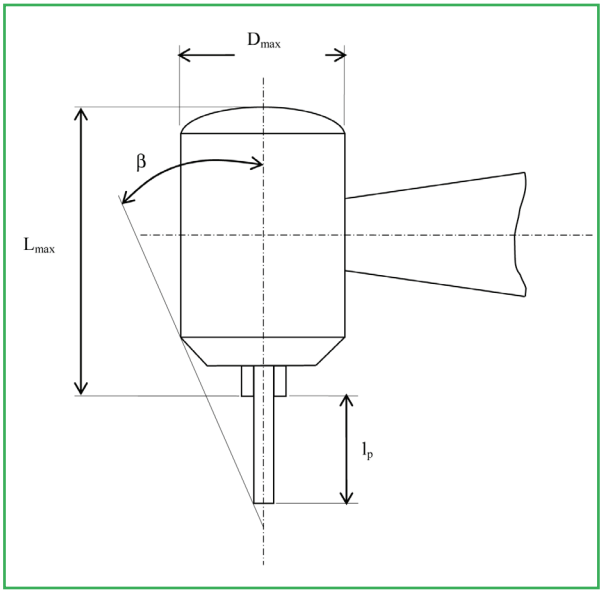

Figure 3A. Head dimensions and nomenclature (see ISO 14457: 2012(E) Figure 4a), where Dmax = the maximum diameter of the handpiece head, Lmax = the maximum length of the non-rotating component of the handpiece, lp = the distance a 19 mm long test mandrel extends from the handpiece head, and β = Visibility angle.

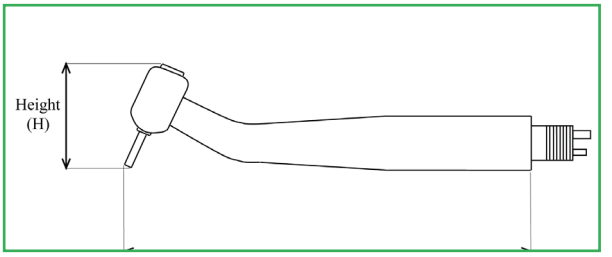

Figure 3B. Overall dimensions of air turbine handpiece, where L = overall length and H = overall height.

Light Profiles

The purpose of this test was to provide information on how light transmitted through the handpiece is dispersed over the working area. To obtain a light profile, a standard 557 carbide bur (19 mm overall length) was inserted in the handpiece and a measurement target was positioned flush against the bur using an optical table.

Of the two disposable handpieces, only the Azenic provides light transmission. Figure 4 shows a representative light profile of an Azenic handpiece with a conventional reusable air-turbine handpiece (Midwest Stylus 360S) for comparison. The images show the light projected onto a target that contains concentric circles spaced 2 mm apart (black lines) and 10 mm apart (red lines). Both photos were taken at the same exposure and distance from the target. The Azenic light profile lights the entire working region and is relatively low in intensity compared to the reusable Midwest Stylus 360S, which is more focused on the working end of the 557 bur.

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Speed

Speed performance for the handpieces in this test, using the manufacturer's stated claims, was an important quality check, including a measure of manufacturing consistency. In this test, free-running speed was measured continuously for one minute while operating the handpiece at the manufacturer's recommended drive pressure. From this data, the mean speed was calculated and the minimum and maximum speed values were recorded. From the difference between the minimum and maximum values, the speed range over the minute was calculated.

Three test runs were performed in a randomized order on each of five handpieces of both brands. The overall mean speed for each handpiece brand is shown in Table 4 along with the standard error of the mean and the overall mean range.

The International Organization for Standardization (ISO) Standard 14457 "Dentistry–Handpieces and Motors"[1] states that "The free-running speed of the handpiece shall be in accordance with manufacturer's instructions at a tolerance of ±10% as specified."

Since both manufacturers state a large operating speed range under no-load condition, the overall measured mean speeds for both products fall within their respective required ranges.

Eccentricity

Eccentricity indicates how much an object in orbit deviates from a perfect circle.[2] If a perfectly circular test mandrel is inserted into a handpiece and rotated one revolution, a perfect circle with the diameter of the test mandrel would be traced for a handpiece with zero eccentricity. Low eccentric performance is important to ensure the best control when using the handpiece to prepare a tooth during restorative procedures.

We measured the eccentricity of individual handpieces using a specified ISO standard test mandrel, a high-resolution camera, and image analysis software.[3] Images of the face of the test mandrel were captured both with the individual handpiece being tested at rest (static state) and while operating the handpiece at the manufacturer's recommended drive pressure (dynamic state). From the captured images, we calculated the difference between the maximum diameter of the path the mandrel traces when operating at the maximum free-running speed and the diameter of the static mandrel, providing a measure of the handpiece eccentricity at that speed.

The mean eccentricity and standard error were calculated based on three test runs for five handpieces of each product. ISO Standard 14457 specifies that the eccentricity of the test mandrel for air-powered handpieces "in rotation and without applied load shall not exceed a total indicated run-out of 0.03 mm."[1] As shown in Table 5, neither handpiece exceeded the ISO maximum. This means that both disposable handpieces pass the standard eccentricity tests by which reusable air-driven high speed handpieces are also tested.

Handpiece Noise

High-speed handpiece noise can affect patient comfort during procedures because a loud or annoying noise can adversely affect hearing and also raise patient anxiety. Frequent exposure to handpiece noise has also been shown to impair hearing[4] and exposure to occupational noise can raise stress levels.[5] The sound level meter employed in this study used a microphone to measure the amplitude of pressure fluctuations and their frequency distribution.

Because the ear is sensitive to a large amplitude range of pressure fluctuations, a logarithmic scale, called the decibel (dB) scale, is used to express sound measurements. The human ear can only detect sound waves of certain frequencies—approximately 20 to 20,000 Hertz (Hz)—and, within this range, the sensitivity of the ear to sound varies. For example, for a young adult with no hearing problems, the minimum detectable sound level in decibels varies at different frequencies: at 1000 Hz, about 0 dB; at 200 Hz and

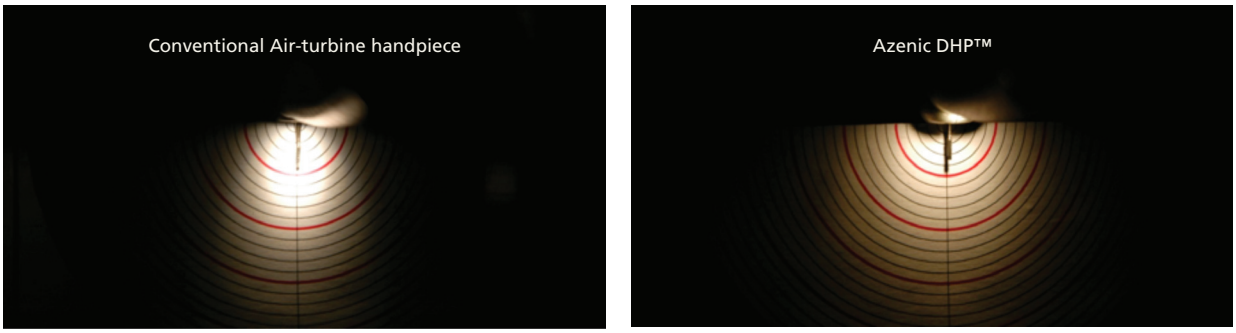

Figure 4. Light profile of an Azenic disposable air-turbine handpiece with a conventional air-turbine handpiece shown for comparison. The images show the light projected onto a target that contains concentric circles spaced 2 mm apart (black lines) and 10 mm apart (red lines). Both photos were taken at the same exposure and distance from the target.

