Revision total hip arthroplasty using a Kerboull-type acetabular reinforcement device with bone allograft

MINIMUM 4.5-YEAR FOLLOW-UP RESULTS AND MECHANICAL ANALYSIS

We retrospectively reviewed 40 hips in 36 patients who had undergone acetabular reconstruction using a titanium Kerboull-type acetabular reinforcement device with bone allografts between May 2001 and April 2006. Impacted bone allografts were used for the management of American Academy of Orthopaedic Surgeons Type II defects in 17 hips, and bulk bone allografts together with impacted allografts were used for the management of Type III defects in 23 hips. A total of five hips showed radiological failure at a mean follow-up of 6.7 years (4.5 to 9.3), two of which were infected. The mean pre-operative Merle d’Aubigné score was 10 (5 to 15) vs 13.6 (9 to 18) at the latest follow-up. The Kaplan-Meier survival rate at ten years, calculated using radiological failure or revision of the acetabular component for any reason as the endpoint, was 87% (95% confidence interval 76.3 to 97.7). A separate experimental analysis of the mechanical properties of the device and the load-displacement properties of bone grafts showed that a structurally hard allograft resected from femoral heads of patients with osteoarthritis should be preferentially used in any type of defect. If impacted bone allografts were used, a bone graft thickness of < 25 mm was acceptable in Type II defects.

This clinical study indicates that revision total hip replacement using the Kerboull-type acetabular reinforcement device with bone allografts yielded satisfactory mid-term results.

Failure of acetabular components often leads to massive bone defects with thin or eburnated residual bone, for which many procedures have been devised to manage the loss of bone stock to enable a stable environment for implantation of a new prosthesis. In cemented revision total hip replacement (THR), acetabular reconstruction using unsupported structural allografts has been associated with increasing failure in the long-term. In contrast, when supported by an acetabular reinforcement device, a low rate of failure has been reported. The use of a metal device protects grafted bone through its screw fixation to the pelvis, thereby partially protecting the grafted bone from excessive loading during the incorporation and remodelling processes. Following these principles will allow a reconstruction with restoration of the centre of hip rotation with the correct biomechanics to optimise joint stability. Since 2001, we have used the Kerboull-type acetabular reinforcement device (KT plate; Japan Medical Materials, Osaka, Japan) made of titanium to support allografts used in acetabular reconstruction. Using the American Academy of Orthopaedic Surgeons (AAOS) classification, we treated Type I defects with a structural allograft, Type II defects with impaction bone grafting using morsellised allograft bone chips and Type III defects with a structural allograft together with impaction bone grafting in conjunction with the KT plate in all cases (Fig. 1).

The aim of this study was to analyse the mid-term results of revision THR using the KT plate and to justify our strategy by examination of the relationship between the mechanical properties of the KT plate and the type and thickness of bone graft by in vitro experiments.

Patients and Methods

After obtaining institutional board approval, we retrospectively reviewed 45 patients (49 hips) who had undergone revision THR with cemented acetabular components using the KT plate between May 2001 and April 2006. All the patients had received either morsellised or bulk allografts. A total of nine patients (9 hips) were lost to follow-up, five of...
who died from unrelated causes and four could not be traced. The remaining 36 patients (40 hips) were reviewed, comprising one man and 35 women with a mean age at the time of the operation of 66.6 years (47 to 79), a mean height of 148.7 cm (136.4 to 166.8) and mean weight of 54.2 kg (38.5 to 68.0). The mean follow-up was 6.7 years (4.5 to 9.3).

The initial diagnoses were osteoarthritis secondary to acetalubar dysplasia in 38 hips, rheumatoid arthritis in one hip, and osteonecrosis of the femoral head in one hip. The revision surgery had been undertaken for aseptic loosening in 39 hips and for infection in one hip. Previous operations included 35 THRs and five bipolar hemiarthroplasties, with a mean time to revision of 14.4 years (1.1 to 25.5).

The acetabular defects as classified by the AAOS system were Type II in 17 hips and Type III in 23 hips.

Either morsellised allograft bone chips (for Type II and III defects) or bulk bone allograft (for Type III defects) were used in all hips. Autogenous bone and artificial bone were not mixed together. The fresh frozen femoral head allografts had been harvested in accordance with the 2003 guidelines of the Japanese Society of Orthopaedic Surgery. The bone was sterilised by pasteurisation using Lobator sd-2 (Telos, Marburg, Germany), and was then cut into an appropriate shape or processed into morsellised bone chips using a bone mill (Japan Medical Materials, Osaka, Japan).

