

Influence of the volume of bone defect, bone grafting methods, and hook fixation on stress on the Kerboul-type plate and screw in total hip arthroplasty: three-dimensional finite element analysis

Nobuhiro Kaku · Katsutoshi Hara ·
Tomonori Tabata · Hiroshi Tsumura

Received: 18 March 2014 / Accepted: 14 June 2014 / Published online: 27 June 2014
© Springer-Verlag France 2014

Abstract For total hip arthroplasty or revision surgery using acetabular reinforcement cross-plates, choosing between bulk and morselized bone grafts for filling acetabular defects is challenging. We used finite element model (FEM) analysis to clarify various stresses on the cross-plate based on bone defect size, bone graft type, and presence or absence of hook fixation to the bone. We constructed 12-pattern FEMs and calculated the maximum stress generated on the Kerboul-type (KT) plate and screw. Bone defects were classified into four patterns according to the volume. Regarding the bone graft type, bulk bone grafts were considered as cortical bone, and morselized bone grafts were considered to consist of cancellous bone. Models were compared based on whether hook fixation was used and whether a gap was present behind the plate. The upper surface of the host bone was fixed, and a 1,000-N load was imposed on the horizontal axis at 71°. Larger bone defects increased the stress on the KT plate and screws. This stress increased when no bone was grafted; it was lower when bulk cortical bone grafts were used for filling than when morselized cancellous bone grafts were used. For cortical bone grafts, the increased stress on the KT plate and screws was lowered with hook removal. Attaching the hook to the bone and filling the gap behind the KT plate with an adequate bone graft reduced the stress on the KT plate and screws, particularly for large bone defects filled by bulk bone grafting.

Keywords Kerboul-type plate · Screw · Total hip arthroplasty · Three-dimensional finite element analysis · Bone defect · Bone grafting

Introduction

Reconstruction of large bone defects involving the acetabulum remains a challenging procedure for hip surgeons. The available reconstructive methods include support rings, large-diameter cementless cups, and cement cups that use impaction bone grafting (IBG) [1, 2]. The available support rings include the Muller support rings, Burch-Schneider support rings, and Ganz plates [3–5].

The Kerboul acetabular reinforcement cross-plate, which was developed in 1974 [6], is a reinforcement device characterized by the fixation of a primary acetabulum consisting of a stainless steel cup. The Kerboul-type (KT) plate is a similarly shaped modified Kerboul acetabular reinforcement device introduced in September 1993. The KT plate consists of a palette, dome, and hook, where screws enter the bone from outside the palette. The titanium KT plate is an excellent reinforcement material that can be filled using bone grafting material, which can help in guiding the defective acetabulum to a suitable cup position. Furthermore, a slightly elevated placement of the plate allows for variations in acetabular reconstruction. Recent reports have described favorable clinical results by using this device [6–13], and certain factors that influence clinical outcomes, such as the size of the bone defect, have been identified. However, stable fixation of a Kerboul acetabular reinforcement cross-plate is generally complex, and some reports have described its loosening or migration [8–13].

An acetabular reinforcing cross-plate is useful for reconstructing large bone defects involving the acetabulum.

This work was performed in the Department of Orthopaedic Surgery, Faculty of Medicine, Oita University, Oita, Japan.

N. Kaku (✉) · K. Hara · T. Tabata · H. Tsumura
Department of Orthopaedic Surgery, Faculty of Medicine,
Oita University, Oita 879-5593, Japan
e-mail: nobuhiro@oita-u.ac.jp

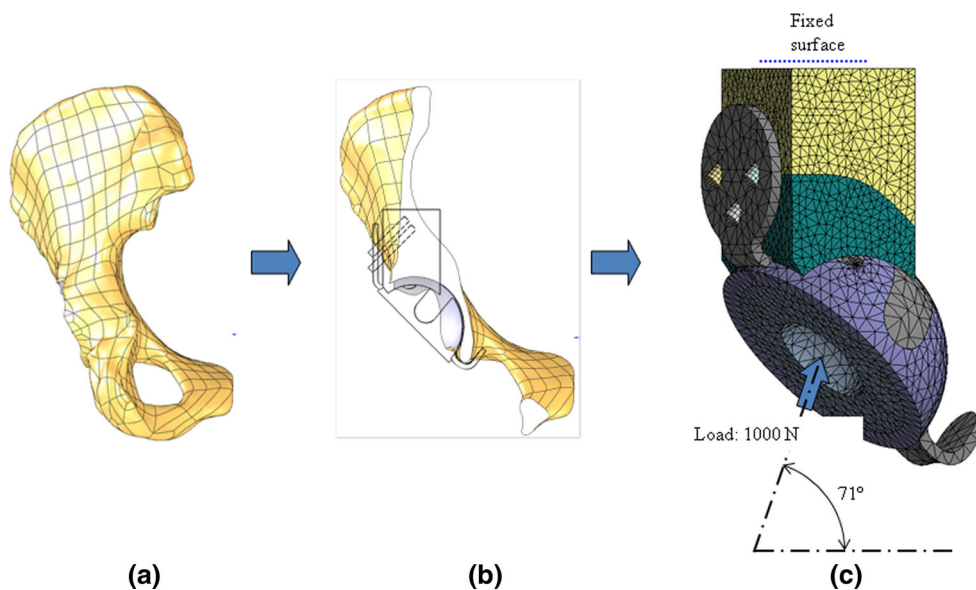
However, from the technical point of view, the placement of a stable KT plate is not necessarily a simple task. When using a bone graft and a cross-reinforcement plate to reconstruct an acetabular defect, bulk bone grafts are found to provide comparatively good initial strength; however, these are somewhat cumbersome to manipulate. In contrast, morselized bone grafts are comparatively simpler to manipulate during surgery, easy to press into the gap, easy to handle, and can be replaced, if necessary; however, they are less reliable in terms of strength. We aimed to identify procedures (conditions) that would reduce the stress on the screw and KT plate compared to that noted in the current surgical techniques that focus on preventing the breakage and/or loosening of screws and KT plate. Factors that influence the stress on the screw and KT plate include the volume of the bone defect, the manner of bone graft, and the fixation of the KT plate hook to the bone during acetabular reconstruction for primary total hip arthroplasty or revision surgery. However, it is difficult to identify the influence rate of the individual factors in clinical practice. We hypothesized that the influence of the factors was dependent on interaction among the factors rather than a simple sum of each factor's influence. In the present study, we analyzed the changes in stress generated on the KT plate and screws, in various conditions, with different sizes of bone defects and types of bone grafts, using a finite element model (FEM) in order to verify our hypothesis.

