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Factors Affecting Dental Air-Turbine Handpiece Bearing Failure

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SUMMARY

Objectives: To investigate the influence of various factors on air-turbine handpiece bearing failure through developing standard protocols for testing the bearing longevity.

Methods: Groups of four air-turbine assemblies (Synea TA-98, W&H, Dentalwerk, Bürmoos, Austria) were subjected repeatedly to a full binary combinatorial set of operating conditions: with and without lubrication, simulated clinical loading, and corrosion protection, all with autoclaving, to the point of failure. A control set was lubricated only. Lubrication (Assistina, W&H), autoclaving (ST-Im30b, Eschmann Bros & Walsh, West Sussex, England), simulated clinical loading (0.56 N at 45° to the turbine axis, after autoclaving), and corrosion protection during autoclaving (magnesium sacrificial anode) were used as required. Free-running speed (Hz) and bearing resistance (μNm) were determined (Darvell-Dyson testing machine) at baseline and after every 10 cycles until turbine failure. Three-way analysis of variance (lubrication × loading × corrosion protection) of log(cycles to failure), with $\alpha = 0.05$, was used.

Results: All autoclaved turbines had failed by 560 cycles, while the controls failed at 960-1000 cycles. All three main effects were significant: loading ($p<10^{-6}$), lubrication ($p<0.0002$), and corrosion protection ($p<0.02$), as was the interaction lubrication × loading ($p<10^{-6}$). No other interaction attained significance.

Conclusions: Running under load was the most important factor affecting bearing longevity. While autoclaving clearly has a detrimental effect, lubrication effectively increases longevity. A sacrificial anode may be economically worthwhile to extend life further, but low-load usage patterns, as generally instructed, are confirmed as beneficial.

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INTRODUCTION

Air-turbine handpieces have been used for most dental cutting procedures for more than 50 years since the invention of the Borden Air rotor in 1957.[1] Although some improvements such as push-button bur release, swivel coupling, and fiber-optic illumination have made it more convenient for use, the main component, a turbine rotor supported by two miniature ball bearings, remains unchanged.[1] Generally, the ball bearings of air-turbine handpieces have two rings, an outer and an inner ring, which enclose the balls. The design of the channels within which the balls roll in these rings, the raceways, is intended to decrease the contact stress between balls and rings and to prevent axial movement of the balls.[2] The inner ring is fitted rigidly to the spindle and rotates with the rotor; the outer ring is fixed in the handpiece head by a resilient (rubber) O-ring.

When relative movement occurs between the inner and outer rings, the balls respond by rolling in the raceways. The balls are separated from each other by a cage that maintains their relative positions, equidistant around the rings. There is also a shield installed, in contact with the outer (but not the inner) ring, both to retain lubricant and to prevent (or at least limit) ingress of contaminants. The precision miniature bearings used are critical components that support and allow the rotor to rotate at high speed. Previous studies have shown that bearing failure, which can occur by damage to the balls, rings, or cages, is the principal determinant of handpiece performance.[3,4] Damage can arise from corrosion or mechanical damage due to wear, debris, or overloading and may occur at various sites. Failure may then be related to factors such as autoclaving time and temperature, lubrication, and bearing design. However, previous studies of handpiece performance have mainly been concerned with the effect of autoclaving, as it has generally accepted that this results in earlier failure of the handpiece bearings.

A number of studies have been based on simulated clinical use. While Wirthlin[5] reported that handpieces subjected to repeated autoclaving fail more rapidly than those that are not, it was acknowledged that the method used to measure speed and power was crude and that maintenance was not well controlled. Angelini's study[3] indicated that the nonmetallic parts of the ball bearings (ie, the retainers or cages) could be easily damaged by high temperature and that the metal parts corroded much more readily in the autoclave environment. However, these handpieces were tested without being subjected to the running conditions that would occur in clinical practice; in fact, they were not running at all. Leonard and Charlton[4] investigated the performance of nine brands of high-speed air-turbine dental handpiece that were subjected to 1000 simulated clinical use and autoclaving cycles, finding that 25 of the 54 handpieces failed before 1000 cycles and that 43% of these suffered bearing failure, all of which resulted from breakdown of the phenolic resin cage. While this result supports Angelini's[3] conclusion that phenolic resin cages were vulnerable to heat, the custom-made handpiece wear testing apparatus was acknowledged as not accurately simulating clinical usage. Nagai and Takakuda[6] investigated the influence of autoclaving on the rotational performance of five brands of ball bearing, showing that although rotation speed suffered a small decrease after 300 cycles, the ball bearings themselves showed little deterioration. However, since only some bearings here were steel, the others being ceramic, with only two handpieces for each brand evaluated, the results are not convincing.

Other studies have involved the actual clinical use of handpieces. Worthington and Martin[7] investigated the effect of repeated autoclaving on handpieces in general practice and reported that some available at that time were not capable of withstanding any autoclaving. However, the criteria used for establishing bearing failure were not clearly defined. Monaghan and coworkers[8] reported that changes in free-running speed, bearing resistance and noise can be used to monitor bearing failure. It was acknowledged, however, that the study design did not permit the resolution of the separate effects of sterilization, wear, and other factors.

