Assessment of microdamage caused by orthodontic miniscrew pilot holes

Sven W. Jensen, Emilija D. Jensen, Wayne J. Sampson and Craig W. Dreyer

Introduction
Temporary anchorage devices (TADs) have been used since the 1990s to improve orthodontic anchorage control. Orthodontic miniscrew implants (OMIs) are the most commonly used TADs and, similar to dental restorative implants, are dependent on primary stability (the mechanical interlock of the screw thread to the cortical bone) and secondary stability (the biologic process of new bone growth and remodelling of immature bone around the implant). However, OMIs are not designed to osseointegrate to the surrounding bone as they are usually only needed throughout orthodontic treatment and therefore for a finite time period. Pilot holes have been recommended to reduce frictional resistance and microdamage to the adjacent bone upon the insertion of OMIs. There are four possible types of microdamage found in bone, defined by microcracks, diffuse damage, cross-hatching and microfractures, which may occur in combination or alone. High values of tension and compression between the bone and screw during insertion can generate adjacent microdamage. The damage to bone has the potential to cause a failure of primary stability or induce an inflammatory process with subsequent loss of secondary stability. The problems with primary or secondary stability can lead to overall failure of the OMI.

Pilot hole pre-drill protocols have been recommended to reduce the tension and compression between bone and the miniscrew during insertion. Previous studies have shown a reduction in insertion torque and microdamage when a pilot hole is drilled prior to insertion. Therefore, pilot hole pre-drill protocols may be implemented without introducing significant cortical bone microdamage.

Materials and methods
Porcine tibia bone was prepared into 30 rectangular bone block specimens with widths of 1.5, 2.0 or 2.5 mm. A pilot hole (0.9 mm diameter) was drilled into each bone specimen. Sequential staining allowed the microdamage on the entry and exit surfaces to be imaged by a confocal laser scanning microscope. Image analysis software was used to measure histomorphometric parameters.

Results
The specimens had a mean total damage area of 0.95 mm², a maximum damage radius of 0.66 mm and a maximum crack length of 0.18 mm. There were no significant differences between the three bone thicknesses for any of the histomorphometric parameters on the entry and exit surfaces (p > 0.05). The total damage area was significantly greater on the exit surface compared to the entry surface (p < 0.0001).

Conclusions
Microdamage caused by the creation of a pilot hole in the cortical bone was minimal and did not appear to be influenced by bone thickness. Therefore, pilot hole pre-drill protocols may be implemented without introducing significant cortical bone microdamage.

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to OMI placement.5,9-12 The manufacturers of OMIs may recommend a pilot hole pre-drill protocol for areas in the mouth where cortical bone is thicker (as found in the posterior mandible), to prevent excessive microdamage and to avoid insertion fracture of the OMI.13,14 A survey of orthodontists found that 4.1% of practitioners always use a pilot hole before OMI placement but a total of 41.7% never use a pilot hole.15 Cortical bone thickness varies within the mouth, but it generally ranges from 1.5 to 2.5 mm.16 Current knowledge indicates that there are no studies that have investigated the potential microdamage produced by the process of drilling a pilot hole. The present study therefore aimed to quantify the damage to bone caused by pilot holes by using an ex vivo porcine model, and as assessed by a sequential fluorescent staining protocol and laser confocal microscopy. It was hypothesised that the microdamage caused by pilot holes is not affected by cortical bone thickness.

Materials and methods

Bone preparation

Three porcine tibia bones, from different animals, were sourced from a local abattoir (Golfland Butchers, SA, Australia). Ethics approval was not required and confirmed by the University of Adelaide Animal Ethics Committee, as the bones were sourced from animals slaughtered as part of routine commercial food production. The proximal and distal ends of the tibia bones were removed, and excess soft tissue and periosteum were detached to provide a clean bone surface.