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Table 4. Free-running speed measurements

Manufacturer Name	Product Name	Manufacturer-stated speed [rpm]	Measured overall mean speed ± standard error [rpm]	Measured overall mean range in speed [rpm]
Azenic, Inc.	Azenic DHP	325,000-375,000	366,357 ± 5,728	57,449
NPH USA Inc.	GSY03D Super Torque Model	≥280,000*	341,450 ± 6,013	46,256

Free-running speed was measured for one minute while operating the handpiece at the manufacturers' recommended maximum drive pressure. For each manufacturer, three test runs were performed on each of five handpieces in a randomized order.
* Written communication from manufacturer.

Table 5. Eccentricity measurements

Manufacturer Name	Product Name	Mean eccentricity ± standard error [mm]
Azenic, Inc.	Azenic DHP	0.014 ± 0.004
NPH USA Inc.	GSY03D Super Torque Model	0.007 ± 0.004

For each manufacturer, three test runs were performed on each of five handpieces.

15,000 Hz, approximately 20 dB; and at 50 Hz and 18,000 Hz, about 50 dB.[6] To account for this type of hearing range variation, the sound detected by the microphone used in this study was processed through an electronic circuit built to weight the sound information in a similar manner to the way the human ear varies in sensitivity with frequency.[7] This internationally standardized weighting system is called A-weighting.

Sound can be divided into its frequencies and presented on a spectrogram chart as shown in Figures 7 and 8. In this type of chart, the frequency range from 20 to 20,000 Hz is divided into sections or bands, using electronic filters. In this study, a 1/3 octave bandwidth filter was used to generate the spectrograms.[7]

For high-speed air-driven handpieces, Mueller et al. have shown that the sound level varies depending on where the microphone for the sound level meter is positioned with respect to the handpiece head.[8] Since the purpose of this test is to provide information on the sound levels to which dentists will be exposed, we positioned the microphone at locations and distances that are typical for practitioners' ears relative to the handpiece head. Data were recorded at two positions: one with the microphone placed in line with main-axis of the handpiece (0 degree position, Figure 5A), and one with it placed perpendicular to the main-axis of the handpiece (90-degree position, Figure 5B). Sound measurements were made with a free-field microphone in an anechoic chamber, which was covered on all sides with material that is highly absorptive of sound waves (non-reflective material), as shown in Figure 6.

The handpieces were operated at the manufacturers' recommended drive pressure under free-running conditions (no load), without the water spray, and measurements were recorded for one minute with the microphone positioned at 0 degrees, as pictured in Figure 5A. Additionally, three tests were performed in the 90-degree position on each of five handpieces in a randomized order with the handpieces under load, as illustrated in Figure 5B.

This entailed cutting into a Macor ceramic block that has hardness similar to enamel with a 100 g applied load and the handpiece operated at the manufacturers' recommended drive pressure with the water spray on (see Figure 6). The cutting time over which sound measurements were recorded depended on how long it took to cut through an equivalent length of Macor.

Note that ISO Standard 14457 "Dentistry – Handpieces and Motors"[1] requires that the A-weighted sound pressure value generated by the handpiece not exceed 80 dB. In this standard, measurements are required to be made with the microphone at 0.45 m.

From Table 6A, it can be seen that at 0.45 m the Azenic DHP exhibits values that are above the 80 dB maximum; furthermore, Table 6B also shows values above this maximum. The free-running data in Table 6B can be compared to data collected under similar conditions for seven different electric handpiece manufacturers previously reported in the ADA Professional Product Review.[9] In this report, with the microphone at 90 degrees and 0.64 m, most of the average LAeq values were between 50 to 60 dB, with two manufacturers going slightly over 60 dB after 40 wear cycles. The previous version of the ISO standard for handpieces (ISO 7785-1) recommended to "reduce the noise level to 65 dB", which the NPH handpiece managed to achieve only under certain conditions. To provide additional perspective on the values in Tables 6A and 6B, some common noise levels are the following: quiet automobile, 50 dB; busy street traffic, 70 dB; and elevated train, 90 dB.[6]

In Figures 7A and 7B, the peak sound level in A-weighted decibels is about 6300 Hz for the Azenic DHP and 5000 Hz for the NPH. However, Figure 8 shows that during cutting of the Macor ceramic block, the frequency of

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Figure 5A. Noise test performed in the 0 degree position. Schematic shows positioning of the head of the handpiece with respect to the microphone of the noise meter using an x-y-z coordinate system. The main axis of the handpiece is positioned along the x-axis, which is the 0 degree position with respect to the microphone that is also positioned along the x-axis. Note that additional free-running speed tests were also performed at the 0 degree position at a distance of 0.45 m along the hypotenuse, in addition to 0.64 m.

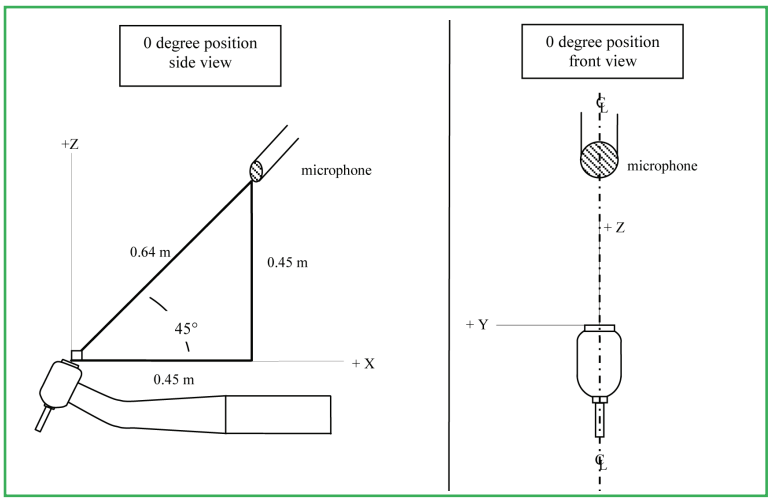

Figure 5B. Noise test performed in the 90 degree position. Schematic shows positioning of the head of the handpiece with respect to the microphone of the noise meter using an x-y-z coordinate system. The main axis of the handpiece is positioned along the y-axis, which is the 90 degree position with respect to the microphone that is positioned along the x-axis.

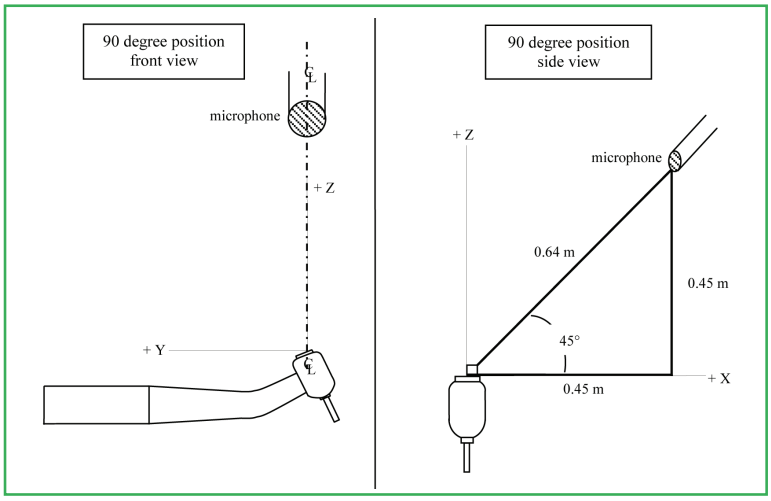

Figure 6. Example of positioning the handpiece and microphone for performing noise measurements while handpiece is under load. Note that the main axis of the handpiece is positioned along the y-axis, which is the 90 degree position with respect to the microphone that is positioned along the x-axis, as illustrated in Figure 5B.