Although from previous studies it has been generally accepted that autoclaving reduces the longevity of handpiece bearings, all those studies had deficiencies. None has identified the precise mechanism or mechanisms by which handpiece failures occur, and the relationship between bearing damage and handpiece behavior has not been investigated.

On the other hand, perhaps because of the high cost of replacement parts, concern over the failure of handpiece bearings subjected to repeated autoclaving has caused some dentists to avoid proper sterilization between patients.[9–12] Nevertheless, it has been recommended that routine autoclaving of all handpieces be mandatory.[13]

Therefore, the purpose here is to develop a standardized protocol to investigate the influence of the key factors on air-turbine handpiece bearing longevity through simulated clinical use with a view to improving the guidelines for handpiece preparation, sterilization, and usage.

MATERIALS AND METHODS

Thirty-six turbine assemblies with steel ball bearings (Synea TA-98, W&H, Dentalwerk, Bürmoos, Austria) were randomly allocated to nine groups of four. Four handpieces (Synea TA-98, W&H) whose original turbine assemblies had been removed provided the housings for the test turbine assemblies. Each turbine assembly was checked for visible external defects or damage prior to use. After mounting, these assemblies were subjected repeatedly to a full binary combinatorial set of operating conditions, that is, a three-way, two-level design: with and without lubrication, simulated clinical

Table 1: *Summary of Test Conditions*

Group	Lubrication	Loading	Corrosion protection	Autoclaved
1	+	+	+	+
2	+	+	−	+
3	−	−	+	+
4	−	−	−	+
5	+	−	+	+
6	+	−	−	+
7	−	+	+	+
8	−	+	−	+
9	+	−	−	−

loading, and corrosion protection, all with autoclaving, to the point of failure (Table 1). A control set, lubricated only, was included. The turbine assembly free-running speed at 2.0 bar and bearing resistance were measured at baseline and after every 10 cycles until failure using a purpose-made instrument (Darvell-Dyson Handpiece Tester, Dental Materials Science, University of Hong Kong).[14] Each test condition was applied, as appropriate, according to the following procedures.

Loading

A loading apparatus was developed to simulate loading during clinical use (Figures 1 and 2). A dental turbine-handpiece ball bearing (Part Number DDR1-418, NMB Technologies Corporation, Chatsworth, CA, USA) was pressed on to a push-button spindle-chuck (Topair 796, push-button model, W&H). A 30-mm-long standard mandrel was fully seated in the chuck. The bearing was fixed into a brass bearing housing by slide fit (tolerance +0.000, −0.001 mm) and capped by a brass disc with two screws to retain it in position. A weight (50 g) carried by this bearing provided a controlled, standardized load of 0.56 N (ie, from the mass of the weight, 50.0 g, and the loading apparatus, 6.9 g, under local gravity) to the handpiece bearings both radially and axially. This was done by clamping the handpiece with the mandrel of the loading apparatus at an angle of 45°.

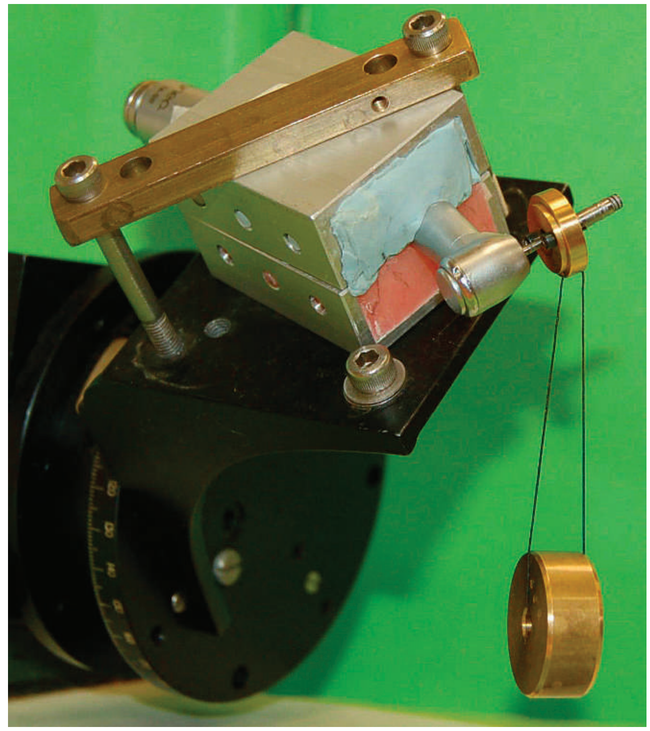

Figure 1. *Handpiece loading apparatus.*

A purpose-made block, the same type as used on the Darvell-Dyson handpiece tester,[14] was made to clamp the handpiece. The load used was arbitrary but guided by the following points: first, to avoid stalling the turbine, it has been reported that, depending on the air supply and instrument design, the load required to stall the handpiece may range from 110 to 200 g[15] or 110 to 150 g[16] (units as reported by those authors); second, to have a long enough lifetime for the loading bearing (see below); and third, to represent a clinically reasonable load,

