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Application of Acetabular Reinforcement Ring with Hook for Correction of Segmental Acetabular Rim Defects during Total Hip Arthroplasty Revision

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Abstract

This study investigated the biomechanical micro-motion associated with the application of acetabular reinforcement ring with hook (Ganz ring) for the correction of segmental acetabular rim defects, by finite element analysis. The objective was to determine whether the Ganz ring is suitable for correcting segmental acetabular rim defects at different regions during total hip arthroplasty revision as well as the number of screws required to fix the Ganz ring. A finite element model of the hip joint was generated to simulate and evaluate the insertion and fixation of the Ganz ring and acetabular cup in the context of segmental rim defects in the anterior column, superior portion, and posterior column. Micro-motion was the greatest in the posterior column defect and the least in the anterior column defect. However, the peak stress distribution on the remaining portion of the acetabular rim was the highest in the superior portion defect, following the posterior column defect and anterior column defect. Increasing the number of fixations of the Ganz ring did not decrease the micro-motion. We found that the Ganz ring effectively provided biomechanical stability during the reconstruction of the segmental rim defect as long as the screws fixed the Ganz ring well to the host bone.

Keywords: segmental acetabular rim defect, Ganz ring, biomechanics, finite element method, total hip arthroplasty revision

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1 Introduction

The reconstruction of bone defects of the acetabulum during total hip arthroplasty and total hip arthroplasty revision is challenging for orthopedic surgeons[1–3]. Many methods have been described for the restoration of the natural rotational center of the acetabulum, with variable success rates[4–10]. Ganz developed a device called the Ganz ring to ensure the initial stability of the cup in the anatomical position during bone grafting[11]. Further, Gill and Ganz recommend the use of 3 – 4 cancellous screws to fix the Ganz ring to the host bone[9]. Thereafter, several reports on the use of the Ganz ring have indicated good outcomes with low rates of biomechanical failure[9–12]. However, failure still occurs in some cases, mostly due to aseptic loosening[12,13], which may be attributed to the poor initial stability of the cup provided by the Ganz ring.

Despite many reports on the use of the Ganz ring for acetabular reconstruction during total hip arthroplasty, no studies thus far have investigated the biomechanical changes in the segmental rim defects following the application of the Ganz ring in total hip arthroplasty revision. Finite element analysis method has been widely used for biomechanical studies in orthopedics, particularly in relation to total hip arthroplasty and revision[14–18]. In our previous biomechanical study using the finite element method, we found that the number of the screws required was different for different types of bone defects, as classified by Crowe in patients with Developmental Dysplasia of the Hip (DDH)[19]. This implied that the position of the screws in the ring affects the initial stability of the cup.

Amirouche *et al*.[20] investigated the biomechanical properties of the cup component in minor type I segmental defects, classified according to the American Academy of Orthopedics Surgeons (AAOS) system. However, the defect of the rim in their study was too small, which would have significantly influenced the component when the cup was inserted into the acetabulum, without any additional bone graft or instruments. Further, in clinical practice, such small segmental rim

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defects are rare. Therefore, we increased the volume of the segmental rim defect and considered the segmental rim defects as occurring in one of three equal parts of the half superior portion of the acetabulum in current study.

Therefore, in the present study, we aimed to employ the finite element analysis method to answer the following questions: (1) What are the biomechanical changes associated with the use of the Ganz ring during total hip arthroplasty? (2) Does the use of the Ganz ring prevent biomechanical failure of the cup? (3) How many screws are required to ensure the stability of the cup?

2 Methods

The finite element models of the hip joint used in the current study were planned in such a way that they accounted for the differences in the natures of the cortical and cancellous bone and also the irregularities at the points of contact between the Ganz ring and bone. The post-grafting bone models were designed on the basis of the typical pelvic model, incorporating the segmental acetabular rim defects commonly observed in actual practice. The model construction and finite element analysis were performed using MSC.Marc/Mentat2005r3 (MSC Software Corp., Santa Ana, CA) software.

