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Early and long-term changes in adjacent vertebral body bone mineral density determined by quantitative computed tomography after posterolateral fusion with transpedicular screw fixation

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ABSTRACT

Objective: The aim of this study is to investigate vertebral body bone mineral density (BMD) changes following posterolateral fusion with transpedicular screw fixation using quantitative computerized tomography (QCT) in short and relatively long-term periods.
Patients and methods: A retrospective study was performed to investigate vertebral body BMD changes in the patients who underwent posterolateral fusion with transpedicular screw fixation at thoracic and lumbar spine. A total of 160 patients were enrolled into the study. According to the follow-up period, patients were divided into two subgroups (group 1, early follow-up, mean follow-up period, 279.3 ± 162.3 days and group 2, later follow-up, mean follow-up period, 969.1 ± 274.2 days). The trabecular BMDs (mg/cm^3) were measured from T12 to L5 as screw free levels by using QCT measurement software. Comparisons between preoperative and postoperative BMD values were assessed using paired *t*-test.
Results: The mean postoperative BMD values of both group 1 and 2 weresignificantly lower, compared with the preoperative values ($79.2 \pm 31.3\ mg/cm^3$ vs. $91.5 \pm 31.4\ mg/cm^3$, $76.1 \pm 25.5\ mg/cm^3$ vs. $89.3 \pm 30.4\ mg/cm^3$, $p < 0.001$ and $p < 0.001$, respectively). There was no significant correlation between BMD loss and number of fused segments. Vertebral BMD loss was significantly higher in the L3 vertebra when located caudally to the operation site than when located cranially (−27.7 ± 19.8% vs. −12.8 ± 27.1%; $p < 0.01$).
Conclusions: The vertebral body BMD values are decreased at the adjacent of the posterolateral fusion with transpedicular screw fixation levels in both cephalad and caudad sides at an average of 9-months-follow-up postoperatively. This BMD loss persisted, but not worsened at an average of 32-months-follow-up. Vertebral BMD loss was significantly higher in the L3 vertebra when located caudally versus cranially to the surgery site.

1. Introduction

Posterolateral fusion with transpedicular screw fixation is a common procedure used to stabilize the spine in many disorders such as segmental instability and deformity. The short-term postoperative complications of this procedure are no different from many other spinal surgical procedures. Some studies, using dual-energy X-ray absorptiometry (DXA) or dual photon absorptiometry (DPA), have reported vertebral body osteopenia associated with rigid plate immobilization during early postoperative follow-up [1–3]. This phenomenon has been explained by altered biomechanics.

In a human study, Limbscomb et al. reported an average bone mineral density (BMD) loss of 15.7% during the first few months after surgery. In that study, a gradual increase in BMD was observed 1 year postoperatively [3]. A unique study using DXA that evaluated vertebral BMD changes over a longer period following posterior spinal instrumentation surgery (PSIS) suggested a significant increase in adjacent cephalad vertebral BMD over a mean follow-up of 10.8 years, in comparison with the BMD values at a mean

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follow-up of 4 years [4]. The long-term changes in BMD have been explained by theories of bone remodeling, stress-shielding effects, and load redistribution [5–7].

Experimental animal studies have shown a gradual decrease in the BMD of vertebrae bridged by rigid instrumentation within a few months of surgery. These studies have also reported that the loss of BMD does not persist, and that the rate of loss reaches a plateau after approximately 6 months [7–9]. Dalenberg et al. demonstrated a recovery of BMD to baseline level after 9 months when the implants were loosened [8]. However, the results of animal studies cannot be adapted directly to human patients. The biomechanics of the bipedal human spine, for example, are significantly different to those of the canine spine [10].

DPA is a relatively insensitive method, and its use in monitoring localized BMD changes in humans is no longer favored. DXA also has some disadvantages including sensitivity to degenerative changes, aortic calcification, and metallic artefacts. DPA and DXA are both projectional methods. Morphologic changes after spinal surgery such as laminectomy can also affect BMD measurements in these techniques. Quantitative computerized tomography (QCT) is accepted as the gold standard technique for the measurement of BMD. QCT can provide true volumetric measurements, and it is not affected by body size or structural bony changes such as degeneration or morphological variability [11].

The purpose of this study was to investigate BMD changes in the vertebral body following posterolateral fusion with transpedicular screw fixation using QCT over short- and relatively long-term intervals. We also aimed to evaluate correlations between BMD changes and the number and level of PSIS. This study is the first to determine vertebral BMD changes following posterolateral fusion with transpedicular screw fixation using QCT.