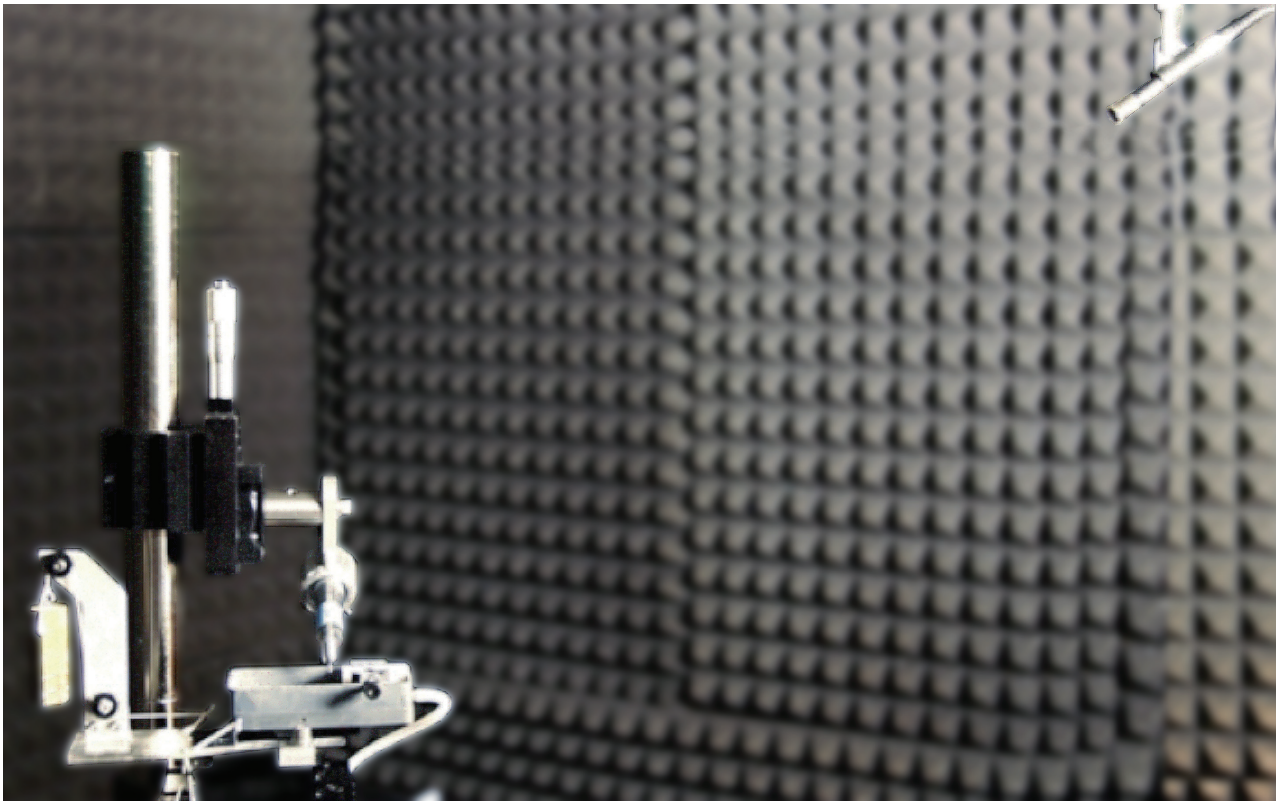

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Table 6A. Average A-weighted Equivalent Continuous Sound Level (LAeq) and average maximum sound pressure level (LAFmax) measurements during free-running recorded over one minute with microphone positioned at 0 degrees and either 0.64 m or 0.45 m.

Manufacturer Name	Product Name	Microphone position [m]	Average LAeq ± std error [decibels]	Average LAFmax [decibels]
Azenic	Azenic	0.64	76.2 ± 1.	78.1
		0.45	81.4 ± 1.6	82.6
NPH USA Inc.	GSY03D Super Torque Model	0.64	59.7	63.2
		0.45	64.4	64.4

For each manufacturer, three tests were performed on each of five handpieces in a randomized order. For all of these tests, the handpieces were operated at the manufacturers' recommended maximum drive pressure under free-running conditions (no load) without the water spray and measurements were recorded for one minute with microphone positioned at 0 degrees and either 0.64m or 0.45m. See Figure 5A for illustration of test set-up.

Table 6B. Average A-weighted Equivalent Continuous Sound Level (LAeq) and average maximum sound pressure level (LAFmax) measurements recorded over one minute with microphone positioned at 90 degrees and 0.64 m.

Manufacturer Name	Product Name	Operating conditions	Cutting time [sec]	Average LAeq ± std error [decibels]	Average LAFmax [decibels]
Azenic	Azenic DHP	Free-running	Not	82.4 ± 1.4	84.7
		Under-load	30	81.6 ± 0.4	84.8
NPH USA Inc.	GSY03D Super Torque Model	Free-running	Not applicable	64.7 ± 1.5	65.3
		Under-load	60	77.0 ± 1.8	80.2

For each manufacturer and operating condition, three tests were performed on each of five handpieces in a randomized order. For the free-running condition tests, the handpieces were operated at the manufacturers' recommended maximum drive pressure under no load without the water spray and measurements were recorded for one minute. For the under-load conditions, the handpieces were operated at the manufacturers' recommended maximum drive pressure while cutting into a Macor ceramic block with a 100 g applied load and the water spray on. The cutting time over which sound measurements were recorded was dependent on how long it took to cut through an equivalent length of Macor®. See Figures 5B and 6 for depictions of the test set-up.

the peak sound level decreases to 5000 Hz for the Azenic DHP, but stays at the same frequency, 5000 Hz, for the NPH. As previously noted, the sensitivity of the human ear to sound varies with frequency, and it is most sensitive to sound at frequencies between 2000 and 5000 Hz.[7] While cutting Macor to simulate clinical use, both handpieces generate sound in the frequency range to which patients, as well as the dental team, are the most sensitive.

From the data generated in this study, dentists should consider wearing hearing protection when using the Azenic DHP handpieces in clinical practice. Dentists should also consider wearing hearing protection at times when using the NPH, since there are test conditions where this handpiece also demonstrated sound levels exceeding 80 dB.

When evaluating the data presented in this report, the specific laboratory test conditions should be considered. For instance, some tests were performed free-running (without a cutting load) and with no water spray. While, these factors could produce sound levels and frequency distributions that are different than in practice, the free-running noise tests serve as useful reference points for comparison and may not be significantly different than clinical conditions. Since air-turbine handpieces are used with a variety of burs and diamond instruments against different materials to be cut, the sound levels produced by the specific loading (cutting) conditions in this study may differ from specific clinical instances. Practitioners should be aware of the potential need for hearing protection for the dental team and for patients when using any high speed air-driven handpiece during clinical procedures.

Insertion Force and Static and Dynamic Extraction Force

Extraction force is the force required to withdraw a standard test mandrel from the chucking device of a dental handpiece. Extraction force tests were performed both statically and dynamically for both handpieces. In the latter test, the handpiece was operated at the manufacturers' recommended drive pressure when the test mandrel was extracted. Extraction forces are an important consideration for operator safety during bur changes and for ensuring proper stability of the bur in the handpiece during handpiece operation.