Materials and methods

Even in an accurate pelvic model, the direction of the load and pelvic shape differ for each patient, and it is difficult to estimate the effects of such individual differences on the

stress generated on the screws and KT plate. In addition, the direction of the load and pelvic shape are not factors that can be controlled by the surgeon. To clarify the effects of these factors, we constructed a three-dimensional FEM using the following parameters. The shape of the acetabulum was simplified in order to identify the changes rather than only evaluate the absolute value of stress due to various factors; moreover, only the bone of the proximal portion of the KT plate was constructed in this study (Fig. 1). The height, width, and depth of the bone model used here were 35, 30, and 30 mm, respectively; the distal portion of the bone was skived along the curvature of the dome of the KT plate. The inner diameter of the dome was 48 mm, and the thickness of the plate was 2.5 mm. The diameter of the polyethylene liner was 44 mm, and the bearing surface diameter of the polyethylene liner was 22 mm. The thickness of the bone cement between the polyethylene liner and the KT plate was 2.0 mm; at the area without the KT plate, this thickness was 4.5 mm. The diameter and length of the screw were 3.6 and 27 mm, respectively. The KT plate was set such that the palette portion was perpendicular to the horizontal axis of the pelvis. A gap of 2.5 mm between the palette and graft bone was allowed. This model consisted of ten nodes and was of the tetrahedral element type. The joints between the KT plate and the bone graft, the host bone and the bone graft, and all the borders around the screws were considered to be fixed with glue, such that they would not allow slipping. The number of nodes and elements in the representative model constructed was as follows: KT plate, 7,584 nodes and 3,690 elements; polyethylene liner, 10,393 nodes and 6,222 elements; bone cement, 7,814 nodes and 3,756 elements; host bone, 17,845 nodes and 10,805 elements; graft bone, 12,909 nodes and 7,541 elements; and screws, 2,616

Fig. 1 Three-dimensional finite element analysis model. **a** FEM of the hemipelvis. **b** Image showing half of the hemipelvis with a KT plate. **c** The FEM model used in this study: this model consisted of ten nodes and was tetrahedral. The upper surface of the graft bed and the hook were fixed, and a load of 1,000 N was imposed at an angle of 71° to the horizontal axis



nodes and 493 elements, respectively (Table 1). Young’s modulus and Poisson’s ratio were set at 17.3 GPa and 0.265 for cortical bone, 0.4 GPa and 0.2 for cancellous bone, 106 GPa and 0.34 for the KT plate (Kyocera, 480005-purity Ti), 110.6 GPa and 0.326 for the screws (Ti–6Al–4V), 2.65 GPa and 0.455 for bone cement, and 1.04 GPa and 0.3 for the polyethylene liner, respectively (Table 2) [14]. The upper surface of the host bone was fixed, and a load of 1,000 N was applied to the inner

surface of the liner at an angle of 71° to the horizontal axis. Fixation conditions of the hook were simulated, wherein “firmly fixed” or “slippage” were allowed [15]. Simulations were performed for 12 patterns with varying bone defect sizes, presence or absence of hook fixation to the bone, and bone graft placement methods (Table 3). Bone defects were classified into four patterns based on the volume (Fig. 2). With regard to the bone graft type, bulk bone grafts were considered to be cortical bone, whereas morselized bone grafts were considered to consist of cancellous bone. Acetabular bone defects were expressed in terms of the bone graft volume; the extent of cancellous bone grafted was varied by changing the size of the defect in the vertical direction (models 1, 9, 10, and 11); and the effects of bone graft volume were then compared. The differences between bulk and morselized bone grafts were also evaluated (models 1–4). The highest values of maximum stress were compared based on whether or not hook fixation was used (models 6 and 8) and whether or not a gap was present behind the plate (models 1 and 7). ANSYS Simulation 11.0 (SASIP, Inc.) software was used for analysis, and maximum stress was estimated for the KT plate and screws. The Pearson product-moment correlation coefficient was used for statistical analysis. The study design was approved by the institutional ethics review board.