The mean follow-up for patients with Type II and Type III defects was 6.76 years (4.5 to 9.1) and 6.67 years (4.5 to 9.3), respectively ($p = 0.85$). The mean age at operation for Type II and Type III defects was 67 years (59 to 77) and 66.3 years (47 to 79), respectively ($p = 0.79$).

Operations were performed using an anterolateral approach as described previously. For cavity defects, the morsellised bone chips were impacted as firmly as possible using metal impactors and a mallet and segmental defects were filled with structural grafts. The hook of the KT plate was placed under the teardrop area, as described previously. At least two screws were passed through the KT plate to fix it to the pelvis before a polyethylene acetabular component was cemented to the KT plate. The femoral components were revised in 37 hips (in 33 patients) for radiological loosening. Antibiotics were administered intravenously 30 minutes before surgery, and at six and 18 hours post-operatively. Mobilisation involved one-third partial weight-bearing between parallel bars or with a walking frame usually starting three days after surgery, with the patient progressing to full weight bearing over the next two to three weeks.

The thickness of the bone graft on post-operative radiographs was evaluated as the maximal distance between the host bone and the superior margin of the KT plate. Post-operative and follow-up radiographs were compared to assess migration of the implant in terms of a) change in the angle of inclination of the acetabular device and b) vertical migration, defined as the distance between the interteardrop line and the centre of the femoral head, as described previously. Substantial migration was defined as a change of $> 3\degree$ in the angle of inclination or migration $> 3$ mm. Radiological failure was defined by any of three following criteria, as described previously: 1) substantial migration; 2) presence of a progressive radiolucent line (RLL) exceeding 2 mm in width in all three DeLee and Charnley zones and 3) breakage of the screws without migration or change in inclination. The mean of independent measurements by three of the authors (HA, KY, MT) of the radiological parameters was calculated and identical evaluation of radiological findings by consensus.

Hip function was evaluated according to the scoring system of Merle d’Aubigné and Postel before operation and at the latest follow-up by three authors (HA, KK, KG).

**Experimental study.** The mechanical properties of structural or compacted allograft bone aggregates were analysed, as described previously. Briefly, the compression stiffness of femoral heads removed from patients with osteoarthritis (n = 2) or with a femoral neck fracture (n = 2) and of the disc-shaped compacted bone aggregates (40 mm in diameter) produced using an ex vivo compaction device with various amounts of morsellised bone chips (n = 3 for each aggregate) was measured by loading the bone aggregates in a uniaxial load-testing machine (Model 1123; Instron, Norwood, Massachusetts). In order to assess the mechanical properties of the KT plate, the load-displacement behaviour and the strain distribution of the KT plate were measured in vitro. The acetabular component (48 mm in diameter) was oriented at 45° of abduction using polymethylmethacrylate cement in the KT plate, and the acetabular component-plate specimen was installed on a mounting unit which had a metal rod for the inferior hook and screw holes and five uniaxial strain gauges were fixed onto the surface of the KT plate, as shown in Figure 2a. Single indentation loading was applied...
approximately 48 hours after installation via a ball-bearing component applied to the polyethylene acetabular component using a universal testing machine (AG-100kNE; Shimazu, Tokyo, Japan) (Fig. 2b). A load up to 2600 N was applied at a cross-head speed of 1 mm/min.

Statistical analysis. The Kaplan-Meier method with 95% confidence intervals (CI) was used to estimate the cumulative probabilities of revision and radiological failure. Comparisons of measurements were analysed using the Student’s t-test with a p-value < 0.01 considered statistically significant.

Results
The mean operating time was 221 minutes (118 to 314) and the mean intra-operative blood loss was 635 ml (170 to 1730). Merle d’Aubigné and Postel hip scores increased from a mean pre-operative value of 10.0 (5 to 15) to a mean of 13.6 (9 to 18) (p < 0.01). Post-operative complications occurred in three hips, comprising infection in two hips (at 3 months and 4 years after operation, respectively), one of which required further revision, and recurrent dislocation in a 65-year-old woman at 1.7 years after a revision operation for aseptic loosening. This hip also required further revision with the intra-operative finding that the KT plate had fractured.

