The Effect of 3 Torque Delivery Systems on Gold Screw Preload at the Gold Cylinder–Abutment Screw Joint

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Purpose: *This study measured the gold screw preload at the gold cylinder–abutment screw joint interface obtained by 3 torque delivery systems.* ***Materials and Methods:*** *Using a precalibrated, strain-gauged standard abutment as the load cell, 3 torque delivery systems tested were shown to have significant differences in gold screw preload when a gold cylinder was attached.* ***Results:*** *Mean preloads measured were 291.2 N for hand torque drivers set at 10 Ncm, 340.3 N for electronic torque controllers at low setting/10 Ncm, 384.4 N for electronic torque controllers at high setting/10 Ncm; and 140.8 N for hand-tightening with a prosthetic slot screwdriver. Significant differences in screw preload were also found between operators using a hand torque driver.* ***Discussion:*** *Hand-tightening delivered insufficient preload and cannot be recommended for final gold screw tightening. Different electronic torque controller units set at 10 Ncm induced mean gold screw preloads that ranged from 264.1 N to as high as 501.2 N.* ***Conclusion:*** *Electronic torque controllers should be regularly recalibrated to ensure optimal output.* (INT J ORAL MAXILLOFAC IMPLANTS 2002;17:175–183)

Key words: *gold screws, screwdriver, screw joint, screw preload, strain gauge, torque controller, torque driver*

One of the most common prosthetic complications in full-arch, implant-supported prostheses involves the prosthetic gold screw joint[1–2] which attaches the implant prosthesis framework to the abutments. Both gold screw loosening[1,3–5] and gold screw fractures[6–10] have been reported at prosthetic recalls.

One of the factors implicated in these gold screw complications has been inadequate torque delivery during the screw-tightening process.[2,11] For the Nobel Biocare System (Göteborg, Sweden), the manufacturer-recommended torque for this screw is 10 Ncm. The optimal preload to be imparted to the prosthetic gold screw to clamp down the gold cylinder to the abutment has been suggested to be 300 N so as to maintain screw joint stability.[12–14] The use of mechanical drivers as a more efficient torque delivery device has been linked to lower incidence of screw loosening.[11]

Variables that influence torque delivery have been reported in previous studies.[15–16] However, torque applied to the screw joint during the tightening operation does not necessarily translate to actual screw preload developed in the screw shank and its equal and opposite compressive clamping force to hold the prosthetic components together. Some energy will be expended to overcome friction between the screw head and the abutment seating area, as well as friction between the screw threads and the implant internal threads of the receiving component.[17–18]

All previous studies investigating variations in torque delivery systems have measured torque using torque gauges or torque meters.[15-19] However, the

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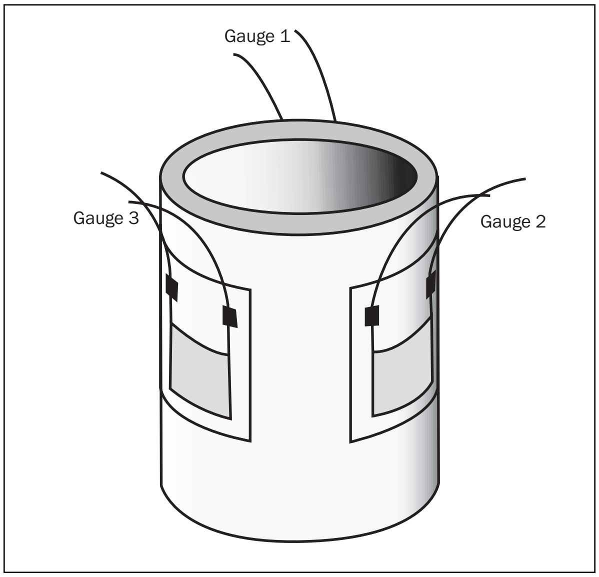

Fig 1a *(Left)* Strain gauge orientation on test abutment.