2.1 Construction of models for acetabular-segmental rim defect secondary to bone grafting

The data on the hip dimensions employed for the construction of the three-dimensional (3D) finite element models were based on the computed tomography scans of the left pelvic bone acquired with a slice thickness of 0.6 mm at Sawbones (Pacific Research Laboratories, Inc., Vashon, WA) using Mimics 17.0 (Materialise, Leuven, Belgium). The dimensions of the cortical bone and the border between the cortical and the trabecular bone were determined using the threshold technique and inspection, if required. Using the above-mentioned data, a typical 3D model of the left pelvic bone was constructed, with 667,372 elements and 131,473 nodes (Fig. 1). The tetrahedron was used as the 3D element form for the construction of the cortical and cancellous bones. The material property values of each element were determined according to the data available from previous study[19,21] (Table 1).

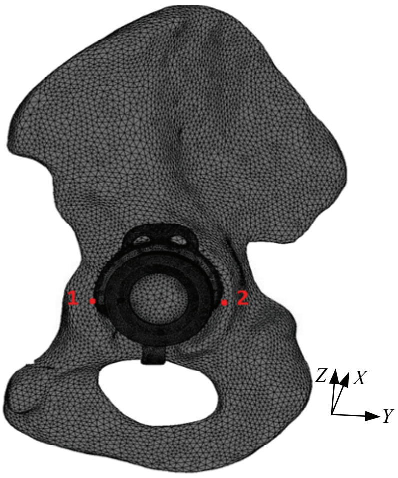

Fig. 1 Model of total hip arthroplasty revision. The model shows the femoral head, acetabular cup, cement, Ganz ring, and acetabulum arranged in a concentric manner at the acetabulum. Numbers 1 and 2 indicate the points for the measurement of relative micromotion between the screw-fixed Ganz ring and the pelvic bone following load application.

Table 1 Element types and material properties[19,21]

Materials	Element type	Young's modulus (E: MPa)	Poisson's ratio (ν)
Cortical bone	Solid	17000	0.3
Trabecular bone	Solid	100	0.2
Bone cement (type PMMA)	Solid	2100	0.4
ARRH	Solid	110000	0.3
Screw	Solid	110000	0.3
Liner (UHMWPE)	Solid	1000	0.46
Prosthetic head (CoCrMo)	Solid	230000	0.3
Bone graft	Solid	150	0.2
Surface	Contact	Friction coefficient	0.88

Using the finite element method, in this study, we considered the segmental rim defects as occurring in one of three equal parts of the half superior portion of the acetabulum: the anterior column, superior aspect, and posterior column (Fig. 2).

The model for the supporting Ganz ring was consistent with the measurements of the acetabular reinforcement ring with a hook (diameter of the Ganz ring, 50 mm)[19]. The Ganz ring was attached to the acetabulum by latching its hook onto the obturator foramen and immobilized in the normal anatomical position with the use of cancellous screws with 6.5 mm threads. The surface of contact between the Ganz ring and the pelvic bone was considered to behave as a nonlinear contact surface, with friction set at 0.88, as described previously[19]. The acetabular cup (outer/inner diameter: 48 mm/26 mm; Hip Joint Prosthesis, AK Medical Inc, Beijing, China) was placed on the Ganz ring with lateral and anterior opening angles of 45 degree and 15 degree, respectively, and fixed by 1-mm-thick cement. The femoral head was assumed to be a hemisphere that attached to the acetabular cup (Fig. 1).

2.2 Number and positions of screws

As described above, 3, 4, or 5 cancellous screws were employed to hold the Ganz ring in position. For the 3-screw model, three 30-mm cancellous screws were advanced through the appropriate openings on the ring such that they penetrated the site of bone grafting to form a triangle with the apex placed superiorly (Fig. 3a). For the 4-screw model, two cancellous screws of the same kind used in the previous model were introduced into the two central openings that formed the base of the triangle in the 3-screw arrangement, with the addition of one screw each in the anterior and posterior directions (Fig. 3b). For the 5-screw model, three screws were placed in the same triangular arrangement used for the 3-screw model, along with two screws placed in the two additional openings applied in the 4-screw arrangement (Fig. 3c). The interfaces between the screws and the bone and ring were considered to be bonded.

2.3 Materials used for bone graft

According previous study, Young's modulus of morcellized bone graft for acetabular dysplasia models has been reported as 42 MPa – 150 MPa, so we chose the biggest Young's modulus, 150 MPa, for morcellized bone graft in models of acetabular defect, which we used during operation[19]. The same value of Young's modulus was applied to the morcellized graft material that was assumed to be used for the correction of the acetabular defects in this study.

