Effect of antibiotic loading on the shear strength at the stem–cement interface (Shear strength of antibiotic loaded cement)

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Abstract The purpose of this study was to investigate the effects of addition of antibiotics into cement powder on the shear properties of the cement–metal interface. The approach involved adding 800 mg of teicoplanin to 40 g bone cement powder in the t-800 group, 1,600 mg teicoplanin in the t-1,600 group, and no antibiotic in the control group. Industrially prepared bone cement containing 500 mg of gentamicin was used as group g-500. Each group consisted of ten samples. Cement–metal interfaces were produced using metal discs with porous surfaces (1 μ m) and templates at the third minute. Shear stability of specimens was measured in a material testing machine. The ANOVA test was used for comparison between the mean shear

results of each group. Results showed that mean shear stress to failure values were 12.28 ± 3.35 MPa for the control group, 11.72 ± 3.09 MPa for the t-800 group, 13.25 ± 2.36 MPa for the t-1,600 group and 13.09 ± 2.58 MPa for the g-500 group. No statistically significant differences were found between results of the groups. Results of the study have proven that addition of 1,600 mg of teicoplanin or 500 mg gentamycin in 40 g of bone cement does not decrease the shear strength at the cement–metal interface significantly on the day of application.

Résumé Arrière plan et propos: quels sont les effets de l'addition d'antibiotiques dans la poudre de ciment sur les contraintes de celui-ci, à l'interface ciment-métal. Méthode: 800 mg de téicoplanine ont été ajoutés à 40 g de poudre de ciment et mis dans le groupe t-800, 1.600 mg de téicoplanine dans le groupe t-1600 et pas d'antibiotique dans un groupe contrôle. Une préparation industrielle du ciment contenant 500 mg de gentamicine a été utilisée dans le groupe g-500. Chaque groupe a rassemblé 10 spécimens. Les contraintes de ces différents spécimens ont été mesurées à l'aide d'une machine. Le test ANOVA a été utilisé pour comparer les différents niveaux de contrainte dans chaque groupe. Résultats: les moyennes des contraintes entraînant une mobilisation a été de $12,28 \pm 3,35$ MPa pour le groupe contrôle, $11,72 \pm 3,09$ MPa pour le groupe t-800, $13,25 \pm 2,36$ MPa pour le groupe t-1600 et enfin $13,09 \pm 2,58$ MPa pour le groupe g-500. Il n'existe pas de différences significatives entre les deux groupes. En conclusion, on peut indiquer que les résultats de cette étude montrent que l'addition de 1,600 mg de téicoplanine ou de 500 mg de gentamycine dans 40 g de poudre de ciment n'entraîne pas une altération des contraintes au niveau de

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Fig. 1 Schematic drawing of metal parts. **a** Metal cylinder with rough surface. **b** Alignment template. **c** Metal shell

l'interface ciment-métal de façon significative et le jour de la mise en place de ce ciment.

Introduction

After the first introduction of antibiotic loaded bone in 1970 [3], two major concerns were discussed in the literature: *efficacy* and *safety*. While the efficacy was proven by several experimental and clinical studies [8, 19], some questions about the safety of the technique still need to be answered.

The bone–cement mantle–implant format has three weak zones: the stem–cement interface, the bone–cement interface and the cement mantle itself [10]. Mechanical characteristics of cement mantle are affected by the addition of antibiotics in the cement powder [9]. In higher doses of loaded antibiotics, decrease in the bending strength and modulus can reach critical values [2, 9]. This decrease might also be related to a decrease in the shear strength of the stem–cement interface (SCI). Despite the wide use of antibiotic loaded bone cements in current clinical practice, only one experimental study has been conducted focusing on the shear properties of bone–cement interface of antibiotic loaded bone cements [16]. To our knowledge, our study is the first to focus on the possible shear stability changes at the SCI interface.

This experimental study aims to answer the question whether antibiotic loading causes a decrease in the shear properties of bone cement. Teicoplanin, a relatively new glucopeptide antibiotic, which is effective against metil-

lin-resistant *Staphylococcus aureus* and gentamycin were tested. Preferred antibiotic doses are currently used in clinical practice.