The porcine bone specimens were prepared by a single operator. Each tibia was divided into three lengths (of approximately 20 mm) using a band saw. A low-speed hard-tissue sectioning machine with a 6 inch diamond wafering blade (Allied High Tech Products Inc., CA, USA) was used to create three to four bone blocks from each length. Bone blocks with widths of approximately 1.5, 2.0 or 2.5 mm were created by two parallel cuts along the cortex of the bone. Ten bone block specimens of each width (1.5, 2.0 and 2.5 mm) were prepared for investigation. The selected widths represented the thickness of cortical bone in the mandible and maxilla of humans and are the thicker bone segments that manufacturers may recommend for the preparation of pilot holes.16,17 Copious water irrigation was used to maintain hydration of the specimens during sectioning.

The preparation of the bone block specimens introduced surface scratches. A wet polish with increasing grades of silicone carbide micromesh paper was used to remove the major surface damage. Bone block specimens were immediately wrapped in phosphate-buffered saline solution-soaked gauze to maintain hydration and physical properties, then stored in a freezer at -23°C. All experiments were performed within two months of bone block preparation. When needed, the specimens were defrosted and immersed in a 0.5 mM aqueous xylene orange solution for 30 minutes then rinsed with distilled water for eight minutes. The xylene orange solution was used to stain for surface scratches to identify any residual damage from specimen preparation.

Pilot hole pre-drill

A custom acrylic clamp was designed to secure the bone block specimens and to measure the compressive force exerted during pilot hole drilling. The compressive force was measured by a compression cell (Omega miniature compression load cell, R4-F6-76535; N2Surplus Inc., VA, USA) resting beneath a perspex clamp that was connected to a laptop computer running LabVIEW software (National Instruments Australia, NSW, Australia). Using a 0.9 mm drill, one pilot hole per bone block specimen was drilled by a single operator to accommodate a 1.5 × 6.0 mm self-drilling Aarhus Anchor screw (MEDICON eG, Tuttlingen, Germany). With continuous saline irrigation, a speed- and torque-controlled motor and handpiece (Elcomed, W&H Dentalwerk Bürmoos GmbH, Austria) was used to maintain the drill at 200 rpm. The applied pressure and time taken to drill the pilot hole were both recorded by the handpiece automatically onto a USB memory stick. The bone block specimens with the created pilot holes were submerged in an aqueous solution of calcein 1 mM for 30 minutes, followed by an eight minute rinse with distilled water. This stain was used to assess the microdamage caused by preparation of the pilot hole.

Microscopic analysis

The bone block specimens were imaged using an Olympus FV3000 confocal laser scanning microscope (Olympus Australia Pty Ltd, VIC, Australia). To excite
and subsequently fluoresce the xylenol and calcine, 561DPSS (569—700 nm red spectrum) and 488 Argon (496—593 nm green spectrum) lasers were used. The entry and exit surfaces of the bone block specimens were imaged to a depth of 100 µm at 10 µm intervals. A composite view of the microdamage to 100 µm was achieved by stacking the images together (Figure 1).

The damage created by the pilot holes was quantified as diffuse damage and linear microcracks. Diffuse damage is localised intense bone deformations and small cracks that overlap each other, whereas microcracks are those cracks extending approximately 100 µm into the bone. Quantitative measurements were made using the ImageJ (National Institutes of Health, MD, USA) program for maximum damage radius, total damage area and maximum crack length (Figure 2).

**Statistical methods**

Statistical analyses were conducted using Stata (Version 15, Stata Corp, TX, USA). All outcome variables were measured continuously and summarised by bone thickness group using means and standard deviations, separately and overall, for each of the entry and exit bone surfaces. The differences between the bone thickness groups in drill time and average drill force were examined using linear regression. The effect of bone thickness and bone surface (entry or exit) on overall damage measures (damage area, damage radius, crack length) were investigated using generalised estimating equations (GEE). An independence working correlation was specified to account for clustering of entry and exit surfaces.

![Figure 1. Laser confocal microscopy images depicting the entry (A) and exit (B) surfaces of a 1.5 mm width bone block specimen. The orange flecks (white arrow) represent the surface preparation damage while the green stain (yellow arrow) highlights the damage caused by pilot hole preparation.](image1)

![Figure 2. Laser confocal microscopy image of the exit surface damage caused by a pilot hole in 1.5 mm width bone. Measurements in mm for (1) maximum damage radius, (2) maximum damage area, (3) maximum crack length.](image2)
observations by specimen. An interaction between the thickness group and bone surface was included to determine whether the differences in damage between the entry and exit bone surfaces also differed between specimens of different thicknesses. The adequacy of all regression models was assessed by visual inspection of the residuals for normality and constant variance.