2.4 Boundary and loading conditions

The loading conditions applied in this study were the same as those applied by Bergmann *et al.* in their study[22]. The magnitude and direction of force were normalized to 100% with respect to the normal gait of individuals who undergo total hip arthroplasty; then, in each model, the center of the head was considered to be subjected to peak load (1948 N). Further, areas representing the sacroiliac joint and pubic symphysis were considered as being under complete restraint. To perform nonlinear analysis, force control was employed in the numerical procedure, and the Newton–Raphson method was applied in the iterative method, with the load applied in 20 incremental steps. The fixation strength of the Ganz ring for each model was assessed on the basis of the relative micromotion observed at the points of interaction between the ring and the pelvic bone as a result of the applied load.

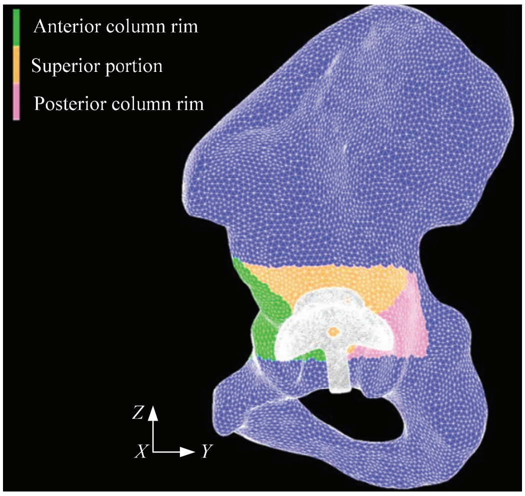

Fig. 2 Illustration of the segmental acetabular rim defect. The defects were considered to occur in the superior half portion of the acetabulum, which was divided into three equal parts, namely, the anterior column rim, superior portion, and posterior column rim.

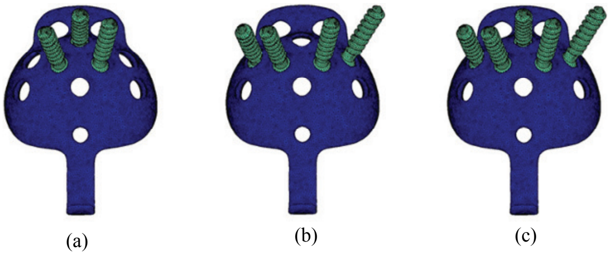

Fig. 3 The positions of the cancellous screws for the Ganz ring in the three tested screw arrangements. (a) 3-screw fixation: 30 mm screw × 3; (b) 4-screw fixation: 30 mm screw × 4; (c) 5-screw fixation: 30 mm screw × 5.

3 Results and discussion

The stability of the acetabular cup mounted using the Ganz ring was evaluated in terms of relative micromotion, which was defined as the distance between the ring and pelvic bone at the interface and measured at two different points around the ring (Fig. 1). In this study, we investigated the biomechanical properties of the Ganz ring used in the correction of segmental acetabular rim defects during total hip arthroplasty revision and found that the Ganz ring was an effective tool for the reconstruction of the acetabulum. According to the results, the micromotion was greater at point 2 compared with point 1 of the cup. The values of maximum relative micromotion were 9.9 μm, 20.6 μm, and 32.8 μm for the anterior column defect, superior portion defect, and posterior column defect, respectively, in the three-screw fixation model at a load of 1948 N with morcellized bone graft Young's modulus was 150 Mpa (Fig. 4). We also evaluated three combinations (screw-3, screw-4, and screw-5) of screws for the fixation of the Ganz ring and found that these combinations were indeed useful in fixing the Ganz ring and that they did not differ in terms of the initial stability of the component. According to the results, for the anterior column defect, the values of micromotion for the three screw combinations were similar at 9.9 μm, 7.7 μm, and 7.5 μm, respectively; for the superior portion defect, the values of micromotion for the three screw combinations were similar at 20.1 μm, 10 μm, and 10.9 μm, respectively; and for the posterior column defect, the values of micromotion for the three screw combinations were similar at 32.8 μm, 35.8 μm, and 34.4 μm, respectively (Fig. 4). Further, we found that the micromotion was higher in the posterior region and in posterior column defects, but lower in the anterior portion defect of the cup, implying that the maximum peak stress was located in the posterior or superio-posterior region of the acetabular rim. This is consistent with the peak stress distribution noted in our results: the superior portion defect had the maximum peak stress of 57.8 Mpa at the posterior region of the cortical acetabular rim, followed by the posterior column defect (maximum peak stress, 30.5 Mpa), at the superio-posterior region of the cortical acetabular rim. The maximum peak stress was the least in the anterior column defect (21.1 Mpa), which was also located on the superio-posterior region of the cortical acetabular rim, which confirms and validates our findings regarding micro-motion and peak stress (Fig. 5).

