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*ORIGINAL STUDY*

# Cement anchors with screw holes for liner cementation into cementless acetabular metal shells

Nobuhiro Kaku, Masashi Hirakawa, Katsutoshi Hara, Tomonori Tabata, Hiroshi Tsumura

*From the Department of Orthopedic Surgery, Faculty of Medicine, Oita University, Oita, Japan.*

**This mechanical study was conducted with the shell-cement interface in order to construct an acetabular metal shell, and to fix a polyethylene liner with bone cement. Six types of models were tested, with all cementations performed under similar conditions. The "lever out" test was conducted 3 times for each group in order to measure the dissociation strength. The average dissociation strength values were 11.5 N·m for those without screw holes; 33.6, 34.7, and 78.7 N·m for those with single holes at 1, 3, and 6 mm depth, respectively; and 41.3 and 101.1 N·m for 2 different configurations with 3 holes at 3 mm depth. The strength of adhesion increased with the use of a cement anchor, and with an increasing length and number of anchors. The application of a cement anchor with a screw hole is clinically useful for increasing the mechanical strength of the shell-cement interface.**

**Keywords :** revision hip surgery, cement anchor, screw hole, cementing a liner, stable cementless acetabular metal shell

## INTRODUCTION

In some cases of artificial hip joint replacement, the acetabulum conforms well to the cementless shell, making the shell technically difficult to remove. Depending on the extent of the bone defect, subsequent reconstruction can pose a significant challenge to the surgeon. Furthermore, difficult subsequent reconstruction can be associated with considerable suffering for patients, particularly in elderly patients, who often desire minimally invasive surgery. In such cases, replacement of only the polyethylene liner, if possible, is preferable. Depending on the manner in which the shell was constructed, removing the liner may result in failure of the locking mechanism between the shell and liner, adding to the difficulty of replacing the liner alone. In certain cases, a slight alteration of the installation angle of the liner may also be desirable.

One option for revision surgery involves preservation of the shell and fixation of a new liner with bone cement. This method preserves the acetabular bone, is comparatively less invasive, and can facilitate a change in the liner installation angle. However, this method, which relies on cement fixation of the liner to the metal shell, is a novel orthopaedic procedure that results in the formationof

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■ Nobuhiro Kaku, M.D., Ph.D.,
■ Masashi Hirakawa, M.D.,
■ Katsutoshi Hara, M.D.,
■ Tomonori Tabata, M.D., Ph.D,
■ Hiroshi Tsumura, M.D., Ph.D.
*Department of Orthopaedic Surgery, Faculty of Medicine, Oita University, Oita, Japan*
Correspondence : Nobuhiro Kaku, Department of Orthopedic Surgery, Faculty of Medicine, Oita University, Oita, 879-5593, Japan
E-mail : nobuhiro@oita-u.ac.jp
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2 new interfaces where mechanical strength may be compromised : a shell-cement interface and a cement-liner interface.

Mechanical studies have shown that the surface shape of the liner and modifications in the surgical procedure have improved; consequently, the cement-liner interface has been substantially strengthened (*7,13,14*). There have also been innovations addressing the shell-cement interface, such as the creation of a groove with a high-speed burr on the shell surface (*12*). However, reinforcing the cement-liner interface may result in the creation of other potentially detrimental interfacial forces (*14*). To our knowledge, no study has previously described the manner in which the presence of a screw hole in the shell might increase the mechanical strength of the interface. In the present study, we aimed to examine the mechanical impact of screw holes on the strength of the shell-cement interface.

## MATERIALS AND METHODS

An anatomical multiple screw hydroxyapatite shell model (KYOCERA Medical, Osaka, Japan), with a 52 mm outer diameter and a 46 mm inner diameter, was used in the present study. These shells have highly polished inner surfaces, and were coated with a thin layer of Vaseline® (Unilever, London, UK) to minimise the impact of surface friction and to aid in isolating the efficacy of the screw hole-derived anchors. The cement anchors were created using screw holes at the shell-cement interface. We examined the length, number, and position of the cement anchors. In total, 6 shell models (SUS304,