Table 1 Number of nodes and elements involved in the construction of representative model #1

	Number of nodes	Element count
KT plate	7,584	3,690
Polyethylene liner	10,393	6,222
Bone cement	7,814	3,756
Host bone	17,845	10,805
Graft bone	12,909	7,541
Screw	2,616	493

Table 2 Young’s modulus and Poisson’s ratio for each object in the model

	Young’s modulus (GPa)	Poisson’s ratio
Cortical bone	17.3	0.265
Cancellous bone	0.4	0.2
KT plate	106	0.34
Screw	110.6	0.326
Bone cement	2.65	0.455
Polyethylene liner	1.04	0.3

Results

All the results of the simulations performed in this study are shown in Table 4. Increasing the horizontal size of the bone defect increased the stress on the KT plate and screw.

Table 3 Conditions for each model

Model number	Height of the bone defect	Hook fixation	Composition of the bone graft	Volume percentage of cortical bone present in the bone graft (%)
1	B	Fixed	Only cancellous bone	0
2	B	Fixed	Only cortical bone	100
3	B	Fixed	Mixed (cancellous bone in the proximal area)	30
4	B	Fixed	Mixed (cortical bone in the proximal area)	70
5	B	Fixed	Mixed (cancellous bone in the proximal area)	75
6	B	Fixed	Nothing (vacant space)	–
7	B	Not fixed	Only cancellous bone	0
8	B	Not fixed	Nothing (vacant space)	–
9	A	Fixed	Only cancellous bone	0
10	C	Fixed	Only cancellous bone	0
11	D	Fixed	Only cancellous bone	0
12	D	Fixed	Mixed (cancellous bone in the proximal area)	65

The simulation conditions indicate the volumes of cortical and cancellous bone, presence or absence of hook fixation to bone, and bone graft placement methods. The height of bone defect is represented as A, B, C, and D, and increases from A to D; this classification has been explained in Fig. 2 in detail

On comparing the size of the acetabular defect—i.e., the amount of cancellous bone grafted—for four different patterns (wherein the outside of the acetabulum was peripheral to the distal screw, between the proximal and distal screws, within the palette and proximal to the screws,

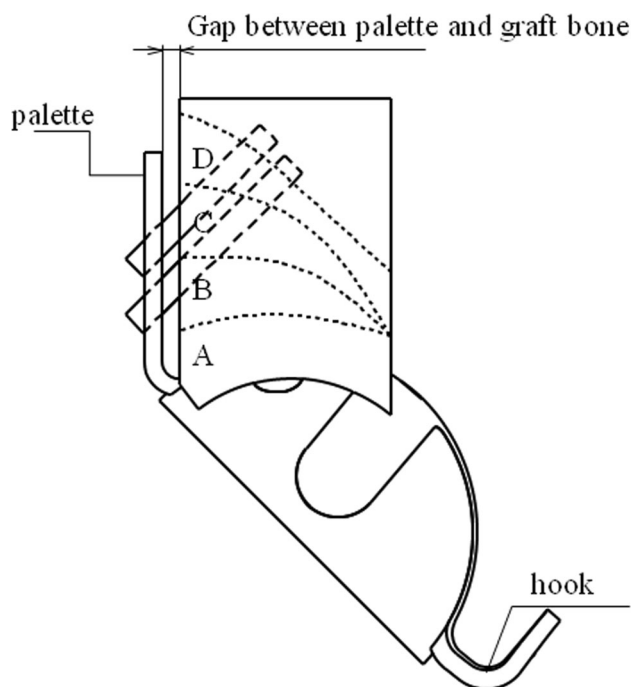


Fig. 2 Size variation of the bone defects. Varying bone defect sizes were classified into four types considering the height of the bone defect in the vertical direction. *A* The bone defect was present inferior to the insertion of the distal screw. *B* The bone defect was present between the distal and proximal screws. *C* The bone defect was present between the proximal screws and the proximal edge of the palette. *D* The bone defect was superior to the proximal edge of the palette

or outside the palette; Fig. 3), we found that a larger amount of grafted bone was associated with greater stress. Similar to the results obtained in model 12, when cortical bone was grafted, a smaller size of the defect led to lower stress on the KT plate and screws (Fig. 4). Changing the type of graft used for the defect between cancellous and cortical bone had little effect on the KT plate; however, proximal grafting of cancellous bone increased the stress on the screws. When the bone graft was gradually switched from cortical to cancellous bone from the proximal area, the stress on the KT plate and screws increased in a directly proportional manner to the volume of cancellous bone (Fig. 5). A comparison of models 1 and 2 showed that the stress on the KT plate was 1.22 times higher for the cancellous bone graft alone as compared with the cortical bone graft alone, and the stress on the screws was approximately five times higher.

Graphical representations of the volume of cortical bone and maximum stress on the KT plate in all the patterns, and of the relationship between the volume of bone graft and the maximum stress on the KT plate, showed that the use of smaller volumes of cortical bone grafts for the bone defect reduced the generation of stress on the KT plate. On the other hand, although some association between the volume of the bone graft and stress on the KT plate was observed, this was not significantly correlated (Fig. 6). Similar results were observed for the screws (Fig. 7).

We also investigated the effect of hook fixation and the presence or absence of a gap behind the KT plate. The presence of a gap had a major effect on the stress on both the KT plate and the screws (Fig. 8). In the absence of a gap, hook fixation had little effect; however, in the presence of a gap, the use of hook fixation had an extremely significant effect on stress (Table 5).