Materials and methods

OrCem 3 low viscosity polymethylmetacrylate (PMMA) bone cement (European Medical Contract Manufacturing, Nijmegen, Netherlands) was used throughout the study. With ten specimens in each group, four study groups were established:

- Control group: No antibiotic was added
- t-800 group: 800 mg of teikoplanin (Targocid 400 mg powder, Sanofi-Aventis) was added in 40 g cement powder
- t-1600 group: 1,600 mg of teikoplanin was added in 40 g cement powder
- g-500 group: 500 mg gentamicin powder was pre-loaded by the manufacturer in 40 g of cement powder (OrCem Genta 3 low viscosity bone cement)

Metal surface and setup

To resemble the stem surface, stainless steel metal discs of 15 mm diameter and 9.75 mm height were used (Fig. 1). One side (surface area=176.7 mm²) of the discs were sand blasted with 80 grade aluminium oxide sand for 30 seconds, resulting in a surface roughness of 1 µm. The metal disk was smoothly fitted in a metal template, which had two continuous openings of 15 mm and 18 mm diameters (Figs. 1 and 2). A metal shell of 18 mm outer and 15 mm inner diameter was fitted in the wider opening (Fig. 2).

Fig. 2 Schematic demonstration of the metal parts in the template (2D cross-section). Bone cement is filled in the metal shell

Fig. 3 Specimens after removal from the alignment template; SCI: stem-cement interface

Because the 15 mm diameter orifice was 10 mm deep, the rough metal surface of the disc had a distance of 0.25 mm relative to the metal shell (Figs. 2a and 3). When the metal shell was filled with the cement, a cement bridge of 15 mm diameter and 0.25 mm length was established between the shell and disc, which helped to prevent any contact between the shell and disc during the shear tests.

Cement preparation

The manufacturer's instructions were followed in the preparation of bone cement. In the control and gentamicin groups, the powder provided by the manufacturer was used, while in the teicoplanin groups, antibiotic powder (800 mg or 1,600 mg) was first placed in a bowl, mixed until the

lumps were dissolved and mixed with the cement powder until a homogenous mixture could be obtained. The monomer liquid was mixed with the cement powder in a vacuum mixing device (MixOR, Smith&Nephew, Memphis, USA) at room temperature (23°C). The cement was delivered into ten shells for each group using a cement gun (InjectOR, Smith&Nephew, Memphis, USA), starting at the third and ending before the fourth minute. After a polymerisation period of 20 minutes, the metal disc-shell-cement blocks were easily taken out of the template (Fig. 3). The specimens were kept in room conditions overnight.

Mechanical testing

The failure tests were carried out on a materials testing machine (Universal Material Testing Machine, model no. SM 100/J1007/4, Tecquipment Ltd, Nottingham, England). The calibration of the load and displacement transducers was performed in the laboratory environment before each test. A custom-made loading instrument was used for shear tests (Fig. 4).

Shear tests were performed at a rate of 10 mm/min, until the cement-disc interface failed. The data obtained from the transducers were simultaneously recorded on a personal computer at 10 Hz using a data-acquisition system (ESAM Traveller Data Acquisition System, no. AA0EA01178, Vishay Measurements Group, Selb, Germany) for the quasi-static loading condition. The peak value before the acute decline in the load-distraction curve was taken as the load to failure, which was recorded in Newtons. SCI shear strength was calculated by dividing the failure load (N) by the surface area of the discs (176.7 mm²).

Statistical evaluation

Results were evaluated using the Kolmogorov-Smirnov test for normal distribution and the one way ANOVA test with LSD post hoc test for any difference between groups (SPSS for Windows standard version 13.0 software, SPSS Science Inc, Chicago, Ill). A *P* value less than 0.05 was considered indicative of statistical significance. Power analysis tests were performed using MedCalc vers. 8.2.1.0 (MedCalc Software, Mariakerke, Belgium).

Results

All specimens failed at the cement-metal interface. One specimen was excluded from the study because of a technical error during the specimen preparation. With macroscopic examination, no irregularity was observed at the cement-metal interfaces.