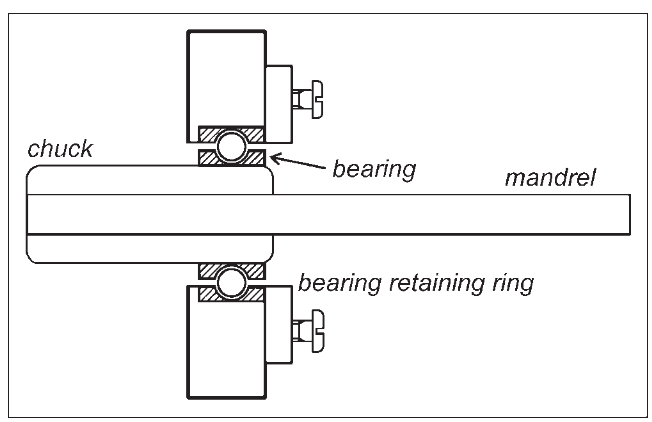

Figure 2. *Schematic vertical section of the loading device.*

the literature indicates that the average applied load during restorative procedures lies in the range 10–150 g.[17,18] The load was a compromise between what would be seen as abusive and enough to obtain a result in a reasonable time.

Test Procedure

For the loaded groups (1, 2, 7, and 8), the procedure used was as follows:

- The loading apparatus or a dummy mandrel was seated in the handpiece chuck.
- The axis of the mandrel was adjusted to 45°.
- The air supply was connected.
- The air was turned on, and the operating pressure was adjusted to 2.0 bar as necessary; the handpiece was allowed to reach operating speed (~2 seconds).
- The handpiece was then allowed to run for 20 seconds.
- The air pressure was turned off; the handpiece was stopped within about two seconds.

A total of 10 repetitions of the last three steps were made in each cycle, representing a nominal four minutes of clinical use. This represents a total of some 171 hours of running time.

Connection of the air supply was by four-hole connector (Roto Quick, W&H) with separate water and air tubes to the handpiece coolant system as well as connections for drive air and exhaust. While running, the handpiece and the load bearing in the brass housing were cooled by water from the handpiece spray system. The water supply was set to not less than 50 mL/min, the minimum required by the handpiece instructions, using a flow meter and valve. Coolant water and air were mixed in the handpiece coolant tube and delivered through five spray nozzles.

The load bearing was lubricated after each four minutes of use. After some period of use, the play between the bearing and the housing increased to the point of collapse. When this occurred or was thought to be imminent, the housing and bearing were replaced; this was after about every 100 cycles.

Groups 3–6 were run (no load) only just enough to determine the free-running speed (40–60 seconds) after each 10 cycles of autoclaving, with groups 5 and 6 being run for an additional 30 seconds to expel excess lubricant (see below) before each autoclaving cycle. Likewise, group 9 (no autoclaving) was run for only 30 seconds to expel oil after each cleaning and lubrication cycle, and for 40–60 seconds every 10 such cycles to determine free-running speed.

Cleaning and Lubrication

The handpiece shell was first cleaned with a 75%alcohol-soaked cloth according to instructions; any liquid residue was removed with absorbent cloth, and it was then blown dry with compressed air. Water-spray nozzles were treated with a nozzle cleaner to remove any dirt or deposits. The coolant tube was blown through with air.

For groups 1, 2, 5, 6, and 9, the handpiece was then lubricated according to instructions (Assistina, W&H). The handpiece head was then directed downward and run for 30 seconds to remove excess oil, again as per instructions. During this, a clean tissue was held around the head to absorb excess oil. If there was any sign of dirt emerging, that is, the tissue appearing to be soiled (discolored oil), the complete cleaning process was repeated until there was no discoloration evident. The handpiece was wiped with gauze.

Autoclaving

An autoclave (ST-Im30b, Eschmann Bros & Walsh, West Sussex, England) was used for autoclaving the turbine assemblies (groups 1–8). The turbine assembly was dismounted before each autoclaving and remounted for testing. The dismounting procedure involved unscrewing the handpiece back cap using the cap wrench, removing the assembly by applying pressure to the spindle. As per the manufacturer's instructions, assemblies were wrapped individually in sterilizer bags (paper side up, plastic side down) and placed in the sterilizing chamber. The program "134°C with drying" was used: 13 minutes to reach 134°C, hold for 3 minutes at 134°C, and up to 17 minutes of drying. The sterilizer was maintained as required (every three months). A total of some 12,000 "turbine autoclave" cycles were conducted.

For remounting, an alignment index had been scribed on the flange of each handpiece head cap and then on the top of the push-button spindle of each turbine assembly at first use. Checking index alignment to avoid possible variation in the loading conditions, the back bearing was carefully inserted into the handpiece back cap and the spindle gently rotated to ensure that it was fully seated. Holding the turbine upright, it was then inserted into the handpiece head and the back cap tightened. A dental bur was then inserted into the chuck and rotated to ensure that the turbine moved freely.