Results

The general characteristics of the specimens are summarised in Table I along with the total damage area, maximum damage area and maximum crack length for both entry and exit surfaces. The differences in the time taken to drill the pilot holes and the average drill force for the three bone block thickness groups were assessed using linear regression models. The time taken to drill the pilot holes was 26.3 seconds longer for the 2.5 mm specimens when compared to the 1.5 mm specimens (95% CI [15.3, 37.4], \(p < 0.0001\)), and 19.5 seconds longer for the 2.5 mm group when compared to the 2.0 mm group (95% CI [8.4, 30.5], \(p = 0.001\)). There were no statistically significant differences detected between the time taken to drill the 1.5 mm and 2.0 mm specimens. The average drill force significantly varied between different thicknesses of bone block specimens, as thicker bone blocks required a higher average drill force (global \(p\)-value = 0.0002). The 2.0 mm specimens required 0.26 N higher average force compared to the 1.5 mm specimens (95% CI [0.01, 0.52], \(p = 0.044\)), and the force was 0.60 N greater for the 2.5 mm specimens compared to the 1.5 mm specimens (95% CI [0.35, 0.86], \(p < 0.0001\)).

For all bone thickness groups, the total damage area was greater on the exit surface of the bone compared to the entry surface. There were no significant differences across the bone thickness groups in total damage area on the entry surface (overall \(p = 0.728\)), nor were there significant differences in the total damage area between the groups on the exit surface (overall \(p = 0.130\)). There was modest evidence for an interaction between the thickness group and bone surface (\(p\)-value for interaction = 0.037), indicating the magnitude of the difference in damage between the entry and exit surface differed according to the bone thickness groups. Specifically, the damage area was 0.30 mm\(^2\) greater on the exit surface compared to the entry surface for bone thicknesses of 2.0 mm (95% CI [0.21, 0.40], \(p < 0.0001\)), and 0.28 mm\(^2\) greater on the exit surface relative to the entry surface for bone thicknesses of 2.5 mm (95% CI [0.15, 0.41], \(p < 0.0001\)). For bone thickness of 1.5 mm, the total damage area was only 0.20 mm\(^2\) greater on the exit surface compared to the entry surface (95% CI [0.16, 0.23], \(p < 0.0001\), Figure 3).

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Bone thickness (mm)</th>
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<tr>
<td>Bone thickness (mm)</td>
<td>1.65 ± 0.16</td>
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<tr>
<td>Time to drill (s)</td>
<td>34.17 ± 8.56</td>
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<tr>
<td>Average drill force (N)</td>
<td>9.36 ± 0.37</td>
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<tr>
<td>ENTRY SURFACE</td>
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<tr>
<td>Total damage area (mm(^2))</td>
<td>0.82 ± 0.07</td>
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<tr>
<td>Max damage radius (mm)</td>
<td>0.60 ± 0.06</td>
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<tr>
<td>Max crack length (mm)</td>
<td>0.10 ± 0.05</td>
</tr>
<tr>
<td>EXIT SURFACE</td>
<td></td>
</tr>
<tr>
<td>Total damage area (mm(^2))</td>
<td>1.02 ± 0.11</td>
</tr>
<tr>
<td>Max damage radius (mm)</td>
<td>0.72 ± 0.04</td>
</tr>
<tr>
<td>Max crack length (mm)</td>
<td>0.26 ± 0.15</td>
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<tr>
<td>OVERALL</td>
<td>1.5 mm (N = 20)</td>
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<tr>
<td>Total damage area (mm(^2))</td>
<td>0.92 ± 0.14</td>
</tr>
<tr>
<td>Max damage radius (mm)</td>
<td>0.66 ± 0.08</td>
</tr>
<tr>
<td>Max crack length (mm)</td>
<td>0.18 ± 0.13</td>
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As observed for the total damage area, the maximum damage radius and maximum crack length were both greater at the exit surfaces compared to the entry surfaces. There was little evidence for an interaction between surface and thickness for either parameter, such that the interaction terms were omitted and the models re-run with the main effects of thickness group and bone surface only. There were no statistically significant differences in the damage characteristics across the bone thickness groups for either parameter (global $p$ for thickness group = 0.990 for maximum damage radius; global $p$ for thickness group = 0.339 for maximum crack length), while there was strong evidence for an effect on the bone surface ($p < 0.00001$) for both damage parameters. Averaged across the thickness groups, maximum damage radius was estimated to be 0.17 mm greater on the exit surface compared to the entry surface (95% CI [0.13, 0.20], $p < 0.0001$), and the maximum crack length was 0.12 mm longer on the exit surface compared to the entry surface (95% CI [0.08, 0.15], $p < 0.0001$).