Fig 1b *(Below)* Master cast with strain-gauged abutments.

actual preload developed in the gold screw from these various torque delivery systems has not been reported.

The aim of this study was to measure the differences between 3 torque delivery systems on the gold screw preload at the gold cylinder–abutment screw joint interface. The systems compared were hand torque driver, electronic torque controller (low and high settings), and hand screwdriver.

MATERIALS AND METHODS

Master Model Fabrication

Five 3.75×10-mm titanium implants (SDCA 001, Nobel Biocare USA, Yorba Linda, CA) were retained in an Ivocap (Ivoclar, San Marcos, CA) edentulous mandibular master cast. The edentulous ridge was milled flat, and 5 implant holes 3.85 mm in diameter, 8 mm apart center to center, and 9 mm deep were parallel-milled in this flattened mandibular ridge. The implants were secured in place with pattern resin (GC International, Scottsdale, AZ). Standard 4-mm titanium abutments (SDCA 006, Nobel Biocare USA) were attached to the implants using abutment screws tightened to 20 Ncm using a hand torque driver (DIA 250, Nobel Biocare USA). The abutments were fixed by a cementing medium (Panavia EX, J. Morita USA, Tustin, CA) between the abutment screw and the internal surface of the abutment cylinder.

Strain Gauge Placement

Three strain gauges (Type EA-06-062AP-120 Option LE, Measurements Group, Raleigh, NC) were attached to each abutment approximately 120 degrees apart (Fig 1a). The strain gauges used had a gauge factor of 2.065 ± 0.5% at 24°C. Gauge adhesive (M-Bond 200 Adhesive, Measurements Group) was used to attach the strain gauges firmly to the cleaned abutment surface. Wire connections were made with the aid of bondable terminals to protect the delicate strain gauge leads. The overall arrangement of 3 gauges to each abutment gave a total of 15 strain gauges for the 5-abutment model (Fig 1b). All 5 abutments were gauged at the beginning as part of a larger follow-up study. However, only 1 abutment was designated as the "test" abutment in this study.

Strain Measurement

Strain measurement was made using a HP 75000 Series B multimeter (Hewlett-Packard, Loveland, CO) with 2 HP E1357A strain gauge multiplexers (Hewlett-Packard). The instrumentation was wired to the 3 strain gauges using 3 of the 16 channels available on the multiplexer boards. An HP IBASIC program (Hewlett Packard) scanned each of the 3 strain gauges 20 times sequentially to give an average strain reading per gauge. Strain readings were performed using the quarter-bridge configuration of the strain multiplexer instrumentation. All strain measurements were made with ambient temperature conditions kept constant. The strain-gauge circuitry was allowed to warm up for at least 1 hour before measurements to allow temperature stabilization.

Calibration of Test Abutment

The steps in the calibration of the designated "test" abutment were:

Fig 2a Hand torque driver (NB DIA 250).

Fig 2b Electronic torque controller (NB DEA 020).

1. A new gold cylinder (DCA 072, Nobel Biocare USA) was placed on the test abutment and a new prosthetic flat-headed, slot gold screw (DCA 075, Nobel Biocare USA) was placed. The gold screw was torqued down with a hand torque driver and then backed off so that no preload was induced. A brass positioning jig previously attached to the gold cylinder was used to aid in repositioning in all subsequent test sequences.
2. The strain instrumentation was zeroed.
3. Known vertical loads, in increments of 50 N up to 300 N, were applied directly onto the gold cylinder–abutment unit by loading the top of the gold cylinder-positioning jig assembly using an Instron Universal Testing Machine (Instron, Canton, MA).
4. Gauge output (microstrain values, $\mu\epsilon$) was recorded from each of the 3 gauges.
5. All calibration measurements were repeated 3 times and the mean was used in the calculations.
6. For each specific gauge, a calibration curve of load versus strain was plotted and a load calibration coefficient computed.