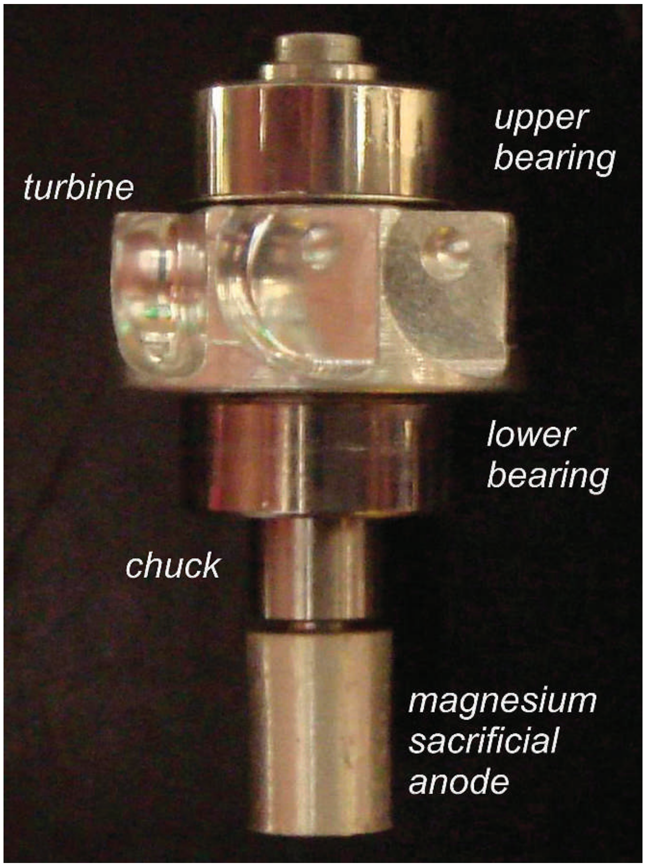

Figure 3. *Corrosion protection. Turbine assembly as prepared for autoclaving with the magnesium sacrificial anode mounted.*

Corrosion Protection

Magnesium rod (MG007924, Goodfellow, Cambridge, UK) was used for sacrificial anodes. This was machined to small billets (6.1 mm length, 3.2 mm diameter), drilled and press-fitted onto the steel shaft of deheaded burs (18.0 mm length, 1.62 mm diameter). This assembly was fixed in the turbine assembly chuck (Figure 3) during the autoclaving of groups 1, 3, 5, and 7.

Failure Criteria

Failure of a turbine was deemed to have occurred when there was an abrupt loss of free-running speed and increase in bearing resistance. If a turbine failed during an evaluation, the air supply was turned off and restarted for a maximum of two attempts. If it did not restart, it was considered to have failed.

Statistical Analysis

Graphical analysis and statistical tests were done in software (SPSS for Windows, version 15; SigmaPlot version 9, SPSS, Chicago IL, USA). Initial inspection showed that the variance of the results depended on the number of cycles to failure, and a logarithmic transformation was found to stabilize the variance adequately. Accordingly, a three-way analysis of variance (lubrication $\times$ protection $\times$ loading) of log(cycles to failure) made. The critical value for statistical significance was set at $\alpha = 0.05$.

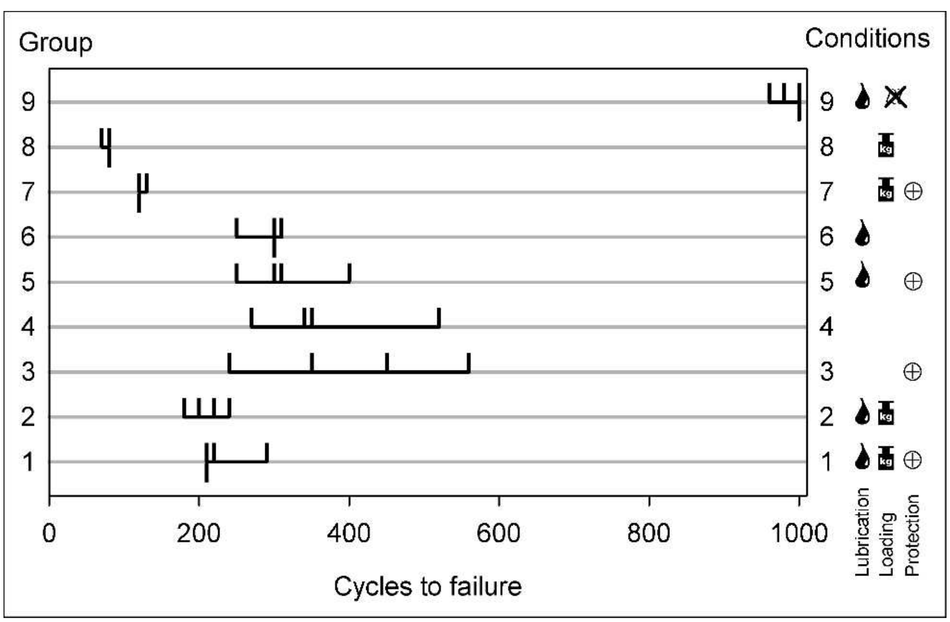

Figure 4. *Number of cycles to failure for all turbine assemblies, all autoclaved except group 9. Descending ticks indicate duplicated (or triplicated: groups 7 and 8) values. Groups 1–8 were all autoclaved each cycle.*

