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Biomechanical competence of six different bone screws for reconstructive surgery in three different transplants: Fibular, iliac crest, scapular and artificial bone

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ABSTRACT

The goal of this study was to determine a combination of screw and transplantation type that offers optimal primary stability for reconstructive surgery.

Fibular, iliac crest, and scapular transplants were tested along with artificial bone substrate. Six different kinds of bone screws (Medartis©) were compared, each type utilized with one of six specimens from human transplants (n = 6). Controlled screw-in-tests were performed and the required torque was protocolled. Subsequently, pull-out-tests were executed to determine the retention forces.

The artificial bone substitute material showed significantly higher retention forces than real bone samples. The self-drilling screws achieved the significantly highest retention values in the synthetic bone substitute material. Cancellous screws achieved the highest retention in the fibular transplants, while self-drilling and cancellous screws demonstrated better retention than cortical screws in the iliac crest. In the scapular graft, no significant differences were found between the screw types. In comparison to the human transplant types, the cortical screws showed the significantly highest values in the fibula and the lowest values in the iliac crest.

The best retention was found in the combination of cancellous screws with fibular graft (514.8 N + −252.3 N). For the flat bones (i.e., scapular and illiac crest) we recommend the cancellous screws.

1. Introduction

In the field of oral and maxillofacial surgery, major osseous defects are reconstructed using bone grafting with microvascular anastomosis. Based upon the scale of the defects and the functionality to be restored, bone grafts are primarily harvested from the iliac crest (Taylor, 1982), the fibula (Hidalgo, 1989) and the scapula (Swartz et al., 1986) which exhibit different internal morphologies depending on the transplant type. Bones from the iliac crest and the scapula (i.e., flat bones) are composed of a relatively thin *substantia corticalis* with a broader *substantia spongiosa*, while fibular bones (i.e., long bones) consist of a relatively broad and compact *substantia corticalis* with a thinner *substantia spongiosa* (Schiebler, 2007).

A fundamental prerequisite for an untroubled, stage-adjusted healing process for the transplanted bone is sufficient primary stability in the defect area. Various systems of osteosynthesis plates along with screws of different geometries are available for fixation. A number of biomechanical trials on differently reconstructed mandibular defects present evidence of the influence of osteosynthesis plate design on the primary stability of the transplant (Steiner et al., 2012; Grohmann et al., 2013; Trainotti et al., 2014; Grohmann et al., 2015; Steiner et al., 2015) However, the primary stability of the screw-bone interface is also essential for bonding and the success of the reconstruction, yet it has not been sufficiently investigated in the literature.

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Numerous investigations can be found in the literature on osteosynthesis screws concerning the retention force and screw-bone interface in human bone (Ansell and Scales, 1968; Saka, 2000), comparative animal models (Bähr and Lessing, 1992; Boyle et al., 1993; Heidemann et al., 1998, 2001; Löhr et al., 2000), artificial bone substitute material (Hughes and Jordan, 1972; Bähr and Kutscher, 1989; Bähr, 1990; DeCoster et al., 1990; Chapman et al., 1996; Jank et al., 2010; Lieger et al., 2015) or computer simulation (Bujtar et al., 2014).

However, research into the retention force of mono-cortical, self-drilling osteosynthesis screws with different screw geometries in combination with the transplants that are commonly used in cranio-maxillofacial surgery (fibular, iliac crest, and scapular graft) has not been published, to our knowledge. It was the objective of this study to determine the combination of screw and transplant type that offers the best available screw-bone bonding.

2. Materials and methods

2.1. Bone specimen and synthetic material

Bone grafts from the scapula, the iliac crest, and the fibula were harvested and deep-frozen from six body donors. Per bone type and donor six samples of similar dimensions were taken using a bone saw (n = 36 specimens per bone graft) from the frozen bone (Fig. 1). After defrosting, the samples were fixed with plasticine in identical positions to the extent possible. The surfaces of trabecular bone at the cuts were protected against penetration of embedment material. Then, the samples were placed in a cylindrical support bowl and embedded in self-hardening 2-component acrylic resin (Memecryl®, Bauer Handels GmbH, Waberg, Switzerland) without any pretension.