Insertion forces are important to ensure the integrity of the bur as well as operator safety. The need to use excessive force to seat a bur or diamond instrument in the chuck could damage the chuck or expose the

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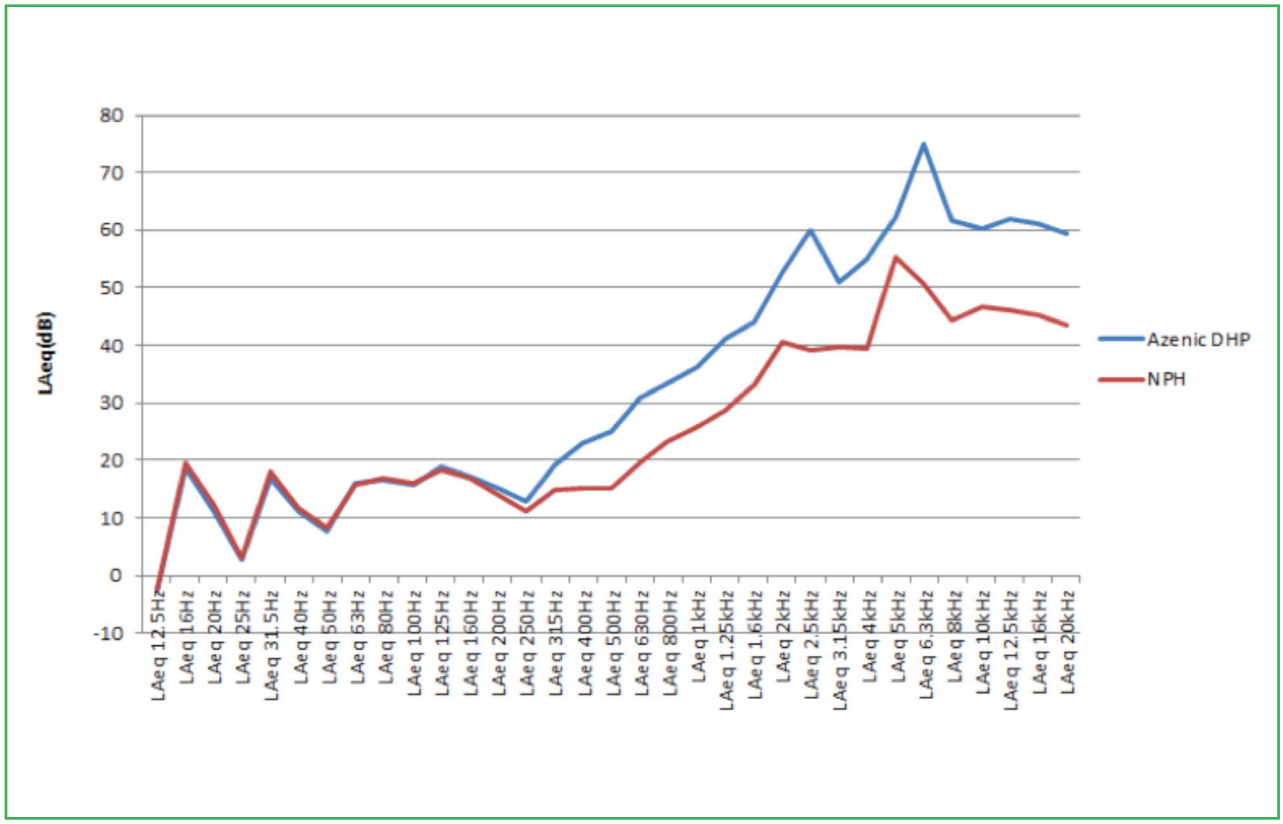

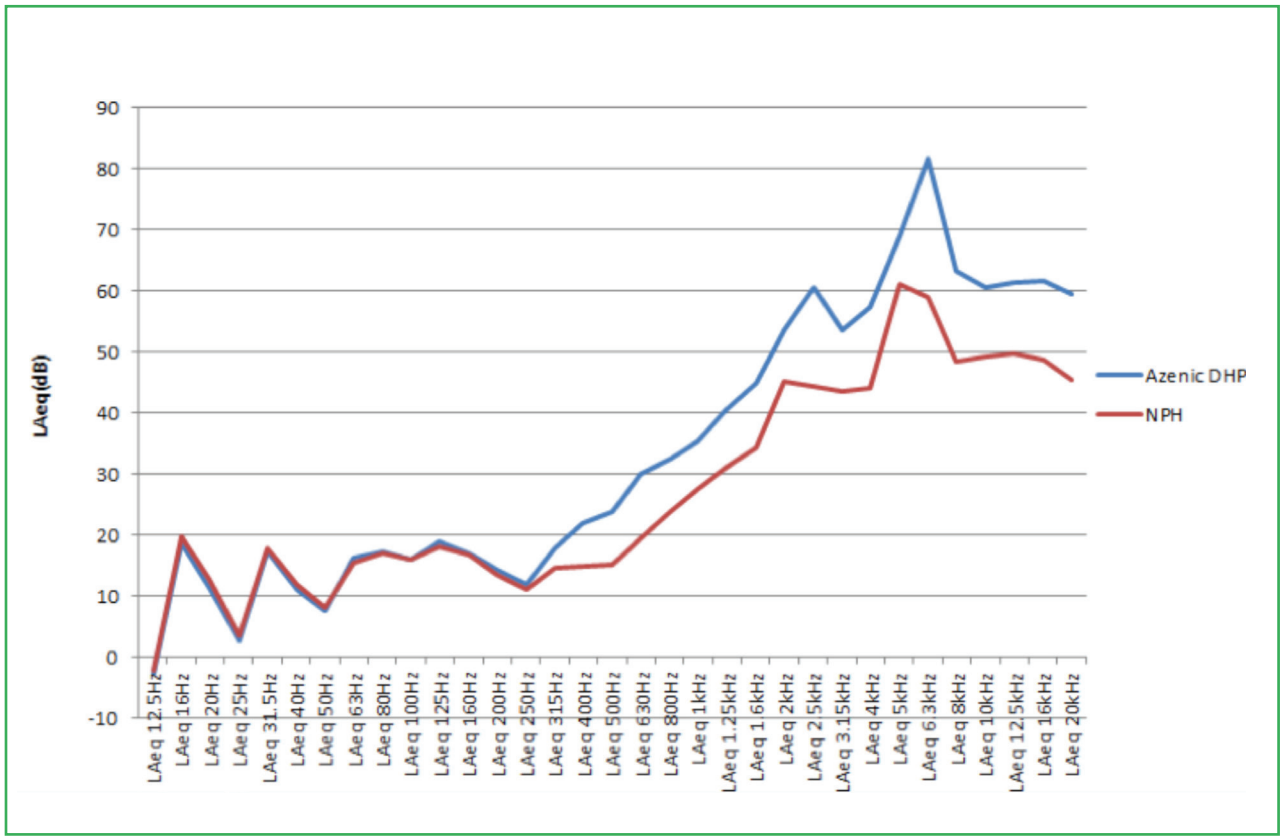

Figures 7A-B. Noise spectrograms from 12.5 Hz to 20 kHz. In Figure 7A, the measurements were taken with the microphone positioned at 0 degrees and 0.64 m, and in Figure 7B, the measurements were taken with the microphone positioned at 90 degrees and 0.64 m. For each figure, the plots for each manufacturer are average spectrograms of three tests performed on each of five handpieces in a randomized order. For all of these tests, the handpieces were operated at the manufacturers' recommended maximum drive pressure under free-running conditions (no load) without the water spray and measurements were recorded for one minute. The plots in Figure 7A correspond to the 0.64 m data in Table 6A, and the plots in Figure 7B correspond to the free-running data in Table 6B.