A similar protocol of using the abutment as a load cell with 4 strain gauges attached and in vitro calibration with known loads has previously been described by Glantz and associates[20] and Carr and colleagues.[21]

Gold Cylinder Position

A preliminary study found that placing the gold cylinder in 4 different positions on the abutment gave different microstrain readings from the 3 strain gauges when the prosthetic gold screw was torqued to 10 Ncm with the hand torque driver. These positions were 90 degrees apart (north, east, south, and west). These differences were repeatable and were not from torque delivery variation. This indicated that the areas of contact of the gold cylinder onto the abutment were highly individual for that particular gold cylinder–abutment pairing and relative seating position. This variability could possibly come from machining effects.

Thus the gold cylinder–abutment pair used for this study was calibrated for a particular seating orientation. This was achieved through the use of a repositioning jig—a brass bar attached to the gold cylinder—which allowed repeatable orientation of the test gold cylinder. The repositioning jig was used to keep the gold cylinder orientation constant throughout all experimental torque down operations.

Experimental Conditions for the Gold-Screw Tightening Procedure

Torque Delivery Systems. The following "systems" were compared:

1. Three hand torque drivers (DIA 250, Nobel Biocare USA) labeled H1, H2, and H3. Torque setting used was 10 Ncm and the short, slot machine driver (DIA 188, Nobel Biocare USA) was used (Fig 2a).
2. Four electronic torque controllers (DEA 020, Nobel Biocare USA) (Fig 2b) labeled E1, E2, E3, and E4. Each was set to the 10 Ncm torque setting. These 4 electronic torque controllers were further tested at both the low- and high-speed settings. The short, slot machine driver (DIA 188, Nobel Biocare USA) was used.

All torque-down operations for the 3 hand torque drivers and the 4 electronic torque controllers were performed by the same operator to reduce variability.

Figs 3a and 3b Torque-down operation: Tightening gold screw to attach standard gold cylinder onto test abutment using (a) machine drivers–hand torque driver (NB DIA 250) or electronic torque controller (NB DEA 020) and (b) hand tightening with prosthetic slot screwdriver (NB DIB 048).

3. Finger tightening with a short, slot hand screwdriver (27 mm, stainless steel, DIB 048, Nobel Biocare USA). Three operators (A, B, and C) performed the torque-down operations and these 3 finger-tightening operations were labeled S1-A, S1-B, and S1-C.

Operator Variability with Hand Torque Driver. To study operator variability in the torque-down operation, 5 operators used the same hand torque driver (H1) to torque down the "standard" gold cylinder. Each operator performed 5 repetitions of the torque-down operation. The operators were 2 experienced clinicians (A, B) and 3 dentists with only initial experience in implant prosthodontics (D, E, and F).

Gold Screw Preload Measurement Procedure

The steps in measurement of the gold screw preload from various torque delivery systems were:

1. The "standard" gold cylinder was placed onto "test" abutment.
2. Correct seating orientation of gold cylinder was checked with repositioning jig.
3. Strain measurement instrumentation was zeroed.
4. Torque-down operation on gold screw was performed using the experimental conditions described above.
5. Strain measurements were taken with the HP IBASIC program scanning the 3 strain gauges sequentially and giving the mean microstrain (με) for 20 readings per gauge.
6. The gold screw was loosened for next repeat measurement.
7. Steps (3) to (6) were repeated 4 times to give a total of 5 measurement repetitions for each torque-down experimental condition. Figure 3a shows the hand torque driver in position during the torque-down operation with the repositioning jig providing the correct abutment orientation. Figure 3b shows the hand screwdriver being used to torque the gold screw.
8. Microstrain (με) measurement values were then placed into a personal computer spreadsheet program (Excel 4.0, Microsoft, Redmond, WA) and the previously computed calibration coefficients specific to each strain gauge were used to calculate gold screw preload. The computed preloads from the 3 strain gauges were averaged.