In the reference group standardised, laminated, and synthetically manufactured material made from polyurethane foam (Sawbone® item#1522-157, Sawbone Inc., Malmö, Sweden) was used as bone substitute. This synthetic bone is composed of two external layers (thickness 3 mm; 20 pcf = 0.32 g/ccm) covering a softer and less dense layer with a thickness (thickness 10 mm; 20 pcf = 0.32 g/ccm). Small blocks (10 × 10 mm) were sawed and individually embedded in the support bowls using the same procedure with acrylic resin. In the group of synthetic materials, eight specimens were prepared for each screw type (n = 48 individual experiments).

The series of tests was carried out using six different osteosynthesis screws manufactured by Medartis, Basel, Switzerland (Table 1). We used four different types of cortical screws (Product ID#: M-5240.13, M-5245.13, M-5255.14, and M-5250.12), as well as one cancellous screw (ID# M-5256.14), and a self-drilling screw (ID# M-5243.13, referred to as SpeedTip). In contrast to the other screws, there is no pilot hole required prior to insertion for self-drilling screws. All six screw types used in our experiment were self-tapping screws. When used in bone with a thin cortical layer (<3 mm) and spongy inner structure, self-tapping screws are known to have a greater retention force compared to non-self-tapping screws (Bähr and Kutscher, 1989; Phillips and Rahn, 1989; Bähr, 1990; Schatzker et al., 1990; Chapman et al., 1996).

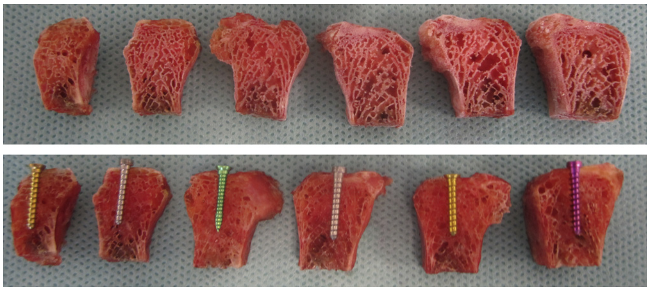

Fig. 1. Bone specimens used in the experiments. Top row: Trabecular structure of pelvic bone samples is macroscopically visible. Bottom row: same samples with the screws placed on top to illustrate size relationships.

For each sample, a screw-in test was carried out, followed by an immediate uniaxial pull-out test, both after the hardening of the embedment material.

2.2. Screw-in tests

Pilot holes were drilled into the embedded monocortical bone samples perpendicular to the cortical surface, according to the guidelines of the manufacturer Medartis (Table 1). Samples of the test series using the self-drilling MODUS SpeedTip cortical screw were not prebored. The screw insertion was made using the material test system Elektroforce® TestBench from Bose Inc. (Framingham, MA, USA); (Fig. 2A). The torques which occurred during the insertion were continuously measured at the same time. The screwdriver blade holder with integrated screw driving mechanism was connected with the test system in a rotationally stable way using a gimbal mounting (Fig. 2B).

2.3. Pull-out tests

Immediately following the screw-in process (Fig. 2C), each sample along with the inserted screw was transferred to the pulling device and the holder was mounted in this second material test system specialized for pulling experiments (Z010, Zwick-Roell, Ulm, Germany). The force which was need for a loosening of the screw-bone bonding was determined by means of a standardized uniaxial pull-out test (Fig. 2D) and all forces were protocolled.

2.4. Statistical analysis

The acquired data was checked for statistical significance using the non-parametric Kruskal–Wallis-Test, which is advised for small sample sizes (n = 6), with a value of $p < 0.05$ as threshold level for statistical significance. Where appropriate the post-hoc Mann–Whitney U-test with Bonferroni–Holm correction for multiple comparisons was also used.

3. Results

3.1. Screw-in tests

In the reference group (Sawbone® bone substitute), the self-drilling cortical screw MODUS SpeedTip showed the highest screw-in torques, followed by the MODUS TriLock cancellous screw (Fig. 3A).

In the group of fibular transplants, the SpeedTip screw showed the highest screw-in torques. However, it should be noted that in two out of six trials of the fibular specimens the subsequent pull-out test could not be performed due to breakage of the screws (Fig. 3B).

In the iliac crest and scapular transplants the SpeedTip screw showed the highest screw-in torques followed by the cancellous screw, however this finding is not statistically significant (Fig. 3C and D).

No differences could be found in the cortical screw groups, neither in one of the bone grafts nor in the synthetic substrate (Fig. 3A–D).

All results of the screw-in test are listed in Table 2.