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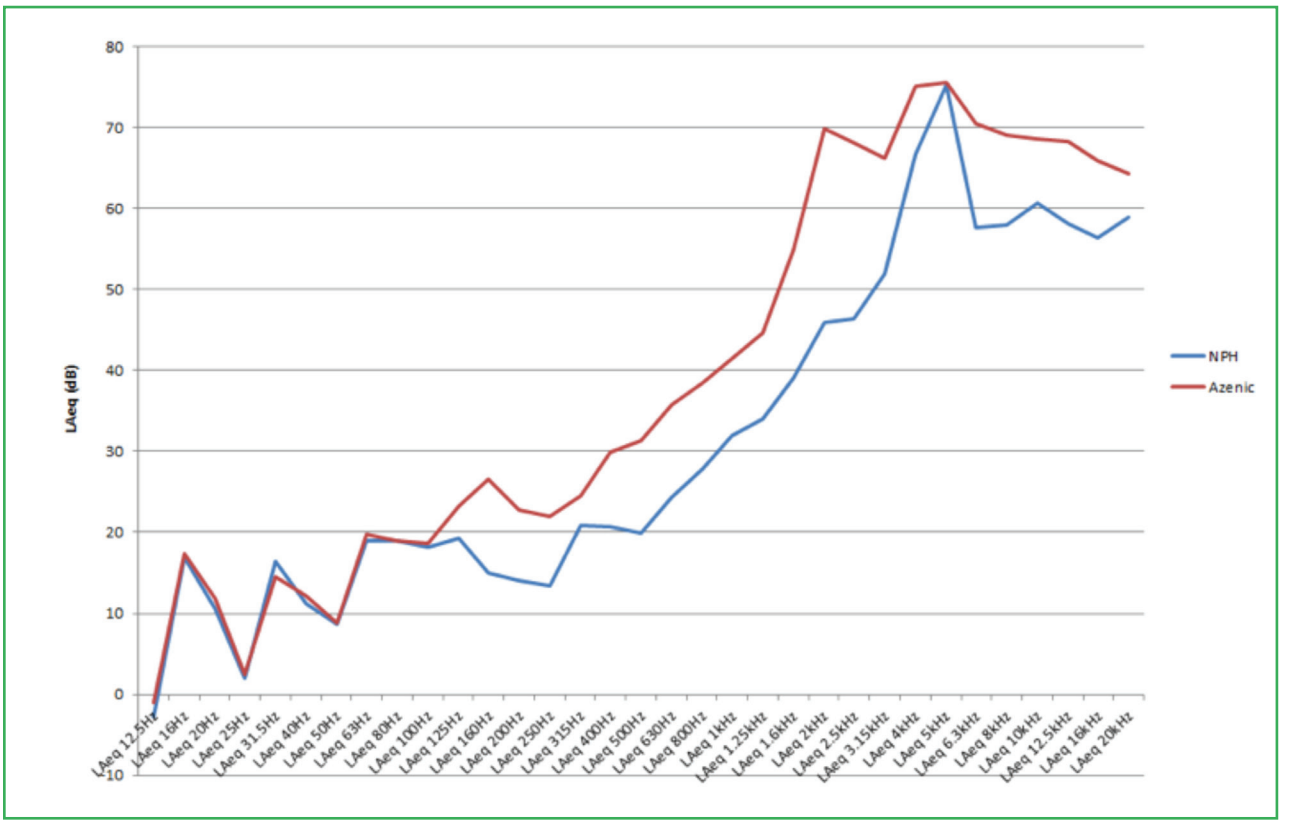

Figures 8. Noise spectrogram from 12.5 Hz to 20 kHz for handpieces tested under-load with the microphone positioned and 90 degrees and 0.64 m. The plots for each manufacturer are average spectrograms of three tests performed on each of five handpieces in a randomized order. The handpieces were operated at the manufacturers' recommended maximum drive pressure while cutting into a Macor® ceramic block with a 100 g applied load and the water spray on. The cutting time over which sound measurements were recorded was dependent on how long it took to cut through an equivalent length of Macor®. The plots correspond to the under-load data in Table 6B.

operator to injury. Since the Azenic DHP handpiece employs a "press-fit" plastic chuck, with instructions to "insert and push the bur in until you feel significant or increased pressure, indicating that you have reached the dead stop built into the turbine," the insertion force for this handpiece was tested. The NPH employs a push-button spring-type, metallic chuck. With this type of chuck, if the push-button is depressed properly, the bur slides easily into the chuck and does not need to be pressed into the chuck, so the insertion test does not apply for this handpiece.

To perform the tests, several custom made components were manufactured, as illustrated in Figure 9A. Each handpiece was fixed in an extraction force fixture that was mounted to the base of a mechanical test system (Figure 9B).

For each dynamic extraction force test, the test mandrel was extracted from the handpiece at a rate of 20 mm/min with the handpiece operating at the manufacturer's recommended drive pressure. For the dynamic extraction tests, a new test mandrel and bearing was used for each test run for a total 15 mandrels and bearings per manufacturer. For both the static and dynamic extraction tests, five tests were performed per handpiece, and three handpieces were tested per manufacturer for a total of 30 tests per manufacturer.

Table 7 shows that the mean extraction force decreases for both handpiece manufacturers when the test is performed dynamically, and this difference was found to be significant for the Azenic DHP (t-test, p=0.021). ISO Standard 14457 "Dentistry–Handpieces and motors"[1] specifies the force required to extract a test-mandrel from a static dental-handpiece should be at least 22 N. In this Standard, the test is performed without the handpiece in operation. Therefore, the 25 N mean static extraction force for the NPH handpieces passes this minimum; however, the dynamic value of 22 N is right at the limit.

Additionally, for the static tests, the insertion force to fully seat the test mandrels was measured for the Azenic DHP handpieces before the mandrels were extracted. In these tests, the mandrels were inserted at 5 mm/min.

It was sometimes difficult to manually push a dental bur into the Azenic DHP, and the mean insertion force of 41 N shown in Table 7 equates to over 9 pounds of force. Practitioners should use caution applying this insertion force to avoid potential damage to the rotary cutting instruments or operator injury during insertion.

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Table 7. **Insertion Force and Static and Dynamic Extraction Force**

Manufacturer Name	Product Name	Mean insertion force ± standard error [N]	Mean static extraction force ± standard error [N]	Mean dynamic extraction force ± standard error [N]
Azenic, Inc.	Azenic DHP	41.5 ± 5.0	51.0 ± 5.0	32.3 ± 0.5
NPH USA Inc.	GSY03D Super Torque Model	Not tested	25.3 ± 1.0	21.7 ± 2.7

For both the static and dynamic tests, five tests were performed per handpiece, and three handpieces were tested per manufacturer for a total of thirty tests per manufacturer. Additionally, the maximum insertion force to fully seat the test mandrels was measured for the Azenic DHP handpieces before the mandrels were extracted.

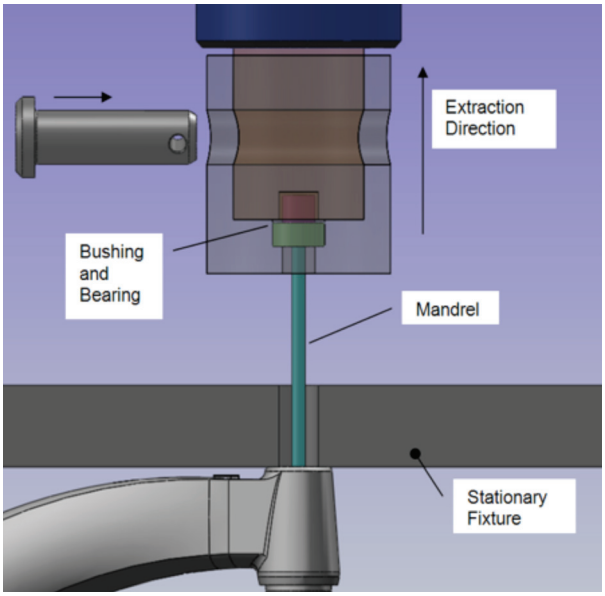

Figure 9A. Illustration of custom made components for extraction force tests, including extra-long test mandrel, bushing, and dental bearing, which are all placed inside a cylindrical crosshead adapter.

Figure 9B. Sample picture of extraction force fixture mounted to the mechanical testing system frame with handpiece positioned for a dynamic extraction force test.

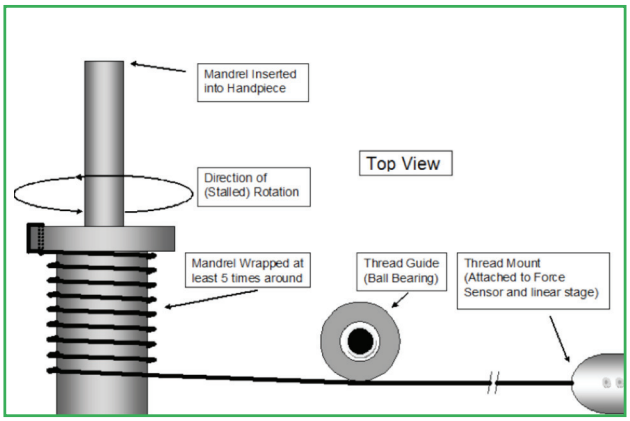

Figure 10. Illustration of stall torque test set-up. The test set-up consists of a custom-made test mandrel with varying diameters. The diameter of the mandrel, which fits into the handpiece, is 1.6 mm.