2. Materials and methods

This was a retrospective study conducted to investigate vertebral body BMD changes in patients who underwent posterolateral fusion with transpedicular screw fixation at the thoracic and lumbar spine between January 2005 and December 2013. The study protocol was approved by the Ethics Committee of our institution. A total of 160 patients were randomly selected from our neurosurgery database. Inclusion criteria were (1) having undergone posterolateral fusion with transpedicular screw fixation at the thoracic and lumbar spine; and (2) at least two lumbar, or lumbar and thoracic, spine CT examinations performed, one during the early preoperative period and the other during the postoperative period. Patients who experienced a failed spinal fusion, who had undergone previous spinal surgery, or who had a known metabolic disorder affecting bone metabolism, known malignancy, renal insufficiency, degenerative scoliosis, vertebral fractures, prominent endplate sclerosis, or artefacts were excluded from the study. Patients who were undergoing therapy for osteoporosis were also excluded. Our QCT BMD analysis software allows us to measure the thoracic 12 and lumbar 1–5 vertebrae. For this reason, at least one of the vertebrae must be screw-free to allow measurement of BMD. We measured the screw-free vertebrae adjacent to the fused segment from T12 to L5 on either the cephalad or caudad side. For example, in a patient with an L1–L5 lumbar spinal fusion, we included the cephalad side screw-free T12 (one level above the fixation) vertebra. On the other hand, in a patient with a T11-L4 lumbar spinal fusion, the caudad side screw-free L5 (one level below the fixation) vertebra was included. Patients who had no screw-free vertebrae on the T12 to L5 levels were excluded. In addition, any screw-free vertebra with a hemangioma or fracture was not included in the analysis. After the exclusion of 80 patients, 160 patients were enrolled into the study. Of these, 117 patients had degenerative lumbar spinal stenosis and 43 spondylolisthesis. All patients underwent posterior decompression laminectomy and posterolateral fusion with laminectomy bone chips as a bone graft, followed by transpedicular screw fixation using the same technique.

The mean follow-up interval was 534.2 ± 387.1 (range 45–1746) days. Patients were divided into two subgroups according to the follow-up duration, since data from the literature suggests a gradual decrease in BMD up to 9 months, followed by a gradual increase or plateauing of the BMD values. Group 1 (early follow-up group; mean follow-up, 279.3 ± 162.3 days) included patients who had been followed-up no more than 600 days. Group 2 (later follow-up group; mean follow-up, 969.1 ± 274.2 days) included patients who were followed-up for more than 600 days.

2.1. CT study and assessment of BMD

Non-enhanced CT imaging was performed for all patients using three different multi-detector CT (MDCT) scanners (Brilliance 64 Philips, Brilliance 16 Philips, and MX 8000 Philips; Philips Medical Systems©, Eindhoven, The Netherlands). The routine spinal vertebrae MDCT examination protocol was as follows: collimation, 16 × 0.75 mm; interval, 0.75 mm; gantry rotation time, 0.75 s; beam pitch, 0.688; 120 kV; 120 mA; matrix, 512; approximate total exposure time 15–20 s. Routine multiplanar reconstructions were performed in standard sagittal and coronal planes, with a slice thickness of 1.0 mm and a reconstruction increment of 0.75 mm. All images were then transferred to a commercially available workstation (Philips Extended Brilliance Workspace V3.5.0.2254) for further QCT analysis. An experienced radiologist performed the measurements. Three measurements were recorded, and the mean values were expressed. A second radiologist then remeasured the images of 20 patients to evaluate the inter-observer variability.

Trabecular BMDs (mg/cm^3) were measured from T12 to L5, the screw-free levels. The thickness of the region of interest (ROI) was 1 cm. The ROI was drawn using a hands-free tracing protocol and was located at the center of the vertebrae. The cortical bone area, posterior venous plexus, and Schmorls' nodes were excluded from the ROI, as far as possible. The mean ROI was approximately 2.5 cm^2, and the total volume measured was roughly 2.5 cm^3. We used a standard QCT BMD protocol by measuring the number of fat and muscle area CT slices to calibrate the scan on the same slice according to guidelines set by the manufacturer (Fig. 1). The current technique has previously been shown as an accurate and sufficiently precise clinical utility for the measurement of vertebral body BMD [12].

2.2. Statistical analysis

Continuous data are expressed as means ± standard deviation and categorical variables as percentages. The Kolmogorov-Smirnov test was used to test the normality of the variables. All variables demonstrated a Gaussian distribution. Therefore, comparisons between preoperative and postoperative BMD values were assessed using a paired *t*-test. For subgroup analyses (according to the level of BMD measured), a Wilcoxon signed-rank test was used to compare preoperative and postoperative BMD values. Multiple linear regression analysis was used to assess the independent associations between BMD loss and other variables. A stepwise selection method was used in the multiple linear regression analysis. Subgroup analyses for continuous variables and categorical variables were performed using the Student's *t*-test and chi-squared test, respectively. Two-sided P-values of less than 0.05 were considered statistically significant. The statistical