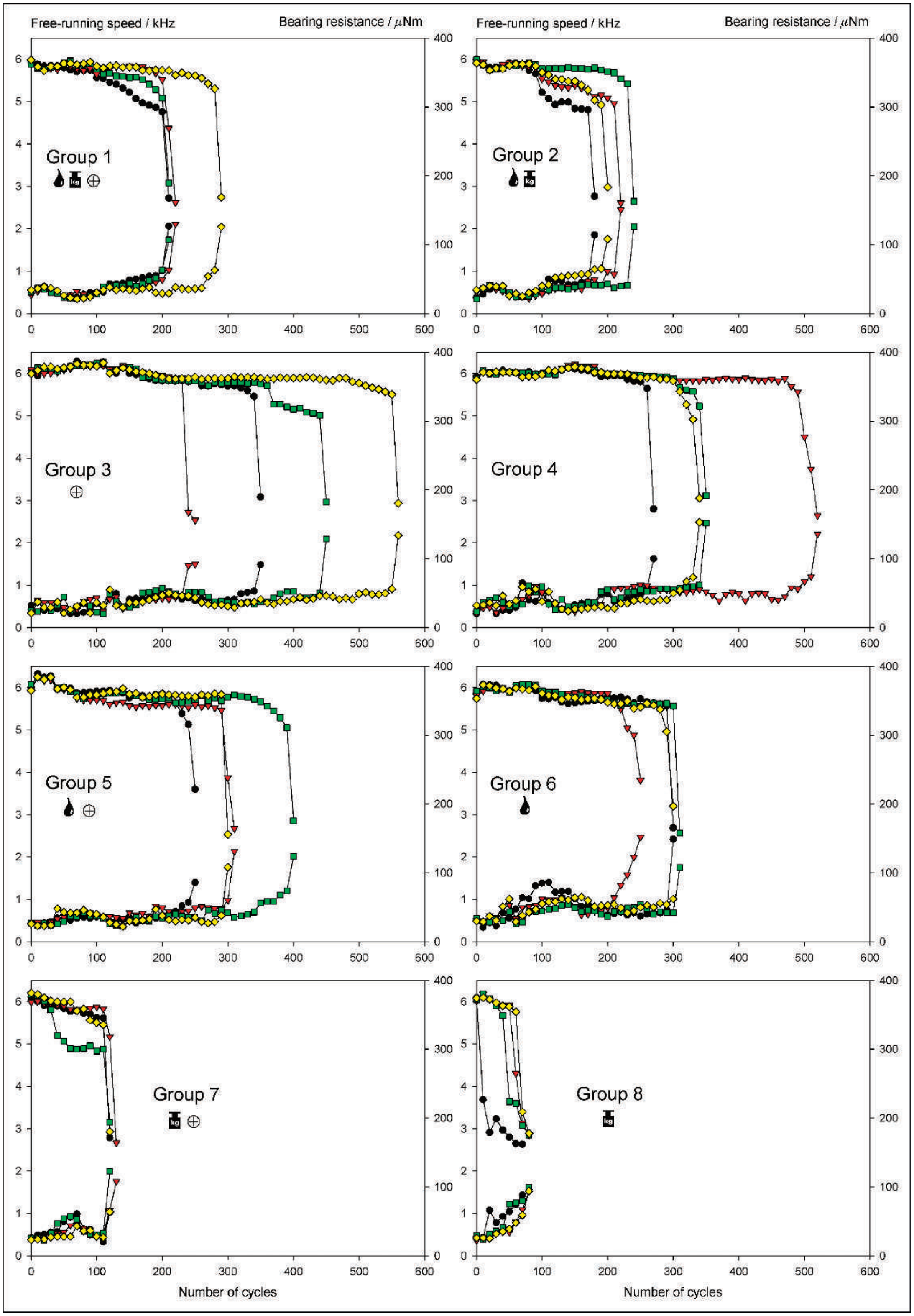

Figure 5. *History plots for group 1–8 turbine assemblies. Upper curves: free-running speed; lower curves: bearing resistance.*

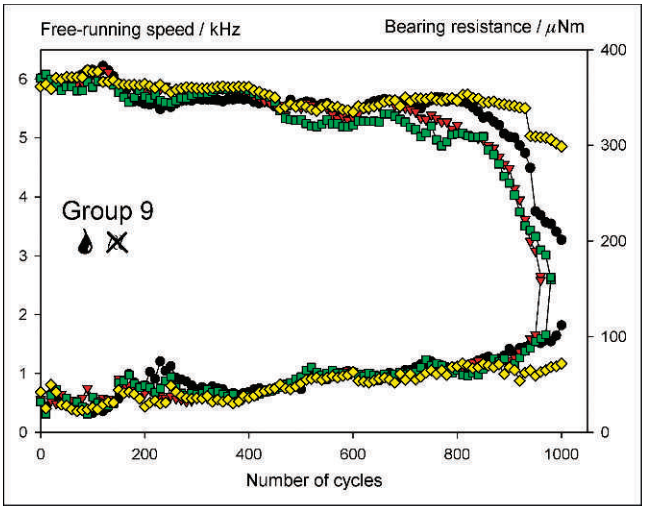

Figure 6. *History plots for group 9 turbine assemblies (controls): not autoclaved or loaded but lubricated. Other details as Figure 5.*

RESULTS

All autoclaved turbines had failed by 560 cycles (Figure 4). Those running under load without lubrication failed very quickly (group 7: 130 cycles, group 8: 80 cycles). All averages here are geometric, that is, calculated from the arithmetic mean of log(cycles to failure).[19] The longest-lasting groups were groups 3 and 4, subject only to autoclaving, but with corrosion protection for group 3, it took, respectively, up to 560 and 520 cycles to failure. In comparison, the control group 9, that is, lubricated but unloaded, nonautoclaved, failed between 960 and 1000 cycles.