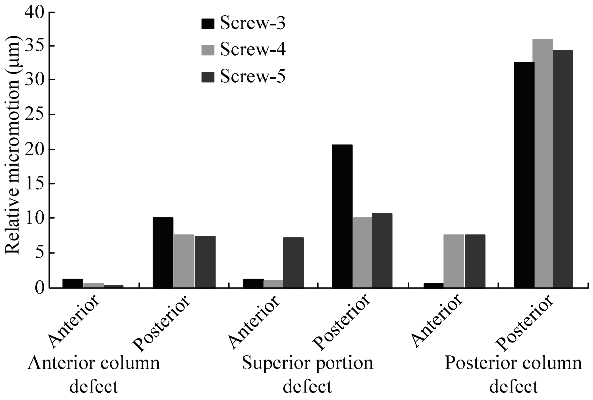

Fig. 4 Relative micro-motion of the Ganz ring in three types of bone defects. Anterior and posterior represent the relative micromotion at points 1 and 2, respectively.

From their finite element analysis, Amirouche *et al.* showed that the minor segmental superior or inferior rim defects had a minimal effect on cup fixation, while a defect in the columns created cup instability and increased the stress at the site of the defect; this implies that column defects require additional methods for complete reconstruction of the acetabulum[20]. Generally, segmental rim defects are larger than the defect considered in their study, and therefore, using the press-fit method without any additional method would lead to initial instability and stress concentration, resulting in early failure. Therefore, in the current study, we sought to emphasize the importance of ensuring good biomechanical stability by using the Ganz ring to reconstruct the acetabulum for the correction of segmental rim acetabular defects during total hip arthroplasty (Figs. 4 and 5).

Previous biomechanical studies based on finite element analysis have shown that the Ganz ring is useful in preventing the collapse of bulk bone grafts applied to load-bearing defects[23] and providing initial stability[19]. Further, follow-up studies have also shown that the Ganz ring yields good outcomes in the correction of acetabular bone defects in actual clinical practice[9,11,12,24]. However, aseptic loosening and mechanical failure has still been reported to occur in 9% of the cases, as reported by Siebenrock *et al.*[12]. With the present acetabular bone defect hip models, the values of relative micromotion reached the highest levels at 36.8 μm; although this is less than 40 μm[25], the amount observed in this study may also affect bone growth at the interface between the

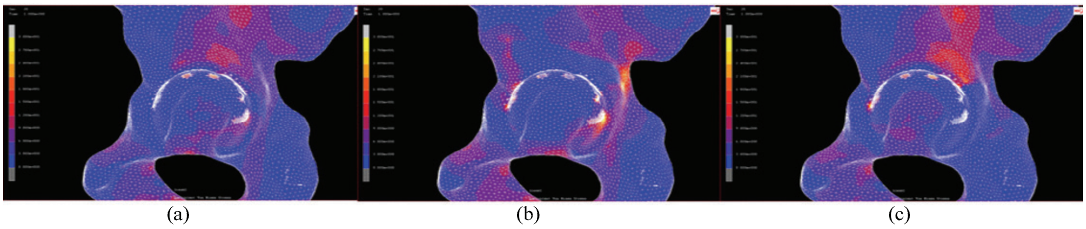
(a) (b) (c)

Fig. 5 Peak stress distribution (MPa) under a load of 1948 N, which simulates one leg stance. (a) Peak stress of the anterior column rim defect and the maximum peak stress located on the superior-posterior of the acetabulum; (b) peak stress of the superior portion defect and the maximum peak stress located on the posterior rim of the acetabulum; (c) peak stress of the posterior column rim defect and the maximum peak stress located on the superior-posterior rim of the acetabulum.