Table 4 Results of all the simulations performed in the present study

Model no.	Maximum KT plate stress (MPa)	Maximum screw stress (MPa)	Cortical bone volume (host bone) (mm ³)	Cortical bone volume (bone graft) (mm ³)	Cancellous bone volume (bone graft) (mm ³)	Cortical bone volume (host bone + bone graft) (mm ³)	Bone graft volume (mm ³)
1	45.0	24.5	21,975	0	11,568	21,975	11,568
2	37.7	5.1	21,975	11,568	0	33,543	11,568
3	43.0	19.5	21,233	3,586	8,759	24,819	12,345
4	41.1	14.2	21,975	8,759	3,586	30,734	12,345
5	38.8	10.5	21,233	9,247	3,098	30,480	12,345
6	122.4	244.9	21,975	0	0	21,975	0
7	25.3	46.2	21,975	0	11,568	21,975	11,568
8	2,610.7	2,823.9	21,975	0	0	21,975	0
19	42.3	16.3	27,752	0	5,826	27,752	5,826
10	48.6	28.3	15,753	0	17,825	15,753	17,825
11	54.0	31.7	10,380	0	23,198	10,380	23,198
12	45.0	23.0	10,229	15,263	8,086	25,492	23,349

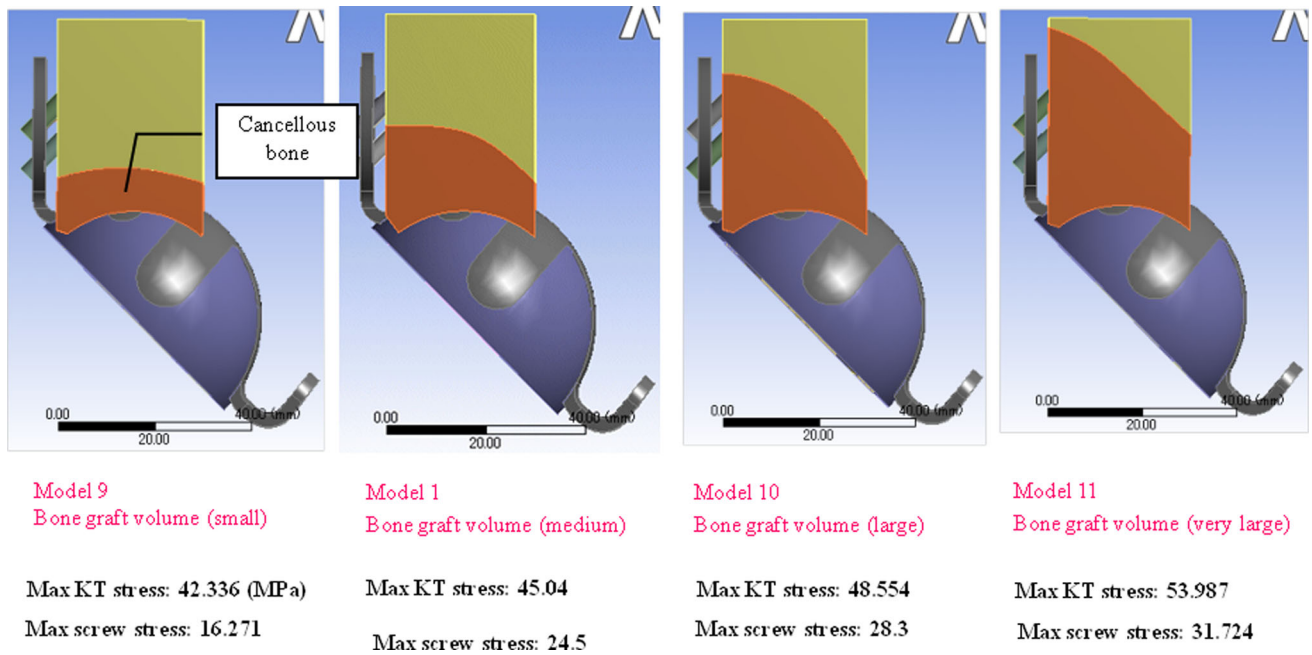
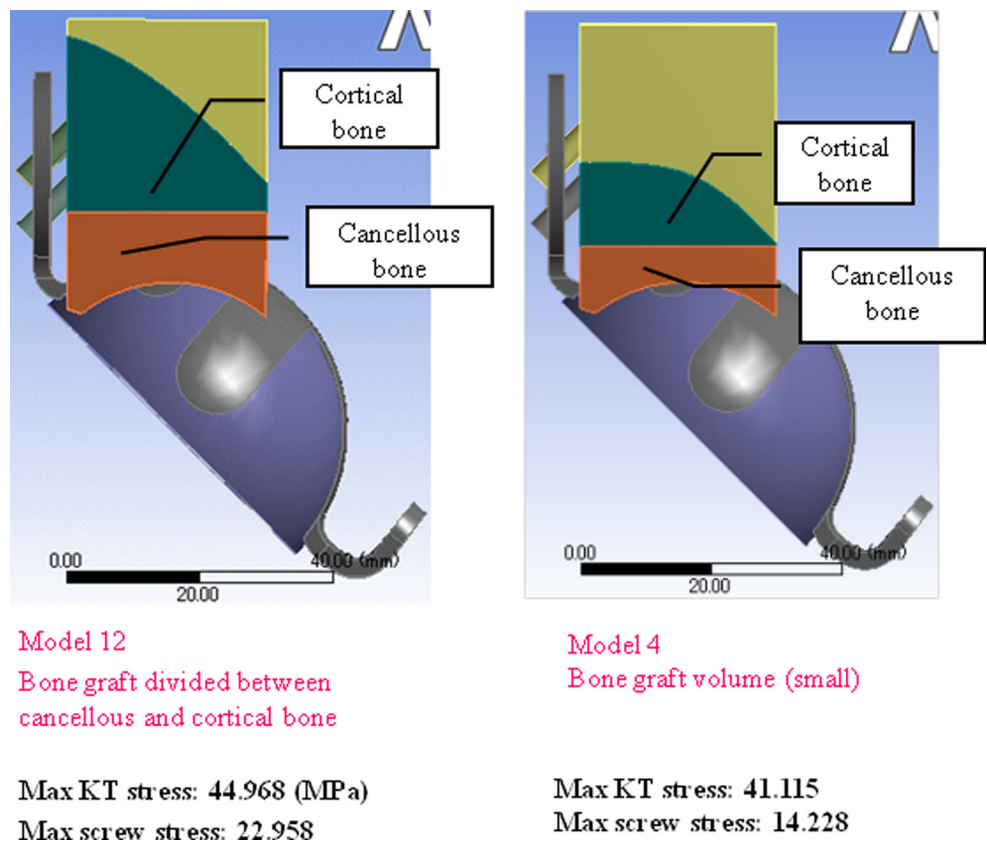