Stall Torque

Stalling of the handpiece is obviously undesirable during clinical use. The stall torque test provides an estimate of the applied torque required to completely stop the turbine from rotating (Figure 10.)

For each plot, every peak on the plot corresponds to the tip of a blade on the rotor passing the air supply nozzle of the handpiece.

Typical stall torque plots are shown in Figures 11A and 11B.

For instance, the rotor of the Azenic DHP has twelve blades, and the plot exhibits twelve peaks as the rotor rotates through a complete revolution. Likewise, the NPH rotor has eight blades, and the plot exhibits eight peaks over 360 degrees. Each plot also shows the typical bearing resistance for the respective handpieces when rotated through a complete revolution. For each brand, the resistance is relatively small compared to the average stall torque for the handpiece; however, the typical bearing resistance for a conventional air-turbine handpiece is also shown on both plots, and it can be seen that it is much lower in comparison.

In Table 8, stall torque results are reported at two different pressures for the NPH handpiece. The manufacturer's recommended drive pressure at the dental unit is 40.0 psi for the Azenic DHP and 35.5 psi for the NPH. For comparison, the stall torque was measured

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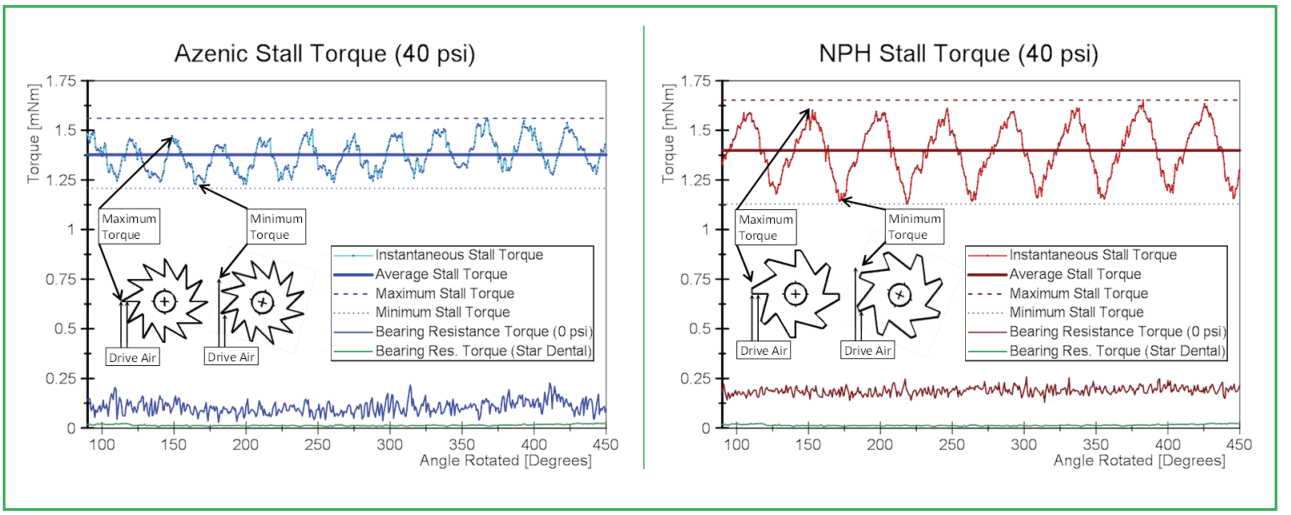

Figure 11A-B. Typical stall torque plots for Azenic DHP (11A) and NPH (11B) handpieces. In the plots, stall torque is shown versus rotation of the turbine, and the plots show one complete revolution (360 degrees) of the turbine. Bearing resistance, measured with supply air turned off, is also shown in the plots. Along with the typical bearing resistance for the Azenic DHP and NPH handpieces, the typical bearing resistance for a conventional air-turbine handpiece is shown on the plots for comparison. The inset diagrams illustrate how the position of the rotor blades relative to the stream of drive air produces the saw-tooth plot of torque versus angle.

Table 8. Stall Torque and Stall Torque Coefficient

Manufacturer Name	Product Name	Supply Pressure Setting [psi]	Mean Gauge Pressure at Handpiece [psi]	Overall Mean Stall Torque ± standard error [mNm]	Mean Stall Torque Coefficient [mNm/bar]
Azenic, Inc.	Azenic DHP	40.0	35.3	1.34 ± 0.01	0.56
NPH USA Inc.	GSY03D Super Torque Model	40.0	37.9	1.39 ± 0.01	0.54
		35.5	33.6	1.23 ± 0.01	0.54

For an individual test run, mean stall torque was calculated by averaging the stall torque over one revolution (see Figures 11A and 11B for an example of variation in stall torque over one revolution). For each manufacturer, the overall mean stall torque was calculated from three stall torque tests performed on each of five handpieces. Supply pressure is equivalent to the pressure set at the dental unit and gauge pressure is the pressure at the inlet of the handpiece (see Figure 13).

at the manufacturer's recommended drive pressure and at a common drive pressure. (Note that NPH stated a recommended drive pressure of 35.5 psi and a range of 29 psi to 43.5 psi). The gauge pressure shown in the table was the average pressure reading recorded from a pressure gauge connected at the inlet of the handpiece during testing (pressure sensor #3 in Figure 12).

From the NPH data it can be seen that stall torque increases with pressure. The stall torque coefficient for the Azenic DHP is similar at 0.56 mNm/bar, but significantly different than the NPH handpieces at both pressures (One-Way ANOVA, p=0.018).

This relationship between stall torque (τs) and pressure (p) is described by the following equation[11]:

$$\tau s = \varphi \cdot p$$

where φ is the stall torque coefficient and (p) is the stagnation pressure, which in this case is approximated to be equivalent to the gauge pressure at the handpiece (pressure sensor #3 in Figure 12). From Table 8, it can be seen that if the overall mean stall torque is divided by

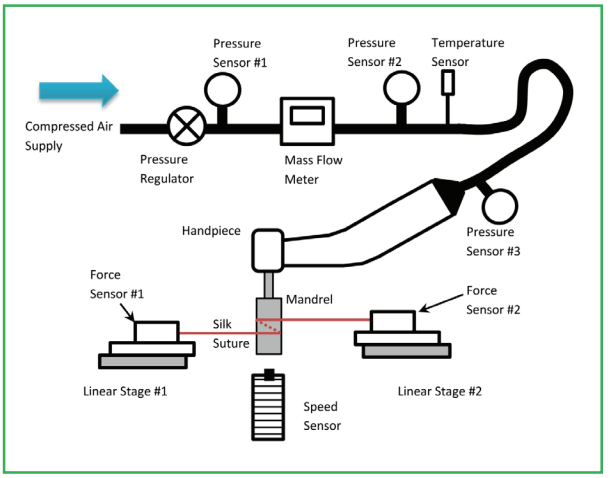

Figure 12. Illustration of test set-up used to control and monitor air pressure and flow, as well as record air temperature.