Ganz ring and host bone, leading to the possibility of aseptic loosening in the case of large posterior column defects. Therefore, we should be careful when reconstructing posterior column defects.

Our previous findings suggest that in DDH patients, the relative micromotion tends to decrease with an increase in the number of screws used for fixation[19]. Many other screw combinations have been used by various surgeons[9,11,12]. However, in the present study, we found that for the correction of segmental rim defects stability was achieved irrespective of the screw combinations used (Fig. 4), as long as the screws were inserted into the host bone.

Nevertheless, this study has a few limitations. Firstly, we did not account for the effect of the biological differences between individuals, bone density, and dynamic biomechanical properties. Secondly, finite element analysis only allows for a mechanical assessment, which may vary with the true conditions observed in an individual during surgery. Lastly, the current study only focused on segmental rim bone defects, and it will be necessary to investigate other more complicated acetabular bone defects in the future.

4 Conclusion

This study provided insight into the biomechanical changes associated with the application of the Ganz ring for the stability of acetabular cup during total hip arthroplasty revision for the correction of segmental acetabular rim bone defects. Our findings provide a guide for Ganz ring reconstruction of a segment acetabular rim bone defect during total hip arthroplasty revision and highlight the importance of the posterior column for the stability of the cup component during total hip arthroplasty and revision. We suggest that special attention should be paid to the correction of posterior column rim defects.

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References

[1] Hayashi S, Hashimoto S, Takayama K, Matsumoto T, Nishida K, Kuroda R. Multiple revision surgeries and acetabular bone defect size may predict daily activity after revision total hip arthroplasty. *The Journal of Arthroplasty*, 2017, **32**, 1606–1611.

[2] Craiovan B S, Grifka J, Keshmiri A, Moser B, Wörner M, Renkawitz T. Bone defect adjusted strategy in revision arthroplasty of the hip: Wich implant in wich situation? Innovations and approved methods. *Orthopade*, 2015, **44**, 366–374.

[3] Numair J, Joshi A B, Murphy J C, Porter M L, Hardinge K. Total hip arthroplasty for congenital dysplasia or dislocation of the hip. Survivorship analysis and long-term results. *Journal of Bone and Joint Surgery*, 1997, **79**, 1352–1360.

[4] Brown N M, Morrison J, Sporer S M, Paprosky W G. The use of structural distal femoral allograft for acetabular reconstruction of paprosky type IIIA defects at a mean 21 years of follow-up. *The Journal of Arthroplasty*, 2016, **31**, 680–683.

[5] Wegrzyn J, Pibarot V, Jacquel A, Carret J P, Béjui-Hugues J, Guyen O. Acetabular reconstruction using a Kerboull cross-plate, structural allograft and cemented dual-mobility cup in revision THA at a minimum 5-year follow-up. *The Journal of Arthroplasty*, 2014, **29**, 432–437.

[6] Abolghasemian M, Sadeghi Naini M, Tangsataporn S, Lee P,

Backstein D, Safir O, Kuzyk P, Gross A E. Reconstruction of massive uncontained acetabular defects using allograft with cage or ring reinforcement: An assessment of the graft's ability to restore bone stock and its impact on the outcome of re-revision. *Bone Joint Journal,* 2014, **96**, 319–324.

[7] Oe K, Iida H, Kawamura H, Ueda N, Nakamura T, Okamoto N, Ueda Y. Long-term results of acetabular reconstruction using three bulk bone graft techniques in cemented total hip arthroplasty for developmental dysplasia. *International Orthopaedics*, 2016, **40**, 1949–1954.

[8] Iwase T, Ito T, Morita D. Massive bone defect compromises postoperative cup survivorship of acetabular revision hip arthroplasty with impaction bone grafting. *The Journal of Arthroplasty*, 2014, **29**, 2424–2429.

[9] Uchiyama K, Takahira N, Fukushima K, Yamamoto T, Moriya M, Itoman M. Radiological evaluation of allograft reconstruction in acetabulum with Ganz reinforcement ring in revision total hip replacement. *Journal of Orthopaedic Science*, 2010, **15**, 764–771.