Fig. 3 Comparison of stress for vertical bone graft volume. The stress increased in proportion to the size of the bone graft volume (defect volume)

Fig. 4 Grafting of cortical bone *en bloc*. However, when bulk bone was grafted peripheral to the distal screw, it yielded results similar to those with a small bone defect pattern, and the stress on the KT plate and screws was greatly reduced



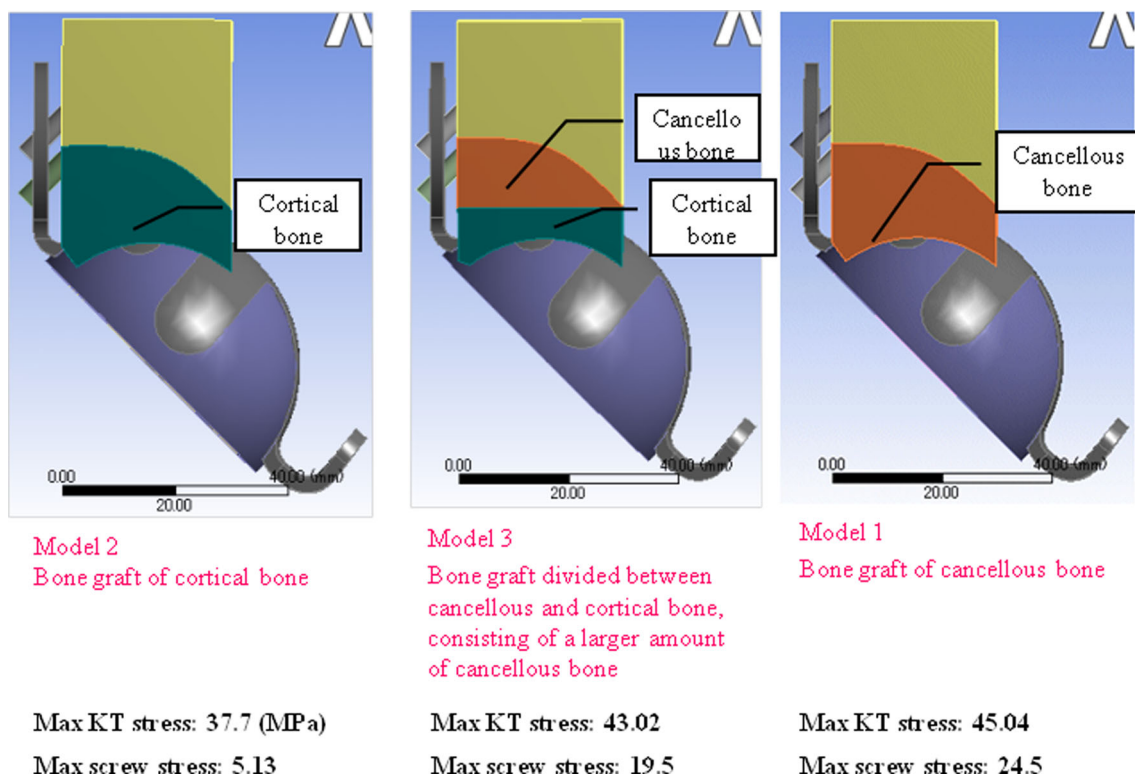
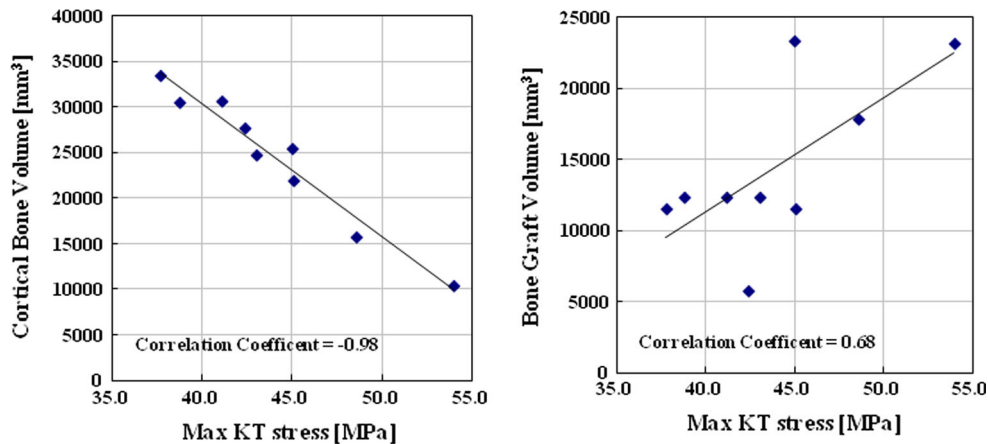