Test result histories are shown in Figures 5 and 6. Free-running speed in all autoclaved groups (1–8) showed a general decline in value with time, which was more apparent on loaded groups (1, 2, 7, and 8). However, there was always an abrupt decrease in value at or shortly before the last monitoring point (ie, before actual failure). Although the bearing resistance of some groups varied to some extent before failure, the trend for increase with time was most apparent on loaded groups. Furthermore, a mostly abrupt increase had also occurred at the last monitoring point.

A three-way analysis of variance (Table 2) showed that each of the three main effects—loading, lubrication, and corrosion protection—was significant. The only interaction to reach significance was lubrication × loading. To try to understand this interaction better, a two-way analysis of variance was made, that is, averaging over the effect of corrosion protection (Tables 3 and 4).

Load influenced bearing lifetime highly significantly when there was no lubrication: groups 7 and 8 failed by 97 cycles on average, but groups 3 and 4 failed at 370 cycles on average (Table 4). However, this effect was reduced when lubrication was present, that is, comparing groups 5 and 6 with

Table 2: *Three-Way Analysis of Variance: Lubrication × Loading × Protection*

Source of variation	*df*	SS	MS	*F*	*p*
Lubrication	1	0.13595	0.13595	19.30006	0.000194
Loading	1	1.02480	1.02480	145.48342	$<$0.000001
Protection	1	0.04464	0.04464	6.33675	0.0189
Lubrication × loading	1	0.39581	0.39581	56.18982	$<$0.000001
Lubrication × protection	1	0.01142	0.01142	1.62179	0.215
Loading × protection	1	0.01710	0.01710	2.42761	0.132
Lubrication × loading × protection	1	0.01316	0.01316	1.86841	0.184
Residual	24	0.16906	0.00704		
Total	31	1.81194	0.05845		

Table 3: *Two-Way Analysis of Variance: Lubrication × Loading*[a]

Source of variation	*df*	SS	MS	*F*	*p*
Lubrication	1	0.13595	0.13595	14.90576	0.000194
Loading	1	1.02480	1.02480	112.35926	<0.000001
Lubrication × loading	1	0.39581	0.39581	43.39633	<0.000001
Residual	28	0.25538	0.00912		
Total	31	1.81194	0.05845		

[a] *Holm-Sidak multiple comparisons: effect of loading within lubrication:* $p=0.00837$*; effect of loading without lubrication:* $p<0.000001$*; effect of lubrication within loading:* $p<0.000001$*; effect of lubrication without loading:* $p=0.064$.

groups 1 and 2, which failed at 300 and 219 cycles, respectively, on average. On the other hand, the protection of lubrication was significant only during running under load, from a comparison of groups 7 and 8 (97 cycles) with groups 1 and 2 (219 cycles), increasing the lifetime substantially. However, there was no detectable protection effect for no load, comparing groups 3 and 4 with groups 5 and 6 ($p=0.064$) (Table 3).

The correlation of free-running speed with bearing resistance was examined (Figure 7), but this was generally very weak overall except at the last one or two data points and offered no predictive value in itself.

DISCUSSION

Loading

Autoclaved bearings running under load with no lubrication failed after 97 cycles on average (groups 7 and 8), but "only autoclaved" bearings lasted to 370 cycles (groups 3 and 4), which indicates that load is a dominant factor. Cyclic stress caused by loading has always been considered the most direct reason for industrial ball-bearing fatigue. Previous studies of dental ball bearings have been focused on the effect of autoclaving on longevity, it being generally believed that the bearing would be affected primarily by repeated autoclaving. However, these studies have ignored the strongest effect, that is, the load on the bearing, which has been understood intuitively or at least reasonably deduced. The present study is the clearest demonstration of this to date.

Table 4: *Interaction of Lubrication × Loading on Number of Cycles to Failure (Geometric Mean Values)*

		Loading	
		−	+
Lubrication	−	370 (groups 3 and 4)	97 (groups 7 and 8)
	+	300 (groups 5 and 6)	219 (groups 1 and 2)

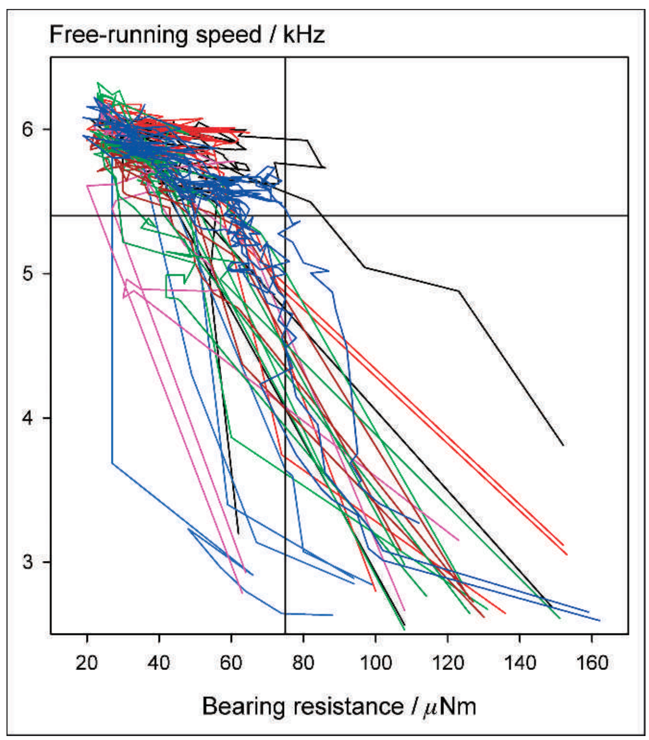

Figure 7. *Correlation plot for free-running speed vs bearing resistance, all data. Example threshold values for preventive maintenance decisions set at −10% nominal original value (ie, 5.4 kHz) and 75 μNm, respectively.*