Statistical Analysis

Both sets of data were subjected to a 1-way analysis of variance (ANOVA) and group means were compared with the Tukey HSD post hoc test at $P = .05$ significance level (SPSS 8.0, SPSS, Chicago, IL).

RESULTS

Torque Delivery Systems

Table 1 and Fig 4 illustrate the mean preload in the gold screw when the standard gold cylinder was torqued down onto the strain-gauged test abutment using the torque-delivering devices tested. The mean preloads measured for hand torque drivers ranged from 286.2 N to 300.1 N with a group mean of 291.2 N (± 33.4). For the electronic torque controllers, mean preloads ranged from a high of 501.2 N for E4 (high) to a low of 264.1 N for E2 (low). The group means for the low settings was 340.3 N (± 71.6) and 384.4 N (± 84.3) for the high settings. In comparison, the mean preloads measured for the hand screwdriver ranged from 123.1 N for Operator A (S1-A) to

163.4 N for Operator C (S1-C) with a group mean of 140.8 N (± 27.5).

Table 2 lists the different statistical subsets amongst the various torque delivering devices obtained from a 1-way ANOVA procedure. All 3 operators using the hand screwdriver achieved significantly lower preloads when compared to the hand torque drivers or the electronic torque controllers. All 3 hand torque drivers were not statistically different from one another. All electronic torque controllers gave higher measured preloads with the high-speed setting compared to the low-speed setting. These differences were statistically significant for electronic torque controllers E2 and E4, but not for E1 or E3.

Operator Variation with Hand Torque Driver

Table 3 and Fig 5 illustrate the mean preloads measured during the torque-down operations of the 5 operators using the hand torque driver, H1. The mean preloads ranged from a high of 300.1 N (± 19.7) for Operator A to a low of 233.4 N (± 30.8) for Operator E. The overall mean for all operators was 261.0 N (± 33.0). One-way ANOVA revealed significant differences between Operators B and E and Operator A (Table 4).

Table 1 Gold Screw Preload (N) from Hand Torque Driver, Electronic Torque Controller, and Hand Screwdriver

Torque driver system	Mean preload* (N)
Hand torque driver‡	
H1	300.1 (19.7)†
H2	286.2 (22.3)
H3	287.2 (53.5)
Group mean	291.2 (33.4)
Electronic torque controller‡	
Low-speed setting	
E1-L	392.3 (15.7)
E2-L	264.1 (18.9)
E3-L	283.7 (13.7)
E4-L	421.0 (27.2)
Group mean	340.3 (71.6)
High-speed setting	
E1-H	418.9 (15.8)
E2-H	319.0 (6.4)
E3-H	298.7 (8.1)
E4-H	501.2 (18.8)
Group mean	384.4 (84.3)
Hand screwdriver§	
S1-A	123.1 (19.4)
S1-B	136.0 (24.6)
S1-C	163.4 (24.6)
Group mean	140.8 (27.5)

*n = 5 measurement repetitions. Each mean was computed from 5 repetitions.
†Standard deviation in parentheses.
‡All 3 hand torque drivers and 4 electronic torque controllers were set at the 10 Ncm setting for gold screw tightening. All torque-down operations were performed by Operator A.
§Hand-tightening with hand screwdriver S1 performed by Operators A, B, and C.