Fig. 5 Comparison of stress for different types of bone graft. A greater volume of cancellous bone graft was associated with a greater stress on the KT plate and screws

Fig. 6 Effect (stress on the KT plate) of cortical bone volume and bone graft volume in the bone defect. The Pearson product-moment correlation coefficient between the cortical bone volume or the bone graft volume and the stress generated at the screw and KT plate was calculated



Discussion

Kerboul cross-plates have been previously used for acetabular reconstruction in artificial hip replacement with varying results. In 2000, Kerboul et al. [6] mainly used structural and secondary morselized grafts in 60 joints, of which one joint required reimplantation surgery within 10 years. Tanaka et al. [7] reported favorable results when using hydroxyapatite granules after reconstruction with corticocancellous bone for segmental defects in 21 joints, none of which required revision within a period of

5.3 years. Kawai et al. [8] used bulk grafts and Kerboul-type plates in 20 hips with rapidly destructive coxarthrosis, and found no migration or loosening during a mean follow-up period of 6.3 years; moreover, none of the joints required reimplantation. Wegrzyn et al. [9] also reported favorable results for the use of structural allografts and cemented dual-mobility cups in 61 cases undergoing revision surgery of Academy of Orthopaedic Surgeons classification grade III and IV acetabular bone defect reconstruction; none of the cases had mechanical failure of the Kerboul cross-plate within a period of 7.5 years, whereas 98 % of cases showed

Fig. 7 Effect (stress on the screws) of cortical bone volume and bone graft volume in the bone defect. The graphs exclude data from models without bone grafts (4, 5, and 6) or hook fixation (8, 9, and 11)

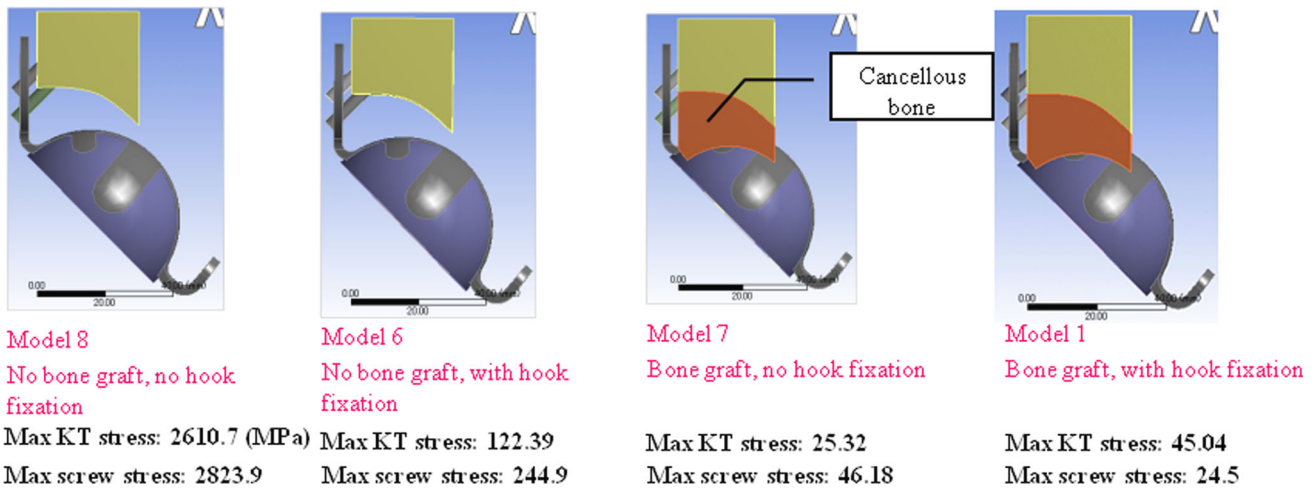
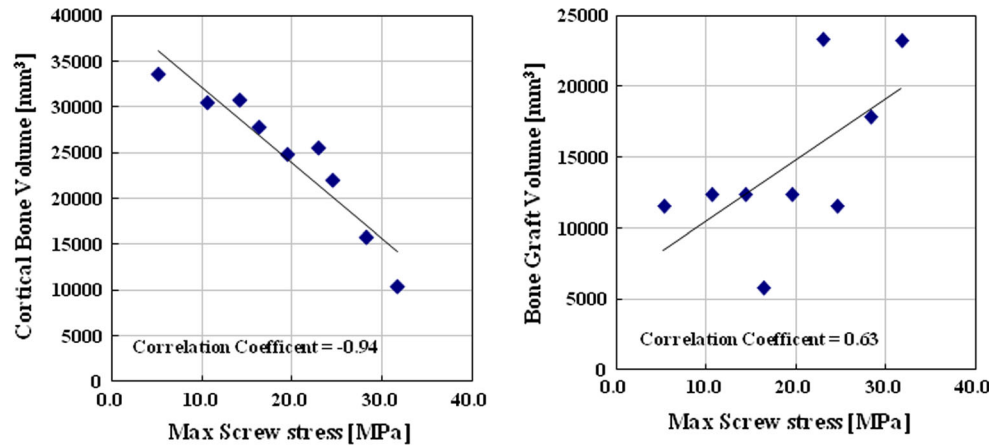