[10] Beckmann N A, Weiss S, Klotz M C, Gondan M, Jaeger S, Bitsch R G. Loosening after acetabular revision: Comparison of trabecular metal and reinforcement rings. A systematic review. *The Journal of Arthroplasty*, 2014, **29**, 229–235.

[11] Gill T J, Siebenrock K, Oberholzer R, Ganz R. Acetabular reconstruction in developmental dysplasia of the hip: Results of the acetabular reinforcement ring with hook. *The Journal of Arthroplasty*, 1999, **14**, 131–137.

[12] Siebenrock K A, Tannast M, Kim S, Morgenstern W, Ganz R. Acetabular reconstruction using a roof reinforcement ring with hook for total hip arthroplasty in developmental dysplasia of the hip-osteoarthritis: Minimum 10-year follow-up results. *The Journal of Arthroplasty*, 2005, **20**, 492–498.

[13] Gerber A, Pisan M, Zurakowski D, Isler B. Ganz reinforcement ring for reconstruction of acetabular defects in revision total hip arthroplasty. *Journal of Bone and Joint Surgery*, 2003, **85,** 2358–2364.

[14] Jiang H. Static and dynamic mechanics analysis on artificial hip joints with different interface designs by the finite element method. *Journal of Bionic Engineering*, 2007, **4**, 123–131.

[15] Lian Q, Li D, Jin Z, Zhen Wang, Sun Y. Patient-specific design and biomechanical evaluation of a novel bipolar femoral hemi-knee prosthesis. *Journal of Bionic Engineering*, 2014, **11**, 259–267.

[16] Ezquerra L, Quilez M P, Pérez M Á, Albareda J, Seral B. Range of movement for impingement and dislocation avoidance in total hip replacement predicted by finite element model. *Journal of Medical and Biological Engineering*, 2017, **37**, 26–34.

[17] Reimeringer M, Nuño N. The influence of contact ratio and its location on the primary stability of cementless total hip arthroplasty: A finite element analysis. *Journal of Biomechanics*, 2016, **49**, 1064–1070.

[18] Russell R D, Huo M H, Rodrigues D C, Kosmopoulos V.Stem geometry changes initial femoral fixation stability of a revised press-fit hip prosthesis: A finite element study. *Technology and Health Care*, 2016, **24**, 865–872.

[19] Zhao X, Chosa E, Yamako G, Watanabe S, Deng G, Totoribe K. Effect of acetabular reinforcement ring with hook for acetabular dysplasia clarified by three-dimensional finite element analysis. *The Journal of Arthroplasty*, 2013, **28**, 1765–1769.

[20] Amirouche F, Solitro G F, Walia A, Gonzalez M, Bobko A. Segmental acetabular rim defects, bone loss, oversizing, and press fit cup in total hip arthroplasty evaluated with a probabilistic finite element analysis. *International Orthopaedics*, 2016, **41**, 1527–1533.

[21] Zhang Y, Ahn P B, Fitzpatrick D C, Heiner A D, Poggie R A, Brown T D. Interfacial frictional behavior: Cancellous bone, cortical bone, and a novel porous tantalum biomaterial. *Journal of Musculoskeletal Research*, 1999, **3**, 245–251.

[22] Bergmann G, Deuretzbacher G, Heller M, Graichen F, Rohlmann A, Strauss J, Duda G N. Hip contact forces and gait patterns from routine activities. *Journal of Biomechanics*, 2001, **34**, 859–871.

[23] Kawanabe K, Akiyama H, Goto K, Maeno S, Nakamura T. Load dispersion effects of acetabular reinforcement devices used in revision total hip arthroplasty: A simulation study using finite element analysis. *The Journal of Arthroplasty*, 2011, **26**, 1061–1066.

[24] Park K S, Seon J K, Lee K B, Kim S K, Chan C K, Yoon T R. Revision total hip arthroplasty using an acetabular reinforcement ring with a hook: A precise follow-up, at average 11.4 years, of a previous report. *The Journal of Arthroplasty*, 2017, **26**, 503–509

[25] Pilliar R M, Lee J M, Maniatopoulos C. Observations on the effect of movement on bone ingrowth into porous-surfaced implants. *Clinical Orthopaedics and Related Research*, 1986, **208**, 108–113.