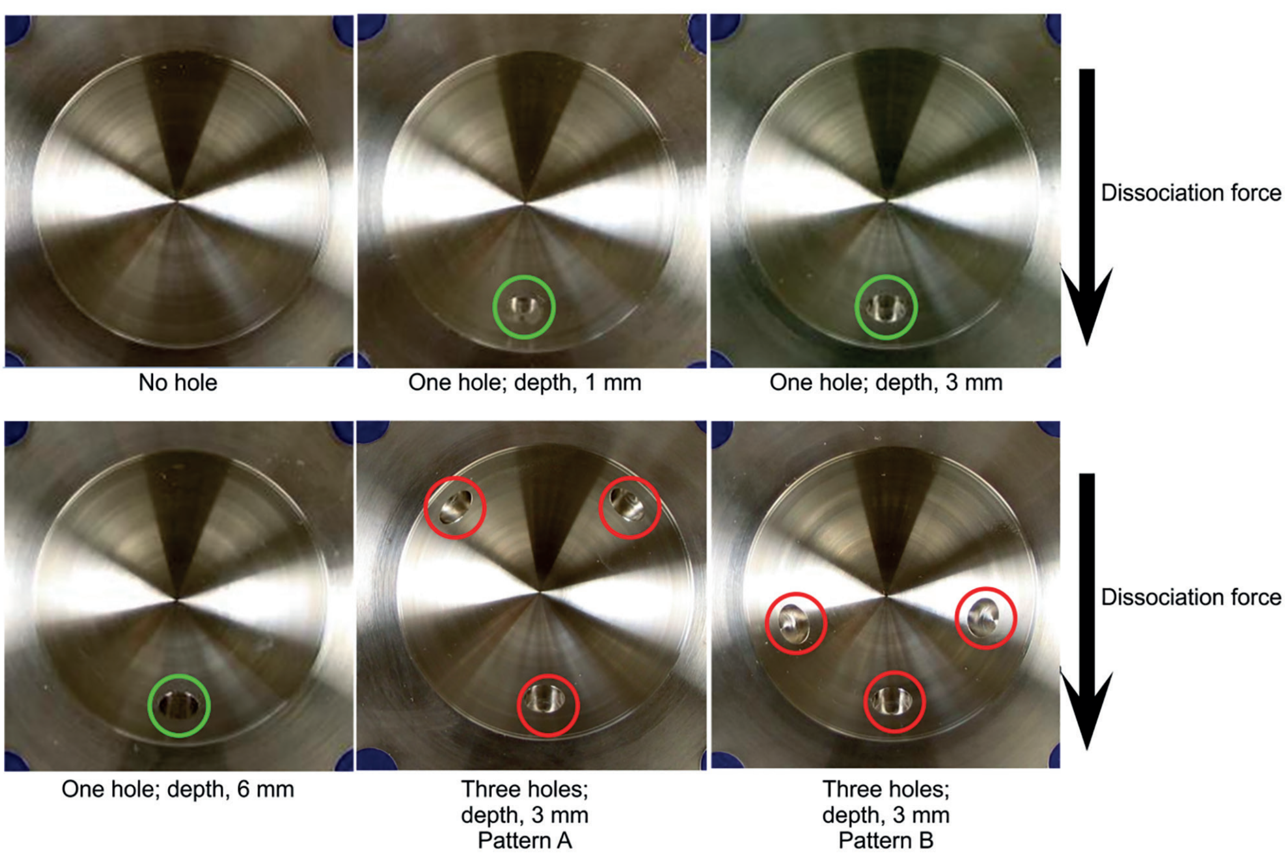
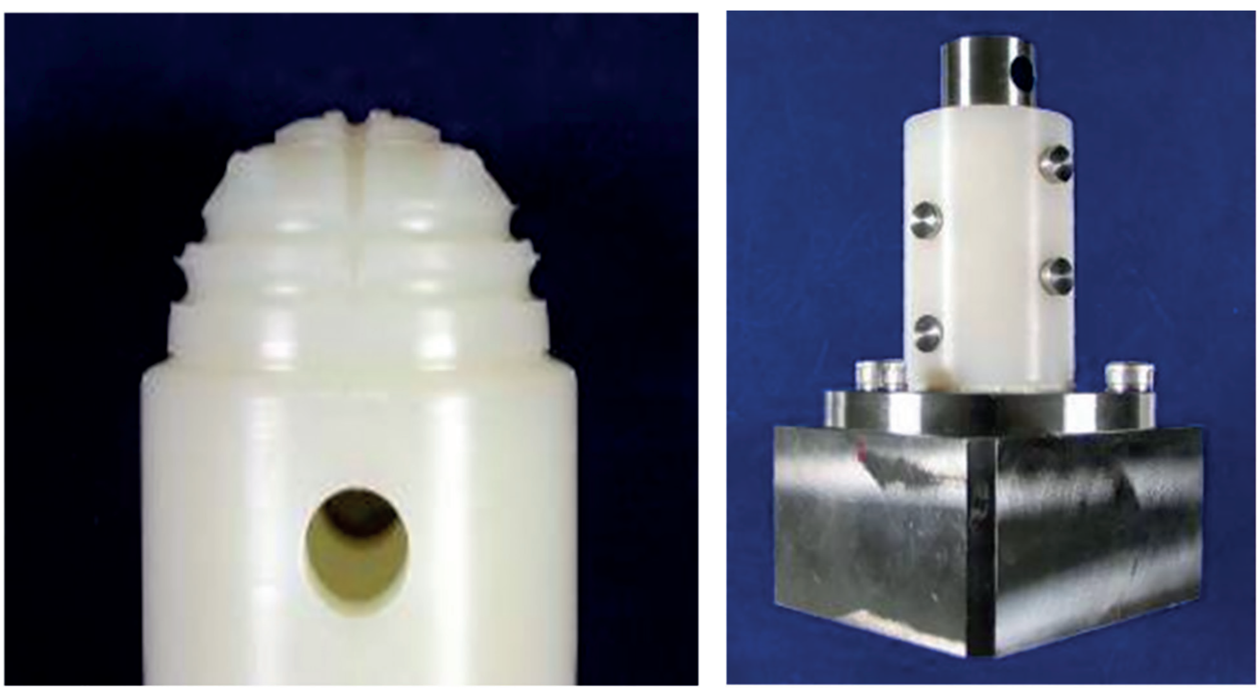