Fig. 8 The effect of hook fixation and the presence or absence of a gap. The presence of a gap had a major effect on stress on both the KT plate and the screws

Table 5 Effect of hook fixation and the presence or absence of a gap

	No gap	With gap
a. Model numbers		
Hook fixed	1	6
Hook not fixed	7	8
b. Maximum stress on the KT plate		
Hook fixed	45.0	122.4
Hook not fixed	25.3	2,610.7
c. Maximum stress on the screw (MPa)		
Hook fixed	24.5	244.9
Hook not fixed	46.2	2,823.9

In the absence of a gap, hook fixation had little effect on stress; however, in the presence of a gap, the use of hook fixation had an extremely significant effect on stress

complete osseointegration of the allograft. Conversely, Lunn et al. [10] reported on the use of morselized grafts in 35 joints; although none required reimplantation over a

mean period of 4.9 years, six joints eventually showed evidence of loosening. Kawanabe et al. [11] used morselized and structural grafts in 42 joints, and evidence of loosening was observed in 14 joints within 8.7 years; moreover, breakage of the KT plate occurred in nine joints. Furthermore, among these 14 cases, the number of cases that received morselized grafts was greater than the number of cases that received structural bone grafts. Out of the 32 joints treated with morselized allografts by Okano et al. [12], evidence of breakage was observed in seven joints over a period of 6.3 years. These results revealed a high incidence of loosening in cases, wherein morselized bone grafts were utilized for large bone defects of the acetabulum. Akiyama et al. [13] reported the occurrence of joint failure, as assessed by radiography, in 5 of 40 joints at an average of 6.7 years after surgery, with a Kaplan–Meier survival rate of 87 % at 10 years, when joint failure by any cause was used as the endpoint. This report observed that for bone defects measuring ≤ 25 mm in height, the use of morselized bone as a bone graft was acceptable.

In previous three-dimensional FEM analyses of acetabular reinforcement devices, Kawanabe et al. [16] used binarization image processing to calculate the stress distribution on the inner surface of the socket for a Kerboul-type device, Burch-Schneider anti-protrusion cage, Mueller ring, and Ganz ring, as well as a cement-fixed socket (control). They observed that the stress on the socket surface was at least halved by the use of any one of the four reinforcement devices as compared with the control, demonstrating the usefulness of these devices in ensuring that bulk bone grafts in the load direction are not crushed.

In the present study, using a FEM, we analyzed the changes in stress generated on the KT plate and screws in various conditions. Since the conditions used in this study would differ from actual clinical conditions, it is important to consider the mechanical trends and the trends of changes in the stress on the KT plate and screws rather than the absolute values observed in the study. The current three-dimensional FEM study found that stress increases with an increase in the size of acetabular bone defects—that is, in proportion to the size of the bone graft. A smaller volume of cortical bulk bone graft within this defect was associated with a greater stress generated on the KT plate and screws. Moreover, the mechanical properties of various bone graft types are not clearly known, and the absolute value of the stress generated in the screw and KT plate would change based on these mechanical properties. Filling the bone defect with good-quality bone grafts appears to be important since we observed that for large bone defects, the stress on both KT plates and screws reduced with an increasing volume of cortical bone graft. Although some association was observed between the volume of the bone graft and the stress on the KT plate, this was not as strong as the correlation of stress with the volume of cortical bone. If the bone graft fully filled the bone defect without leaving a gap behind the plate, hook fixation had little effect on the stress generated on the KT plate and screws. However, if a gap was present, the presence or absence of hook fixation had a highly significant effect on the stress generated. Fixing the KT plate hook firmly at the bone of the obturator foramen is thus an extremely important surgical procedure for preventing the breakage of the KT plate and screws. For large acetabular bone defects, the use of a fixed cortical bulk bone graft in the gap, along with the concurrent use of morselized bone grafts to fill the gap to the maximum possible limit, would be effective in ensuring the initial fixation of the KT plate. Bone cement is a useful filling material for gaps in bone defects. However, if used in excess quantity, this would reduce the advantages offered by the use of the KT plate in terms of bone strength.