Fig. 4 Loading instrument for shear tests (parts drawn separately)

No significant difference was observed between failure loads of the antibiotic loaded bone cement groups and the control group (one way ANOVA, F ratio=0.519, $P=0.672$). Mean load (N) and shear stress (MPa) to failure values were 2170.4 ± 591.1 N (12.28 ± 3.35 MPa) for the control group, 2070.2 ± 546.2 N (11.72 ± 3.09 MPa) for the t-800 group, 2341.4 ± 417.6 N (13.25 ± 2.36 MPa) for the t-1600 group and 2235.2 ± 406.1 N (13.09 ± 2.58 MPa) for the g-500 group (Fig. 5). Statistical evaluation showed normal distribution of results in all groups ($P=0.739$ or higher). Post hoc LSD test results proved that antibiotic loading did not decrease the initial shear strength of bone cement significantly when compared to the control group (mean difference=100 N for the t-800 group [95% CI: (-353 N) to 553 N] ($p=0.656$), mean difference=171 N for the t-1600 group [95% CI: (-624 N) to 282 N] ($p=0.449$) and mean difference=65 N for the g-500 group [95% CI: (-530 N) to 400 N]) ($p=0.779$).

Using the given results, power analysis test (type I error set at 0.05 and type II at 0.20) showed that at least 508 specimens were required to reach the significant difference level between the control and t-800 groups, 141 for t-1600 and 955 for the g-500 group.

Discussion

Analysing retrieved implants, both Harris [11] and Jasty [14] concluded that the mechanism of loosening of cemented femoral components was debonding at the stem–cement interface (SCI). Debonding of SCI may occur as a result of excessive shear or tensile stresses, or their combinations. Data on in vivo stresses at the SCI is limited. Finite element studies have estimated shear stresses at the prosthesis stem–bone cement interface to be between 5 and 8 MPa, nearly twice the tensile stresses [5, 15, 18]. Debonding was dominated by the shear failure of the interface [18].

Fig. 5 Graph summarising results

Shear strength of the SCI is affected by several factors including the stem's surface roughness [4, 7, 20, 21], pre-heating the stem [12, 21], pre-chilling the cement monomer [13], the type of cement used [20], precoating of the stem [1, 17], metal type [4], and even the loading rate [22]. Possible effects of all these factors were eliminated in our study, using a standard protocol for all groups.

Surface roughness of the stem is the most important factor for the SCI strength, where increased roughness results in higher shear strength values. A roughness of 1 μm was preferred in this study, depending on the findings of previous studies about shear strength and clinical outcome. Around the level of 1 μm , an acute increase in SCI stability was reported, reaching the estimated in vivo shear stresses [4, 7]. Although higher levels of roughness provide higher shear strength values, they are not preferred in clinical settings since rough stems have been shown to have higher failure rates compared to polished stems [6].

Mean shear strength values in all groups of our study were between 11.7 and 13.2 MPa, well above the estimated limits of in vivo SCI stresses. Nevertheless, numerical results of this study cannot be directly interpolated to clinical settings or compared to other studies.

One drawback of the study protocol is the lack of cyclic loading tests. Inclusion of cyclic loading tests requires evaluation of additional parameters like load, loading rate or loading type, which make a comparison between published studies nearly impossible. Most of the published studies have focussed on only static shear strengths. Another shortcoming of the study is the absence of simulation of in vivo conditions, the saline immersion. Saline immersion causes significant decrease in SCI stability [1, 7]. Because the antibiotic powder is expected to be released out of the cement mantle, it can be hypothesised that post immersion results of antibiotic loaded bone cements should be worse than dry specimens.

Conclusions

According to the results of this experimental study investigating effects of antibiotic loading on the stem–cement interface (SCI) shear strength, the following conclusions may be drawn:

1. Addition of 1,600 mg teicoplanin or 500 mg gentamicin in 40 mg of cement powder does not significantly effect shear strength of the SCI on the day of application.
2. Under the described laboratory conditions and for the particular cement type, SCI shear strength of antibiotic loaded bone cement is well above the expected clinical shear stresses.

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Contribution of authors Dr. Kilicoglu, Dr. Yazicioglu and Mr. Bozdag designed the study.

Dr. Kilicoglu, Dr. Koyuncu, Dr. Ozden, Mr. Bozdag and Mr. Sunbuloglu gathered the data.

Dr. Kilicoglu and Mr. Bozdag analysed the data.

Dr. Kilicoglu and Mr. Bozdag wrote the initial drafts.

Dr. Ozden and Mr. Bozdag prepared the drawings.

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