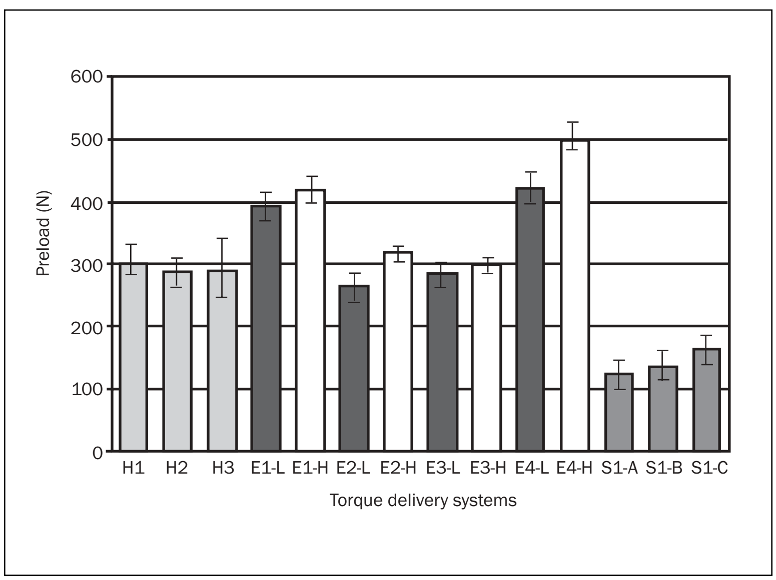

Fig 4 Mean preload (N), by torque delivery system; error bars are ± 1 SD.

Table 2 One-way ANOVA of Torque Delivery Systems*

Statistically significant subsets
[S1-A, S1-B, S1-C]†
[E2-L, E3-L, H2, H3, E3-H, H1]
[E3-L, H2, H3, E3-H, H1, E2-H]
[E1-L, E1-H, E4-L]
[E4-H]

*Tukey HSD post hoc test for statistical subsets.
†Groupings within brackets are not significantly different from each other (*P* < .05).

Table 3 Gold Screw Preload from 5 Operators Using Hand Torque Driver H1

Operator code	Mean preload* (N)
Operator A	300.1 (19.7)†
Operator B	234.5 (18.6)
Operator D	264.4 (28.5)
Operator E	233.4 (30.8)
Operator F	272.6 (9.8)
Overall mean	261.0 (33.0)

*n = 5 repetitions.
†Standard deviation in parentheses.

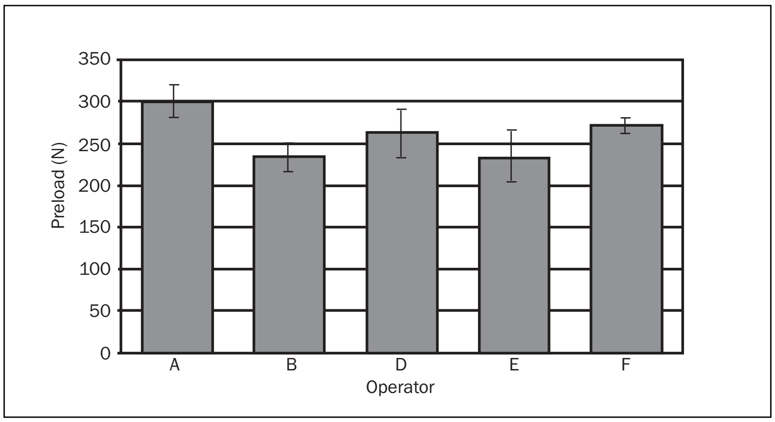

Fig 5 Mean preload (N) by operator for hand torque driver (H1); error bars are ± 1 SD.

Table 4 One-way ANOVA of Operators for Hand Torque Driver H1*

Statistically significant subsets
[Operator E, Operator B, Operator D, Operator F]†
[Operator D, Operator F, Operator A]

*Tukey HSD post hoc test for statistical subsets.
†Groupings within brackets are not significantly different from each other (*P* < .05).

DISCUSSION

Drift of Gauge Output with Time

The drift of gauge output with time was checked in the pilot phase and was shown to have an average drift of 25 με over a 6- to 8-hour period when ambient laboratory conditions were kept constant. Thus, the drift over the time course of a typical measurement sequence (10 seconds) can be assumed to be negligible as a source of measurement error.