The mean thickness of the bone graft was 18.7 mm (3 to 47) in all hips: 14.6 mm (3 to 23) in Type II defects and 21.7 mm (14 to 47) in Type III defects. In one hip, as described above, there was a fracture of the plate, whereas no breakage of the screws was seen in any of the hips. At the final evaluation, the mean change in the angle of inclination was 1.2° (0° to 10°): 0.94° (0° to 8°) in Type II defects and 1.4° (0° to 10°) in Type III defects. One hip with a Type II defect and three hips (including one with recurrent dislocation and one with infection) with Type III defects exhibited a change of > 3° in the inclination angle. A progressive RLL > 2 mm in width was seen in the infected hip with Type III defect at 8.3 year follow-up. The mean vertical migration was 0.58 mm (0 to 5): 0.16 mm (0 to 0.8) in Type II defects and 0.88 mm (0 to 5) in Type III defects. One hip with a type III defect had migrated vertically > 3 mm.

The rate of survival of all patients at ten years was 87% (95% CI 76.3 to 97.7); 94.1% (95% CI 82.3 to 100) in Type II defects and 81.2% (95% CI 64.3 to 98.1) in Type III defects using radiological failure or revision of the acetabular component for any reason as the end point, respectively (Fig. 3). The survival rate in Type II defects was stable beyond four years after operation, while that in Type III defects decreased during the follow-up period.

Experimental study. The KT plate is made of pure titanium (ASTM B265Gr1) with a Young’s modulus of 106 GPa and
0.2% proof stress of 272 MPa (yield strain: 2570 μ). The result of the load-strain behaviour of the KT plate showed that the region of the inferior hook (Gauge 2) exhibited the lowest stiffness and that the yield strain at the inferior hook was generated by the applied load of approximately 1330 N, which corresponded to a forced displacement of approximately 1 mm (Fig. 4). When the applied load exceeded approximately 2450 N, which corresponded to a forced displacement of approximately 4 mm (Fig. 4), the base of the plate with screw holes (Gauge 1) entered the plastic region, and the strains at the other sites (Gauges 3 to 5) remained within the elastic range (Fig. 4a).

Figure 5 shows the load-displacement characteristics of structural bulk allografts and morsellised bone aggregates. Bone allografts with good bone quality showed high resistance to displacement (Fig. 5a). In contrast, bone allografts from osteoporotic femoral heads showed low elasticity (Fig. 5b), and compacted morsellised bone aggregates clearly showed a thickness-dependent change in load-displacement properties (Fig. 5c). Based on these data, compacted morsellised bone aggregates that had an approximate thickness of 25 mm showed resistance force with a displacement of < 4 mm at the base of the plate with the screw holes (Fig. 5d).

Discussion
The Kerboull plate (Howmedica, Herouville, France) reinforcement acetabular device was introduced in 2000 and made of 316L stainless steel. The Young’s modulus of this implant is 193 GPa and 0.2% proof stress of 290 MPa. This device has a hook inserted under the teardrop and a rounded plate fixed above the acetabulum with iliac screws which restores the appropriate centre of rotation for the hip. Using this device in conjunction with bulk allografts, survival was 92.1% at 13 years. Others have reported radiological evidence of aseptic loosening of the Kerboull plate in six of 35 patients when acetabular reconstruction was performed using impaction grafting. In addition, we previously reported that the survival rate using the Kerboull plate in the morsellised graft group and in the bulk graft group at ten years was 53% and 82%, respectively. Therefore, a structural bulk graft was recommended for acetabular reconstruction using the Kerboull plate.

The KT plate was introduced as a modification of the Kerboull plate, made of titanium, with similar geometry. The authors reconstructed the acetabulum using a KT plate with hydroxyapatite granules and, if necessary, autogenous iliac or fibular bone with a survival rate of 100% at a mean follow-up of five years and four months. Baba and Shitoto reported a survival rate of 87.5% for the KT plate at five years.