**Discussion**

The pilot hole pre-drill protocol used on porcine tibia bone created minimal overall microdamage. The area of the drill hole was 0.64 mm$^2$ and the average total damage area was 0.82 mm$^2$, leaving the total damage produced by the drilling at 0.18 mm$^2$. The total damage produced by the insertion of OMIs without pilot holes has been reported to be 10.54 mm$^2$. Therefore, a total damage area of 0.18 mm$^2$ from drilling a pilot hole is comparatively low, and clinicians may be confident that using a 0.9 mm pilot hole for cortical bone thicknesses between 1.5 and 2.5 mm does not create clinically significant additional microdamage.

The damage observed in the bone specimens was mainly diffuse damage, which was expected due to the cutting action of the drill. As the drill penetrates the bone, the flutes carry bone fragments to the surface while exerting minimal compressive force on the axial walls. Microcracks are formed as a result of compressive force and are expected at the time of OMI insertion. The microcracks found in the present study were associated with diffuse damage and ranged from a maximum crack length of 0.04 to 0.58 mm. The microcracks were minimal compared to those formed during OMI insertion, as previous studies reported a maximum crack length of up to 3.15 mm in 1.5 mm thick porcine bone. Shank et al. found less total damage, diffuse damage and microcracks when OMIs were inserted after a pre-drill protocol in an in vivo canine model.

The histomorphometric values for bone specimens of each thickness differed significantly between the entry and exit surfaces. This can be explained by cortical bone break-through caused by the downward
Microdamage from pilot holes

force applied to the bone, which creates splintering and fracturing of the bone pieces on exit.\textsuperscript{21,22} This breakthrough phenomenon has been observed previously following the insertion of OMIs,\textsuperscript{19} and attributed to the compressive force exerted at the entry surface compared to the tensile force at the exit surface. Bone has been found to be weaker under tensile force, and microdamage would therefore be expected to be greater under tensile load.\textsuperscript{23} In vivo, cancellous bone may stabilise the bone on the exit surface; however, only cortical bone was used to produce bone specimens of uniform thicknesses for investigative purposes and to enable imaging of the exit surface via confocal laser microscopy.

Porcine bone has a similar structure, mineral density and remodelling capability as human bone. However, the use of porcine bone was a limitation of this study. The current methodology included the removal of periosteum and immersion in various chemical solutions to facilitate laser microscopy. A previous study reported that microcracks are dependent on the structure of bone,\textsuperscript{18} and porcine tibia may have different properties compared to that found in the maxilla and mandible.\textsuperscript{24-26} As the microdamage was clinically insignificant when a pre-drill pilot hole protocol was used, it is unlikely that this value would vary greatly for human bone. However, future studies should evaluate the histomorphometric outcomes using human cadaver bone with soft tissues in situ to validate this hypothesis.

Conclusion

The histomorphometric characteristics observed by confocal laser microscopy found minimal microdamage during pilot hole placement in cortical bone of 1.5, 2.0 and 2.5 mm thicknesses, representing cortical bone thickness of human maxilla and mandible at most OMI sites. The findings of the present study support the clinical preparation of a drilled pilot hole prior to the insertion of an OMI no matter what the bone thickness.

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Conflict of interest statement

The authors declare that they have no conflicts of interest nor financial advantage from the study.

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