Linearity of Microstrain Output

Following calibration loading, the compressive strain output for each gauge was correlated with applied load. This relation was found to be linear for each of the 3 gauges independently. From this, the calibrated test abutment acted as a load cell to measure the compressive preload delivered by the clamping action of the gold screw during torque-down operations. This compressive preload between the prosthetic components would be equal in magnitude to the tensile preload developed in the shank of the gold screw.

"Lobing" Effect

The "lobing" effect had been demonstrated in a previous study[22] using roundness measurements that revealed the existence of a tri-lobed configuration to the cylindric diameter of the gold cylinder. Peak-to-valley differences were only in the order of 5 µm and would be a normal consequence of the machining process. The influence of this transverse plane geometric feature to the abutment-cylinder interface fitting surface plane was shown by the different patterns of strain output when the same gold cylinder was reseated in varying positions on top of the test abutment. The microscopically "high" areas cause premature contacts at the abutment-cylinder interface in one position, and the "influence area" of this strain generation changed when the location of the gold cylinder was reseated in a different position because the position of the "high" areas causing the premature contacts was now altered.

This "lobing" effect meant that all the experimental torque-down procedures required the use of a standard gold cylinder located in a controlled, repeatable position thus allowing valid comparison between the variables in this study. A repositioning jig was used to ensure repeatable replacement of the gold cylinder.

Variations Between Torque Delivery Systems

For the final screw-tightening operation, the manufacturer's current recommendation is for the electronic torque controller to be set at the low-speed setting. All 4 electronic torque controllers tested gave higher gold screw preload with the high-speed setting compared to the low-speed setting. These differences were statistically significant for 2 of the electronic torque controllers—units E2 and E4 (Table 2). Possible causes of the higher preload measured in all 4 units with the high-speed setting are: *(1)* the inertia of the system, and *(2)* method of sensing torque, both of which could result in a system tendency to overshoot the desired final torque. There was no observable trend in preloads measured with repeated measurements. The variation appeared to be random. Error in measured torque for the electronic torque controller has been reported as being less than 10%.[23]

The preloads achieved by the 3 hand torque drivers tested were not statistically different from one another. The values measured for these 3 hand torque drivers are within 5% of the recommended preload of 300 N[12–14] for the gold screw.

The electronic torque controllers gave a far wider range of preload values. Units E1 and E4 gave consistently higher preload values at both low and high settings compared to E2 and E3, which were older and therefore had more use. It would appear that the values obtained from the newer sets, E1 and E4, which presumably were more recently factory-calibrated, could deliver preloads up to 67% greater than the theoretically recommended preload of 300 N in the prosthetic gold screw.

All the hand torque drivers and electronic torque controllers tested were units that had been loaned from clinics where they had been in regular clinical use and had been assumed to be functioning correctly by the clinicians using them. Thus, these clinicians were completely unaware of the high preloads being induced by some of these units.

The difference between hand torque drivers and electronic torque controllers would lie in the different torque-regulating or torque-sensing mechanism of the 2 systems. The mechanical torque-regulating mechanism of the hand torque driver would appear to deliver more consistent output at the 10-Ncm torque level. The manufacturer does not provide recommendations for regular recalibration of the electronic torque controllers.[24] It would even appear that the newer (and presumably recently factory-calibrated) electronic torque-controller units tested were in error and delivered excessive torque, which resulted in higher preload that is dangerously close to the reported ultimate tensile strength of the gold screw of 600 N.[12,13]

Goheen and coworkers[16] reported significant variation in torque output from an electronic torque controller as a function of speed setting. However, only 1 unit was measured in that study. The present study was able to demonstrate differences in gold screw preload between the low and high settings at the 10-Ncm torque setting amongst the 4 units tested, indicating that this is a more common problem than previously suspected.

Previous studies[2,11] have implicated inadequate torque delivery leading to low preloads as the main failure mode of the gold screw because of premature screw joint opening. A recent study by Gutierrez and colleagues[19] raised the issue of extremely excessive torque delivery from hand torque wrenches that had their spring mechanisms corroded through autoclaving in regular clinical use. This excessive torque could cause the screws to go beyond yield and affect the long-term stability of the screw joint. The preload range measured in the present study raises the alternative hypothesis that another cause of gold screw joint failure could be the induction of excessive preloads from electronic torque-controller units that are off calibration. The authors recommend recalibration of electronic torque controllers at regular intervals to ensure optimal output.