In addition to the development of infection in two patients, three hips in three patients in this study exhibited radiological failure with substantial migration of the device. In one hip with a Type II defect, the medial wall was ruptured in the process of impaction bone grafting, resulting in disruption of a contained defect and insufficient compaction of morsellised bone chips. In one hip with a Type III defect, a structural bulk allograft located in the load-bearing area partially collapsed beneath the device, which possibly fractured because of recurrent dislocation. In the other hip with a Type III defect, a large structural bulk...
allograft could not fully support the mechanical loading during the incorporation and remodelling process and partially collapsed. Therefore, although some concern remains that substantial migration may occur many years after acetabular reconstruction of massive bone defects in cases with Type III defects, our results indicate a satisfactory mid-term outcome in acetabular reconstruction using the KT plate with allografts. Our mid-term outcome is comparable with
the outcomes reported by other groups with different methods of acetabular reconstruction, including impaction bone grafting and cementless acetabular components. Long-term follow-up is also essential in the assessment of failure and revisions involving bone allograft.

The use of a reinforcement device with structural allografts has been variously reported. Our group and Kerboull et al reported better results using the Kerboull plate than with structural bulk allografts. Berry and Müller and Zehntner and Ganz reported high rates of failure for reconstruction using an acetabular reinforcement device with morsellised allografts, suggesting that morsellised allograft cannot support an acetabular component securely possibly due to inadequate compaction resulting in instability and subsequent subsidence of the implant during the process of incorporation and remodelling. Schreurs et al reported a survival rate of 95% at ten years for revision of the acetabular component for aseptic loosening using impaction bone grafting and a cemented acetabular component with a wire mesh and no acetabular reconstruction devices. Therefore, when well-compacted morsellised bone in a contained cavity provides sufficient mechanical strength to support the implant when loaded.

The material property of the device is one of the possible factors that may influence the outcome of acetabular reconstruction using reconstruction devices. The smaller yield strain of the stainless steel (1500 µ) Kerboull plate versus the titanium (2570 µ) KT plate indicates that the Kerboull plate has a narrower tolerance to forced displacement compared with the KT plate. Several studies on the Kerboull plate have reported the breakage of the screws and of the implant itself whereas breakage of the implants of the KT plate has been reported only in this study. Experimental analyses revealed that, because the KT plate is more elastic than the Kerboull plate, the strength is greater at the yield point in the stress versus strain curve, at which the curve levels off and plastic deformation begins. For the Kerboull plate, the region of the inferior hook and the base of the plate with the screw holes exhibited the lowest stiffness and the yield strain was generated by an applied load of approximately 1300 N. In contrast, for the KT plate, even though the yield strain at the inferior hook was generated by an applied load of approximately 1330 N, the base of the plate with the screw holes entered the plastic region when the applied load exceeded approximately 2450 N, which corresponded to a forced displacement of approximately 4 mm.

The stability of the acetabular component depends largely on the stiffness of the allograft. In vitro experiments showed that the resected osteo-arthritis femoral heads of osteoarthritis with good bone quality possess a high resistance force to displacement and that they have adequate mechanical properties to support the KT plate. In contrast, the osteoporotic femoral heads of femoral neck fractures have low mechanical properties and a higher risk of collapse. Therefore, a structural bulk allograft of good bone quality should be employed with the KT plate for defects in a load-bearing area. When appropriate well-compacted and graded morsellised allografts can be used to fill a contained defect, as the mechanical property of the bone aggregates depends on the density of the packed bone chips and optimum inter-particulate surface area contact. The increase of these variables produces more stiffness and less recoil of the grafted bone. Analysis of the compression load versus displacement curve of morsellised bone aggregates and of the KT plate revealed that well-compacted, well-graded morsellised bone aggregates with a thickness of 2.5 mm can provide sufficient stability for the KT plate, within 4 mm of deformity, which is the yield point of the base of the plate with the screw holes in the KT plate. Breakage of the inferior hook, which has a lower yield strain, is a possible risk associated with the use of morsellised bone graft with the KT plate. However, in this study, no breakage of the plate occurred when using morsellised graft to manage Type II defects. Only one hip with a Type II defect displayed radiological failure caused by insufficient compaction due to disruption of a contained defect.

In conclusion, the mid-term clinical outcome of acetabular reconstruction using the KT plate in combination with bone allografts is satisfactory. When morsellised allografts are used, the defect should be contained and should have a width < 2.5 mm. Long-term studies are required to monitor bone graft incorporation and the stability of the device.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

References