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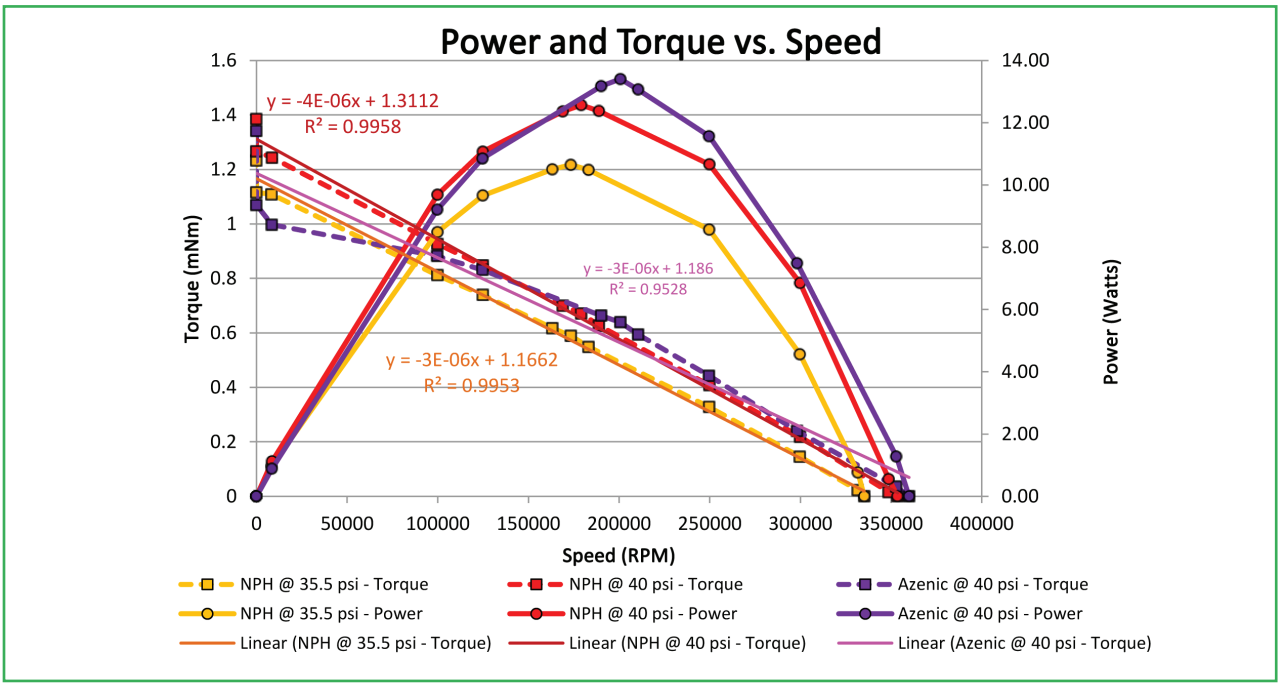

Figure 13. Torque and Power versus Speed for Azenic DPH and NPH handpieces. For each manufacturer, three tests were performed on each of five handpieces. For each plot, the data shown is the mean of all trials for each group. Note that during each individual test, thousands of data points were continuously recorded; however, to create the composite plots shown in this figure, a computer program was created to select values at specific, uniform speeds as well as at and near peak power. This allowed for multiple trials to be effectively combined into the representative curves shown here.

the gauge pressure, after converting psi to the metric unit of bar, then the stall torque coefficient is obtained. For the NPH handpiece, it can also be seen that stall torque is indeed proportional to pressure by a constant value (stall torque coefficient), which in this case is 0.54 mNm/bar. The stall torque coefficient for the Azenic DHP is similar at 0.56 mNm/bar, but significantly different than the NPH handpieces at both pressures (One-Way ANOVA, p=0.018). The supply pressure (pressure sensor #2) in these experiments is essentially equivalent to the pressure at the dental unit (there is approximately six feet of tubing between pressure sensors #2 and #3 in Figure 12).

The supply pressure (pressure sensor #2) in these experiments is essentially equivalent to the pressure at the dental unit (there is approximately six feet of tubing between pressure sensors #2 and #3 in Figure 12).

A closer look at Table 8 shows that for the 40 psi supply pressure, the gauge pressure for the two manufacturers is different. The gauge pressure for the Azenic DHP is lower, which is related to the higher mass flow rate measured. Because there is more air flowing through the system, there is more friction against the tubing walls and, thus, more pressure dissipated over a given length of tubing. Therefore, even though the overall mean stall torque for the NPH is slightly higher than the Azenic at a supply pressure of 40 psi, the stall torque coefficient for the Azenic DHP is slightly higher than the NPH. This is because the amount of supply pressure that makes it through the tubing to the handpiece itself, which is what is used to calculate the stall torque coefficient, is lower for the Azenic DHP.

Torque and Power Characterization

For an air-turbine handpiece, power can be thought of as the rate at which it does work (i.e., work per second) as it cuts through something, such as tooth structure. Since an air-turbine handpiece is essentially a rotating machine, power is calculated by taking the product of the torque and the angular velocity. To experimentally determine the power output of a handpiece, the torque behavior of the handpiece must be measured with respect to its speed.

During each individual test, the speed was continuously recorded in revolutions per minute (rpm) using an optical infrared tachometer. From the collection of simultaneous force and speed data, torque-versus-speed curves were generated, as shown in Figure 13. There is a linear relationship between applied torque and rotational speed, which is typical of air-turbine handpieces (i.e., as torque increases, speed decreases).

Figure 13 shows plots of power versus speed. Maximum power output occurs neither at free running speed nor when the stall torque is approached and the speed drops to zero, but when the speed is in the middle of the two extremes.

In this study, three torque-versus-speed curves were generated for each of five handpieces at the manufacturer's recommend operating pressure. Since power varies with pressure, three torque-versus-speed

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Table 9. **Peak Power and Various Handpiece Parameters at Peak Power**

Manufacturers Name	Product Name	Supply Press. Setting [psi]	Mean Peak Power ± standard error [W]	Mean Torque at Peak Power ± standard error [mNm]	Mean Speed at Peak Power ± standard error [rpm]	Mean Mass Flow Rate ± standard error [SCFM]	Mean Efficiency Index at Peak Power ± standard error [%]
Azenic, Inc.	Azenic DHP	40	13.4 ± 0.5	0.639 ± 0.025	200,800 ± 3,300	2.24 ±0.04	16.9 ± 0.9
NPH USA Inc.	GSY03D Super Torque Model	40	12.6 ± 0.3	0.671 ± 0.005	179,200 ± 5,600	1.44 ±0.02	23.7 ± 0.6
		35.5	10.7 ± 0.3	0.549 ± 0.002	173,400 ± 4,500	1.30 ± 0.01	23.7 ± 0.6

For an individual test run, peak power was calculated based on torque and speed measurements. Efficiency was calculated by dividing peak power by the maximum theoretical power delivered in the compressed air (based on the associated pressure, flow rate, and temperature data for that point). For each manufacturer, the overall mean for peak power and the associated torque, speed, and efficiency values, were calculated from three dynamic torque tests performed on each of five handpieces. Supply pressure is equivalent to the pressure set at the dental unit (pressure sensor#2 in Figure 12). SCFM equals standard cubic feet per minute, with the standard conditions set at one atmosphere and 0°C.

curves were generated for each of five additional NPH handpieces at the recommended operating pressure of the Azenic DHP for comparison (Table 9).

In addition, the mean peak power for the Azenic DHP was slightly higher than for the NPH. However, this difference was not statistically significant (t-test, p=0.191). At 40 psi, the mean torque at peak power for the NPH handpiece (0.671 mNm) is slightly higher than for the Azenic DHP (0.639 mNm), but the difference is not statistically significantly (t-test, p=0.239).

Since the mean speed at peak power for the Azenic DHP (200,800 rpm) is higher than for the NPH (179,200 rpm) and since power is the product of torque and speed, the Azenic DPH shows slightly higher but not statistically greater mean peak power than the NPH.

Although there is no standard for minimum peak power, the mean peak powers measured in this study are comparable the range of peak power values seen in the literature for reusable air-driven high-speed handpieces.

Efficiency

The efficiency or ability of the handpiece to convert compressed air power into cutting power may be an important consideration in applications where compressor capabilities may be limited, such as the case where the need for clinic mobility limits the compressor capacity.