Any external load that is applied to an air-turbine handpiece is transferred to its bearings *via* the shaft in the handpiece chuck. The load can be decomposed into two components: radial (normal to the chuck axis) and axial (along the chuck axis). Investigation of the effect of such loads separately on the bearing could lead to better understanding of behavior. However, many operating variables involved in dental cutting, such as choice and wear of the rotary cutting instrument, type of workpiece, and operator usage, could influence bearing performance, all of which could interact with the effect of load on the bearing. While they should in principle be isolated or under strict control before applying a test load, this is clearly a challenging problem.

The testing regime used here met two important requirements: a reproducible and simple test method and good control of operating variables. The use of the loading device eliminated all effects related to cutting instrument, workpiece, and operator and provided a combination of radial and axial loads to the bearing through its angulation. In contrast, in previous studies, fixed angles of 90° or 0°, giving only pure axial or radial loads, have been applied;[20–23] clinical relevance is therefore lacking when such "pure" loading is at best uncommon. That is, such an approach cannot simulate real dental cutting procedures, which include combinations of plunge cutting, slot milling, and surface reduction and more complex loading.[17] Although the fixed angle of 45°, giving equal radial and axial loads simultaneously, cannot fully represent all cutting types, it is believed to have simulated dental cutting, at least on average, much more effectively than previous studies.

Lacking data on the duty cycles employed by dentists in actual clinical work, most experimental work on cutting instruments applied to the workpiece (or *vice versa*) has been in the range of 5-300 seconds at a time,[17] although it is recognized that constant force for even a short period is not realistic. The quasi-static loading (ie, ignoring the dynamic effects of the rotating bearing system) used here, for a series of 10 repetitions of 24 seconds duration each, is estimated to represent a clinical duty cycle to a total of 4 minutes running. While we accept that all the choices made in this regard are essentially arbitrary, with no specific justification possible, we believe them to be reasonable. However, a key aspect of any test protocol is good discriminatory power, and this does appear to have been achieved without resorting to abusive "accelerated" testing. In addition, one model of handpiece and turbine assembly was used throughout, with consistent lubrication and air pressure of 2.0 bar, minimizing the effects of such factors.

The considerable variation in free-running speed observed over the lifetime of each turbine assembly suggests the action of several factors beyond simple wear, as indicated perhaps by the general lack of correlation with bearing resistance (Figure 7). Free-running speed seems to be the more sensitive of the two, and this suggests a possible approach to preventive maintenance. Thus, setting a threshold of −10% with respect to the as-new free-running speed, here 5.4 kHz (324,000 rpm), would be effective, while using a figure such as 75 μNm for bearing resistance would not in general be helpful. We may also note from this insensitivity that feeling the bearing resistance manually, by rotation of a mandrel or bur between finger and thumb, is unlikely to allow detection of incipient failure.

Lubrication

Most dental ball bearings require lubrication for better performance and durability.[3,24] The lubricating oil used in dental bearings must easily form a fluid film, providing a load-carrying component that effectively separates the contact surfaces, and give good conduction of heat within the bearing. Both main lubrication methods in use in dentistry—spray cans for manual lubrication and automatic units[25]—provide an oil mist that passes over the bearing. In addition, there is a dropper-style applicator for oiling a handpiece, and this also needs pressurized air to deliver the oil to the bearing after applying 2–3 drops to the drive air hole. Usually, ball bearings need only small amount of lubricant for normal operation.[26] However, in actual dental applications, again given the lack of data on duty cycle,[17] the amount of oil that could suffice remains unclear. For the sake of operational reliability, most dental bearings are required to be lubricated before autoclaving or after every use, according to instructions; under such circumstances, both inadequate lubrication or over-lubrication might occur. Heat generated inside the bearing as a result of insufficient or improper lubrication raises the operating temperature of the bearing and the lubricant, leading to decreased bearing life.[26] Such damage can be avoided by selecting the appropriate lubricant method and frequency. Lubrication here was done through an automated machine, and the relubrication interval was under strict control according to the manufacturer's instructions. The results showed that proper lubrication had a significantly positive effect

($p<10^{-6}$) on bearing longevity when running under load (Table 3). On the other hand, "If excessive lubricant cannot escape from the bearing, churning or working causes the temperature to rise to such an extent that the lubricant loses its lubricity and the bearing fails from defective lubrication."[26] Although it is impossible to flush completely all excess oil just by 30 seconds of running after maintenance[27] (and this begs the question of what exactly constitutes an excess or, conversely, how much oil is considered to be correct), whether normal running of a dental air-turbine could cause the oil temperature to rise to the point where it loses its function has not been reported. However, flushing the handpiece with enough lubricant will not only ensure that oil reaches all moving parts but should also prevent the destructive accumulation of debris and a consequent decline in performance.[28,29]