Our study has certain limitations. FEM analysis typically requires the maximum simplification of the clinical condition. However, certain differences are present in the

strength and quality of the bone, which occur owing to a femoral neck fracture or osteoarthritis of the hip among the same bulk-formed transplant bone. In addition, the strength of the bone graft as a whole varies according to the pressure when using morselized bone in the clinical setting. However, the quality of bone graft used in this study was defined by only two conditions—i.e., as cortical and morselized bone. To our knowledge, the physical properties of various types of bone grafts have not been determined thus far. In the future, it is important to examine the effects of the differences in the physical properties of bone grafts on the stress generated on the KT plate and screws. In this study, graft bone strength was assumed to decrease during the process of incorporation of the graft into the host bone, and Young's modulus was accordingly altered. Moreover, with respect to the quality of the material of the plate, stainless steel differs in terms of elasticity and plasticity from titanium. Differences in temperature, the presence of blood, and changes over time with exercise and rest *in vivo* are also clinical factors that can affect the stress generated on the KT plate and screws. In this FEM analysis, these clinical changes could not be examined.

Conclusion

In conclusion, when using the KT plate for the reconstruction of the hip in the presence of acetabular bone defects in the clinical setting, it is important to fill the gap behind the KT plate to the maximum possible extent with graft bone and bone cement in order to provide optimal initial stability. Subsequently, it is necessary to fix the hook of the KT plate at the bone of the obturator foramen in a reliable and correct manner. In cases with huge acetabular bone defects, the use of a bulk bone graft is effective in reducing the stress on the KT plate and screws compared to the use of a graft of morselized bone alone. These technical points are expected to be useful in preventing breakage and loosening of the KT plate.

Conflict of interest Each author certifies that he or she, or a member of their immediate family, has no commercial associations (e.g., consultancies, stock ownership, equity interest, and patent/licensing arrangements) that might pose a conflict of interest in connection with the submitted article.

References

1. Lee JM, Nam HT (2011) Acetabular revision total hip arthroplasty using an impacted morselized allograft and a cementless cup: minimum 10-year follow-up. *J Arthroplasty* 26:1057–1060
2. Buttaro MA, Comba F, Pusso R, Piccaluga F (2008) Acetabular revision with metal mesh, impaction bone grafting, and a cemented cup. *Clin Orthop Relat Res* 466:2482–2490

3. Jones L, Grammatopoulos G, Singer G (2012) The Burch-Schneider cage: 9-year survival in Paprosky type 3 acetabular defects. Clinical and radiological follow-up. *Hip Int* 22:28–34
4. Mibe J, Imakiire A, Watanabe T, Fujie T (2005) Results of total hip arthroplasty with bone graft and support ring for protrusio-acetabuli in rheumatoid arthritis. *J Orthop Sci* 10:8–14
5. Uchiyama K, Takahira N, Fukushima K, Yamamoto T, Moriya M, Itoman M (2010) Radiological evaluation of allograft reconstruction in acetabulum with Ganz reinforcement ring in revision total hip replacement. *J Orthop Sci* 15:764–771
6. Kerboull M, Hamadouche M, Kerboull L (2000) The Kerboull acetabular reinforcement device in major acetabular reconstructions. *Clin Orthop Relat Res* 378:155–168
7. Tanaka C, Shikata J, Ikenaga M, Takahashi M (2003) Acetabular reconstruction using a Kerboull-type acetabular reinforcement device and hydroxyapatite granules: a 3- to 8-year follow-up study. *J Arthroplasty* 18:719–725
8. Kawai T, Tanaka C, Ikenaga M, Kanoe H, Okudaira S (2010) Total hip arthroplasty using Kerboull-type acetabular reinforcement device for rapidly destructive coxarthrosis. *J Arthroplasty* 25:432–436
9. Wegrzyn J, Pibarot V, Jacquel A, Carret JP, Béjui-Hugues J, Guyen O (2014) Acetabular reconstruction using a Kerboull cross-plate, structural allograft and cemented dual-mobility cup in revision THA at a minimum 5-year follow-up. *J Arthroplasty* 29:432–437
10. Lunn JV, Kearns SS, Quinlan W, Murray P, Byrne JO (2005) Impaction allografting and the Kerboull acetabular reinforcement device: 35 hips followed for 3–7 years. *Acta Orthop* 76:296–302
11. Kawanabe K, Akiyama H, Onishi E, Nakamura T (2007) Revision total hip replacement using the Kerboull acetabular reinforcement device with morsellised or bulk graft: results at a mean follow-up of 8.7 years. *J Bone Joint Surg Br* 89:26–31
12. Okano K, Miyata N, Enomoto H, Osaki M, Shindo H (2010) Revision with impacted bone allografts and the Kerboull cross plate for massive bone defect of the acetabulum. *J Arthroplasty* 25:594–599
13. Akiyama H, Yamamoto K, Tsukanaka M, Kawanabe K, Otsuka H, So K, Goto K, Nakamura T (2011) Revision total hip arthroplasty using a Kerboull-type acetabular reinforcement device with bone allograft: minimum 4.5-year follow-up results and mechanical analysis. *J Bone Joint Surg Br* 93:1194–1200
14. Crowninshield RD, Maloney WJ, Wentz DH, Humphrey SM, Blanchard CR (2004) Biomechanics of large femoral heads: what they do and don't do. *Clin Orthop Relat Res* 429:102–107
15. Williams M, Lissner HR (1963) Biomechanical analysis of knee function. *J Am Phys Ther Assoc* 43:93–99
16. Kawanabe K, Akiyama H, Goto K, Maeno S, Nakamura T (2011) Load dispersion effects of acetabular reinforcement devices used in revision total hip arthroplasty: a simulation study using finite element analysis. *J Arthroplasty* 26:1061–1066