Peak efficiency is calculated by dividing the measured peak power by the maximum theoretical power available in the compressed air. For this calculation, peak power is determined as described previously in the "Torque and Power Characterization" section. The maximum theoretical power available in the compressed air is determined from using data from the sensors, meters, and regulators shown in Figure 12. Specifically, the measured pressures, mass flow rate, and temperature of the compressed air being supplied to the handpiece are used with equations described elsewhere[11,12] to calculate the maximum theoretical power. Table 9 shows the mean efficiency index at Peak Power calculated for each handpiece manufacturer. At the reported pressure, data were calculated from three dynamic torque tests performed on each of five handpieces for each manufacturer.

From Table 9, it can be seen that the efficiency of the Azenic DHP handpiece was significantly less than that of the NPH handpiece, at either pressure (One-Way ANOVA, $p < 0.001$). This is largely due to the higher mass flow rate of air measured during operation of the Azenic DHP. If efficiency is considered in terms of the mass of air flow per unit time required to provide a specific amount of power, then it is not surprising that the NPH handpiece is more efficient. In Table 9, the mean peak power for the two handpiece brands is similar at a supply pressure of 40 psi; however, the mean mass flow rate at peak power for the NPH is only about 65% of the Azenic DHP. This corresponds to a greater consumption of compressed air for the Azenic DHP.

Compressors typically state their capacity in terms of a mass flow rate at a given pressure. In applications where compressor capacity may be a limiting factor, the higher air consumption of the Azenic handpiece could theoretically result in reduced performance or increased strain on the system.

Performance parameters after simulated use

The purpose of this series of tests was to measure the effects of simulated use on some key performance parameters for the disposable air-turbine handpieces. Noise level, eccentricity, and free-running speed were measured before and after subjecting the handpieces to the same wear protocol.

The simulated wear was performed by using diamond instruments (Midwest Diamonds—Flat Cylinder FG, 5/Pkg Coarse, Size #836-012-C, 1.2mm Diameter) for

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Table 10. Pre- and Post-wear Average A-weighted Equivalent Continuous Sound Level (LAeq) and average maximum sound pressure level (LAFmax) measurements during free-running recorded over one minute with the microphone positioned at 0 degrees and 0.45 m.

Manufacturer Name	Product Name	Wear condition	Average LAeq ± std error [dB]	Average LAFmax [dB]
Azenic, Inc.	Azenic DHP	Pre-wear	76.1 ± 0.9	77.3
		Post-wear	77.6 ± 0.7	79.0
NPH USA Inc	GSY03D Super Torque Model	Pre-wear	65.1 ± 1.4	66.0
		Post-wear	62.6 ± 0.9	63.7

For each manufacturer, three tests were performed on each of five handpieces in a randomized order. For all of these tests, the handpieces were operated at the manufacturers' recommended maximum drive pressure under free-running conditions (no load) without the water spray and measurements were recorded for one minute. After wearing, for each manufacturer, the tests were repeated on the same handpieces: three tests were performed on each of five handpieces in a randomized order. See Figure 5A for illustration of test set-up.

Table 11. Pre- and Post-wear free-running speed and eccentricity measurements.

Manufacturer Name	Product Name	Wear condition	Measured overall mean speed ± standard error [rpm]	Mean eccentricity ± standard error [mm]
Azenic, Inc.	Azenic DHP	Pre-wear	342,763 ± 11,203	0.022 ± 0.002
		Post-wear	303,490 ± 38,228	0.032 ± 0.002
NPH USA Inc	GSY03D Super Torque Model	Pre-wear	338,369 ± 4,785	0.011 ± 0.002
		Post-wear	327,122 ± 8,708	0.022 ± 0.004

Free-running speed was measured for one minute while operating the handpiece at the manufacturers' recommended maximum drive pressure. For each manufacturer and for both free-running speed and eccentricity, three test runs were performed on each of five handpieces in a randomized order before wear and then the tests repeated after wearing.

a total of 32 horizontal cuts at depths of 0.120 inches into a single lot of Macor ceramic block specimens under a 100 g applied load. All handpieces were operated at the manufacturers' recommended drive pressure. Each cut lasted for 30 seconds and each bur was replaced after two minutes of cutting. The total cutting time of 16 minutes was chosen because the instruction sheet for the Azenic DHP handpiece states: "The DHP, with appropriate burs, can be used for duration of up to 16 minutes cutting time for single patient use." Therefore, for both manufacturers, we decided to perform cutting on ceramic blocks, with similar hardness to enamel, for a total of 16 minutes. Note that the NPH GSY 03D in Table 1 indicates a cutting time of 3 to 4 hours.

For each manufacturer, five handpieces were subjected to the wearing procedure. Before the wearing procedure, free-running speed, eccentricity, and noise were measured as described previously. For the noise tests, in particular, measurements were recorded over one minute with the microphone positioned at 0 degrees and 0.45 m. For each parameter, three tests were performed on each of the five handpieces for each manufacturer. After the wearing procedure, the free-running, speed, eccentricity and noise tests were repeated on the same two groups of five handpieces.

Table 10 shows the results of the effect of the wear protocol on noise. Wear did not have a significant effect on noise level for either of the handpiece brands: NPH (paired t-test, p=0.067) and Azenic (paired t-test, p=0.285). Table 11 shows the results of the effect of the wear protocol on free-running speed and eccentricity. Although the mean overall speed decreased for both handpiece manufacturers post-wear, the decrease was not significant: NPH (paired t-test, p=0.236) and Azenic DHP (failed normality, conducted signed-rank test, p=0.313). Likewise, eccentricity increased for both handpiece manufacturers post-wear, but the increase was not significant: NPH (paired t-test, p=0.073) and Azenic DHP (paired t-test failed normality, conducted signed rank test, p=0.063). However, the mean eccentricity for the Azenic DHP handpiece increased to 0.03 mm, which is right at the previously mentioned limit specified in ISO Standard 14457.

The wear tests indicate that both handpieces will perform at a consistent level throughout 16 minutes of cutting time that attempts to simulate handpiece wear in a way that correlates with potential clinical performance in cutting enamel.

Summary

For decisions regarding the weight, balance, and dimensions of disposable air-driven high speed handpieces, dentists must ultimately make a personal determination of comfort during use under the conditions present in their own operatory during patient treatment. Since the NPH does not offer a light, dentists who

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desire through-the-handpiece lighting should consider the Azenic, although the light is not comparable in quality to typical reusable lighted handpieces. Dentists concerned about noise may want to consider the NPH; however, the NPH was also shown to be higher than the recommended standard under some conditions. The NPH offers a bur changing system that is easier to use, may be less damaging to burs, and may offer greater safety for the dental team. Tests for stall torque and mean peak power for both handpieces showed no statistical differences. Although there is no standard for minimum peak power, the mean peak powers measured in this study are comparable to typical power values seen in the literature for reusable air-driven high speed handpieces.[1,2]

The NPH performed more efficiently than the Azenic at the same compressed air pressure and may be desirable for conditions such as mobile operations where only relatively lower compressor capacity is available. The performance of the handpieces did not degrade significantly for the variables measured during tests designed to simulate clinical cutting of enamel. Based on testing in the ADA Laboratories, both handpieces appear to offer an acceptable alternative to reusable air-driven high speed handpieces and could be considered for clinical use as provider judgment may warrant based on clinical conditions and treatment considerations.

Product Snapshot

	Azenic DHP from Azenic, Inc.	Hi-Speed Turbine Handpiece for Single Use-GSY Series from NPH USA, Inc.
Light	No	Yes
Bur Release	None	Push-button release
Noise level	Hearing protection recommended	Hearing protection recommended
Power	Similar to reusable handpieces	Similar to reusable handpieces
Performance Degradation	None over 16 minutes	None over 16 minutes
Suitable Option	Acceptable alternative to reusable handpiece	Acceptable alternative to reusable handpiece

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