It was noted that the lifetime of autoclaved bearings under the condition of no load but with lubrication (groups 5 and 6: 300 cycles on average) was not statistically different from that of only-autoclaved bearings (groups 3 and 4: 370 cycles). One reason may be that the lubricant offers no protection under the extreme conditions of autoclaving. The oil film cannot prevent water from reaching the metal by dissolving in and diffusing through it, especially under the high-temperature, high-humidity conditions of the autoclave, assisted by the low oil viscosity at high temperature. Another possible reason might be related to the repeated mounting and dismounting of the turbine assembly. Groups 3 and 4 were mounted and dismounted only after every 10 cycles, when their performance was monitored, but other assemblies were done every cycle. Whether this process has an effect on the bearing cannot be ascertained here. However, it is expected that the effect, if any, should be very slight since they were handled carefully and not subjected to any great forces. Indeed, since the control set, group 9, with only lubrication but dismounted each 5 cycles, failed between 960 and 1000 cycles, the influence of such mounting and dismounting indeed appears to be very small (one assembly in group 9 broke while dismounting after 1000 cycles: the rear bearing separated from the spindle). Even so, group 9 survived more than three times as many cycles as groups 5 and 6 (300 cycles), which were under the conditions of lubrication and autoclaving. This also indicates that autoclaving does contribute substantially to bearing failure, although it appears not to be the leading factor compared with loading (groups 7 and 8: 97 cycles on average).

Autoclaving

Dental bearing rings and balls usually are made from 440C stainless steel.[2] The high carbon and chromium provides high hardness, and the chromium provides considerable resistance to corrosion due to chromium being oxidized to form a transparent protective surface oxide film. However, in certain environments, where aqueous media and, in particular acids penetrate the bearing, the oxide film may be damaged, and it cannot provide enough protection for the steel surface so that corrosion occurs. The corrosion process of steel is of an electrochemical nature. The following representative reaction of iron thus may occur during autoclaving in the presence of oxygen and water:[30]

$$2\,Fe + {}^{1}/_{2}\,O_2 + 5\,H_2O \leftrightarrow 2\,Fe(OH)_3 + 4\,H^+ + 4\,e^-$$

Steam and its condensate provide the corrosive medium during autoclaving, and since the air in the sterilizer chamber cannot be fully removed, dissolved oxygen and carbon dioxide (acidifying) would promote corrosion. A sacrificial anode is a piece of metal that is more easily oxidized than that which is to be protected; the latter therefore becomes the cathode in an electrochemical cell.[31] This method has been used primarily for underground metallic structures that are in direct contact with soil and prone to corrosion. The anodes are usually magnesium or magnesium-based alloys, but occasionally zinc and aluminum have been used. Magnesium was used here because of its high electropositivity in comparison with handpiece and turbine materials. The anode here was fixed in the turbine chuck to provide an electrical connection during autoclaving in a manner that would be practical in ordinary contexts should it be found to be effective. However, a possible problem worth noting is that leaving a mandrel in the handpiece during autoclaving might compress the chuck spring, according to some manufacturers. Subjecting such a spring to heat under tension might affect the chuck system. Although no such failure was observed now, this should be checked. Even so, a sacrificial anode would appear to offer some benefit and could with value be further investigated even if the electrical connection has to be modified. As far as we know, this the first dental application of this technique.

In addition to corrosion, damage caused by heat arising from autoclaving cannot be avoided. Previous studies have confirmed that nonmetallic parts are easily damaged at high temperature.[3] Dental bearing cage materials commonly used include polyamide-imide (Torlon) and phenolic composites.[32,33] Phenolic cages have a tendency to become brittle and break—the maximum heat tolerance is 149°C,[3] but they will maintain low friction characteristics even in the absence of proper lubrication due to the material's porosity, which can provide some oil storage.[34] Torlon is a thermoplastic characterized by good stability and strength at high temperature and so can provide good autoclave resistance. This material has the disadvantage of being nonporous, so it can hold no lubricant,[35] and this leads to immediate destruction if there is no lubricant available in the bearing.

Some attempts have been made to obtain a good combination of wear and autoclave resistance by modifying the polyamide resin or phenolic material or with additives in the materials.[32,33] However, there appears to be no independent research to confirm these materials' advantages. No other class of material has been developed for this application.

CONCLUSION

Through a protocol designed to simulate clinical use of steel dental ball-bearing, air-turbine handpieces, given that autoclaving is a required procedure, load was found to be the most important negative influential factor on bearing longevity. The appropriateness of following recommendations to use light loads is therefore reaffirmed.[36,37] Lubrication, as expected, was found to have a significant positive effect on bearing longevity and especially so for handpieces running under load. The importance of following lubrication instructions is thereby confirmed. In addition, the use of a sacrificial anode was found to have a significant beneficial effect, suggesting that corrosion during autoclaving is an important factor contributing to failure. Given the high cost of dental turbines, the fitting of a relatively cheap sacrificial anode to the handpiece for autoclaving can be recommended.

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