The specimens were placed in a cylindrical holder, no further sample overlapping blocks of 100 slices (1.3 mm) along the z-axis. were strongly inhomogeneous (Fig.2), evaluation was performed in 15 structural indices were assessed using direct techniques [9]. As samples fixed threshold to extract the mineralised bone phase. From the images, images were segmented using a low-pass filter to remove noise and a interest of app. 4.5 x 6.0 x 10.0 mm

PLLA cage with 12, 24 and 36 month follow-up (F12, F24, F36); follow-up (S6); titanium cage with six months follow-up (T6); Flexible Lumbar interbody fusion with cage devices has become a routine research.) The exterior size of the cages was 18x10x10 mm penetration the endplates of both vertebrae (Fig.1). PLLA cages had a wall thickness of 1.5 mm. From the retrieved vertebral segments a 5 mm thick sagittal slice was cut (Fig.1b) and embedded in PMMA to ensure integrity of the specimen. Then the volume within the cage (the fusion zone) was cut out for scanning in a high-resolution MicroCT system, resolution of 13 µm.

The following samples were obtained for analysis by micro-CT: Stiff PLLA cage with three months follow-up (S3); idem with six months follow-up (S6); titanium cage with six months follow-up (T6); Flexible PLLA cage with 12, 24 and 36 months follow-up (F12, F24, F36); titanium cage with 30 and 36 months follow-up (T30; T36); and Stiff PLLA cage with 36 months follow-up.

The specimens were placed in a cylindrical holder, no further sample preparation was necessary. From the resulting voxel data, a volume of interest of app. 4.5 x 6.0 x 10.0 mm³ was selected. The grey value images were segmented using a low-pass filter to remove noise and a fixed threshold to extract the mineralised bone phase. From the images, structural indices were assessed using direct techniques [9]. As samples were strongly inhomogeneous (Fig.2), evaluation was performed in 15 overlapping blocks of 100 slices (1.3 mm) along the z-axis.

Introduction

Lumbar interbody fusion with cage devices has become a routine procedure with a high rate of clinical success after short-term follow-up. The main goals of interbody cages are to correct spinal deformations and to provide primary stability to the spinal segment until interbody fusion is obtained. It is unknown, however, how the process of spinal fusion evolves, and when fusion is actually achieved. It is even more difficult to establish the mechanical quality of a successful arthrodesis.

The aim of a cage device is to create an optimal environment for fusion. Design and material play a pivotal role in this. Mechanical stability of the fused segment is mainly determined by the design and size of the cage [1,2], though not by its orientation [3,4]. The material of the cage, however, is the main determinant of mechanical loading of the bone graft and consequently of the spinal fusion rate, because cage stiffness is the single most important factor for stress shielding [5,6]. It is likely that, even if fusion is achieved in a titanium cage, it is inferior to a fusion that would be obtained in a cage made of less stiff material.

In an animal study with three years follow-up, we histologically and histomorphometrically described the development of spinal fusion in time, and found the deteriorating effect of cage stiffness on spinal fusion [6,7]. Out of this three-years study, we obtained some bone samples from the fusion zone for further analysis with micro-CT. Purpose of this analysis was to describe the architectural changes of the fusing bone material in time, and to study the effect of cage stiffness on the bone architecture within the cage.

Methods

Nine bone samples were available from a long-term in vivo study on resorbable spinal cages described elsewhere [6-8]. In that study, Poly E-Lactic Acid (PLLA) and titanium (Ti) interbody cages were placed at L3-L4 in 2-3 year old Dutch milk goats. (The Dutch Animal Research Committee approved all animal surgery and handling procedures were performed in accordance with Dutch Government laws for animal research.) The exterior size of the cages was 18x10x10 mm³, so that they penetrate the endplates of both vertebrae (Fig.1). PLLA caged had a wall thickness of 0.75 ("flexible") or 1.5 mm ("stiff"), the titanium caged had a thickness of 1.5 mm. From the retrieved vertebral segments a 5 mm thick sagittal slice was cut (Fig.1b) and embedded in PMMA to ensure integrity of the specimen. Then the volume within the cage (the fusion zone) was cut out for scanning in a high-resolution MicroCT system, which is commercially available under the name µCT 20 (Scanco Medical, Bassersdorf, Switzerland). Scanning was performed with a resolution of 13 µm.

The following samples were obtained for analysis by micro-CT: Stiff PLLA cage with three months follow-up (S3); idem with six months follow-up (S6); titanium cage with six months follow-up (T6); Flexible PLLA cage with 12, 24 and 36 months follow-up (F12, F24, F36); titanium cage with 30 and 36 months follow-up (T30; T36); and Stiff PLLA cage with 36 months follow-up.

The specimens were placed in a cylindrical holder, no further sample preparation was necessary. From the resulting voxel data, a volume of interest of app. 4.5 x 6.0 x 10.0 mm³ was selected. The grey value images were segmented using a low-pass filter to remove noise and a fixed threshold to extract the mineralised bone phase. From the images, structural indices were assessed using direct techniques [9]. As samples were strongly inhomogeneous (Fig.2), evaluation was performed in 15 overlapping blocks of 100 slices (1.3 mm) along the z-axis.

Essential results

From 2D sections a quick impression of the state of fusion and the bone architecture is obtained (Fig. 2). After three months, the densely impacted bone graft is still present (Fig.2a), but after six months a fine trabecular bone architecture is found throughout the fusion zone within the PLLA cage (Fig.2b). After 36 months, this is replaced by a much coarser structure with less, but thicker trabeculae (Fig.2c). In the titanium cage, there is no fusion after six months; the trabecular bone structure above and below the gap is fine as in the PLLA cages (Fig.2d). At 36 months, fusion is also reached within the titanium cage, but the trabeculae are thinner, and the bone density is less (Fig.2e).

![Fig. 2: Slices from the fusion zone, a. stiff PLLA cage at 3 months; b. stiff PLLA cage at six months; c. stiff PLLA cage at 36 months; d. Titanium cage at 6 months; e. Titanium cage at 36 months.](image)

Quantitatively, the most striking result was a homogenisation of bone structure indices along the z-axis with time. The Structure Model Index (SMI, [9]) for example, shows strong peaks in the fusion area on the short term, but after 12 months in the PLLA cages it clearly flattens out. In titanium cages, however, a peak can still be found after 36 months, indicating a less "mature" bone architecture. The same is found with indices like Surface Curvature (dS/dr), [9]), Trabecular Number, and, to a lesser extent, Connectivity Density. Coarsening of the structure is underscored by Trabecular thickness increasing from some 150 µm to more than 200 µm and Trabecular Spacing increasing from 250 µm to 500 µm; Trabecular Number decreases accordingly. These indices all vary with z, especially in short term follow up and in the titanium cages.

Discussion

Reconstructed bone specimens allow for a detailed and quantitative analysis of the bone architecture in 3D. Nine bone specimens were available from a larger animal study for structural analysis. With these, the development of the bone architecture during spinal fusion could be determined qualitatively, and the deteriorating effect of cage stiffness was re-established. Although the specimens were considered "typical" considering only one specimen for each type of cage and time point is a lesser drawback of this study. Another limitation is the fact that only a part of the fusion zone was used for analysis, which was due to other analyses performed with the specimens [6-8]. Nonetheless, this study for the first time presents the development of the bone architecture during spinal fusion, and also confirms that cage stiffness strongly interferes with this process, which is still visible after 36 months. For a more quantitative study, specifically to the mechanical quality of the bony fusion, more specimens covering the whole fusion zone are required.

References


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