Operator Variation with Hand Torque Driver

The hand torque driver requires the rotation or twisting of the handle, and the clutch release mechanism is designed to consistently deliver the set torque. However, this consistency of torque delivery has not been shown in any previous studies in terms of ability to deliver a repeatable compressive preload to the gold cylinder–abutment system.

Subjective reports from clinicians appear to indicate some differences among operators when using the same hand torque driver. The rotation of the handle requires some degree of hand strength and familiarity of "feel" to deliver an "assured" tightening. Also, the speed of turning the torque driver handle was felt by some operators as possibly influencing the torque delivered. This aspect is quite subjective and would be difficult to standardize clinically with each clinician having his own preferred technique. The operators in this study were instructed to perform the torquing operation using their own preferred technique and no specific instructions were given so as not to influence the results.

The preloads measured varied by up to –22% of the theoretically recommended preload of 300 N. The overall mean of all 5 operators at 261.0 N (± 33.0) agrees with the 300 N value and indicates that the hand torque driver was the device that delivered the most accurate torque output and hence induced preload.

Hand Screwdriver Tightening Versus Torque Drivers

The screw preloads obtained with screwdriver tightening were significantly lower (by 46% to 59%) than the desired preload of 300 N. This despite the fact that each of the 3 operators applied considerable force so as to achieve a perceived "clinically acceptable" level of tightening. This finding confirms the manufacturer's recommendation that the final tightening of the prosthesis should not be done with a hand screwdriver, as the preload achieved would be inadequate for long-term screw joint stability.

Effect of Casting and Manipulation During Prosthesis Fabrication

Carr and associates[21] have reported that preload at the gold cylinder–abutment interface is affected by the casting process and other processing manipulations that the gold cylinders undergo during the prosthesis fabrication process. Their results indicated that the as-received control gold cylinder can develop a preload of 321 N (± 15), which agrees with the preload measured in this study for hand torque drivers. The casting, divesting, and polishing procedures commonly used in prostheses fabrication were shown to result in significant reduction in the measured preload. The preload values reported here may therefore be reduced depending on the specific manipulations the gold cylinder may undergo during the prosthesis fabrication process. However, this study used a pristine, as-received gold cylinder as the standard test cylinder in the measurements to reduce the increased experimental variability that might be expected with a gold cylinder that has undergone the casting process and other manipulations.

Possible Clinical Variables

It should also be noted that this experiment was performed in vitro under "ideal" conditions. In the actual clinical situation of intraoral hand-tightening of gold screws, the use of rubber gloves, slippery conditions from oral fluids influencing the finger grip on the screwdriver, different operator perception of adequate torque, and limited access and visibility would make the torque delivered by hand-tightening probably less than what was achieved in this experiment. Also, the operators applied tightening torque with no psychologic fear of applying excessive torque that could cause loss of osseointegration, as in the clinical situation of implants in patients.

CONCLUSIONS

1. The 3 torque delivery systems tested were shown to have significant variation in preload induced in the gold screw. Mean preloads induced in the gold screw were 291.2 N for hand torque drivers set at 10 Ncm, 340.3 N for electronic torque controllers at low setting/10 Ncm, 384.4 N for electronic torque controllers at high setting/10 Ncm, and 140.8 N for hand-tightening with a prosthetic slot screwdriver.
2. Significant differences in screw preload induced were found between operators using a hand torque driver.
3. The use of a hand prosthetic screwdriver delivered insufficient preload to the gold screw.
4. One electronic torque controller was found to induce screw preloads that were 67% greater than the desired optimal preload of 300 N in the gold screw.

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