*Fig. 1*. — Different anchor test configurations. Study measures included screw hole depth, number, and position. The surfaces of the acetabular metal shell models were coated with petroleum jelly (0.2 g). The depth of the screw hole was equivalent to the length of the cement anchor.

comprising mainly stainless steel, Japanese Industrial Standards) were created (Fig. 1). A shell without any screw holes was used as the control. Three shells had a single cement anchor of 1 mm, 3 mm, or 6 mm length. The remaining shells had 3 mm long cement anchors installed around the periphery (Pattern A), or distal to the location at which dissociation force was applied (Pattern B). A number of concentric circumferential grooves and four 2 mm-long pegs, composed of ultra-high molecular weight cross-linked polyethylene, were added to the liner model to reinforce the cement-liner interface (Fig. 2a). The liner had a 28 mm diameter bearing surface. Three tests were performed with each model.

Before coating with Vaseline, each shell inner surface was carefully cleaned with gauze. Bone cement (Lot No. JHN022, Surgical Simplex P; Howmedica, Kalamazoo, MI, USA) without antibiotics was prepared according to manufacturer instructions. A liner with a lever-arm was installed at the centre of the bearing surface. After mounting 4 rods to prevent the 2 surfaces from separating during installation, bone cement was mixed for 1 min at 23°C ± 1°C, left undisturbed for 2 min, and then manually applied in a thick layer to the shell surface. Subsequently, a liner with a lever rod, as described above, was crimped to the shell for 6 min, with a force of 600 N; special care was taken to avoid ‘‘bottoming out’’ of the liner against the shell. The shell with the newly installed lever rod was allowed to stand for another 10 min after unloading (Fig. 2b). Shells with lever rods were mounted on the stainless steel shell fixture, and the fixture was attached to a universal testing machine (Instron Model 1123; Instron, Canton, MA, USA) with 2 nuts.

The test involved applying a rotational force, at a rate of 5°/min, using the universal testing machine; the maximum force was measured at



(a) (b)

*Fig. 2.* — Components of the test model. a) Cement socket model. A number of grooves and knobs strengthened the cement-liner interface. Surgical Simplex P bone cement was used, and the temperature of the test environment was set to 23°C ± 1°C. b) Bone cement procedure: (1) the bone cement was mixed with liquid monomer and powdered polymer, and stirred for 1 min; (2) the mixture was allowed to sit for 2 min; (3) the shell surface was coated with bone cement, after being placed in the testing machine; (4) the outer surface of the socket was inserted into the shell with a downward orientation and a 600 N load for 6 min; (5) after unloading, the model was allowed to sit for 10 min; and (6) the interlocking force was measured.

the time of dissociation. Dissociation torque was calculated using the following formula from a lever-out distance of 87 mm and an interlocking force (Fig. 3) : Torque [N·m] = F [N] × L [m]. Analysis of variance and *t*-tests were used for statistical analysis of the results. A *p*-value of $< 0.05$ indicated statistical significance.

## RESULTS

The average dissociation strength values were 11.5 N·m for the models without screw holes; 33.6, 34.7, and 78.7 N·m for those with single holes at 1, 3, and 6 mm depth, respectively; and 41.3 N·m for Pattern A and 101.1 N·m for Pattern B models with 3 screw holes at 3 mm depth. A greater interlocking force was associated with increased anchor length (Table I). In models with 3 cement anchors, the interlocking force was greater for the Pattern B group, where the cement anchors were concentrated distal to the point of application of the dissociation force, than for the Pattern A group, where the anchors were installed around the periphery (Fig. 4). In the comparison between groups, Pattern B was significantly superior to other models, excluding the single-screw 6 mm depth model. Statistically significant differences were not observed when comparing other groups.

Breaking occurred within the interface between the shell and cement for the 1 mm and 3 mm anchor points, but between the cement and liner when the anchor length was 6 mm, confirming that a stronger adhesion between the shell and cement had been obtained (Fig. 5). In the case of the 1 mm long anchors, the base of the cement anchors broke and the cement cracked at the anchor base; this was also noted in the model with the 3 mm long anchor. The cement cracked in the test configuration involving the 3 mm deep, 3-anchor Pattern A group, and peeling occurred between the shell and cement. In the Pattern B group, peeling occurred between the cement and liner, indicating that a strong adhesion between the shell and cement was present (Fig. 6).

## DISCUSSION

Clinical experience with cement fixation of a polyethylene liner to a metal shell is substantial. In 1984, Kim et al. reported on a surgical procedure which yielded very favourable fixation to the

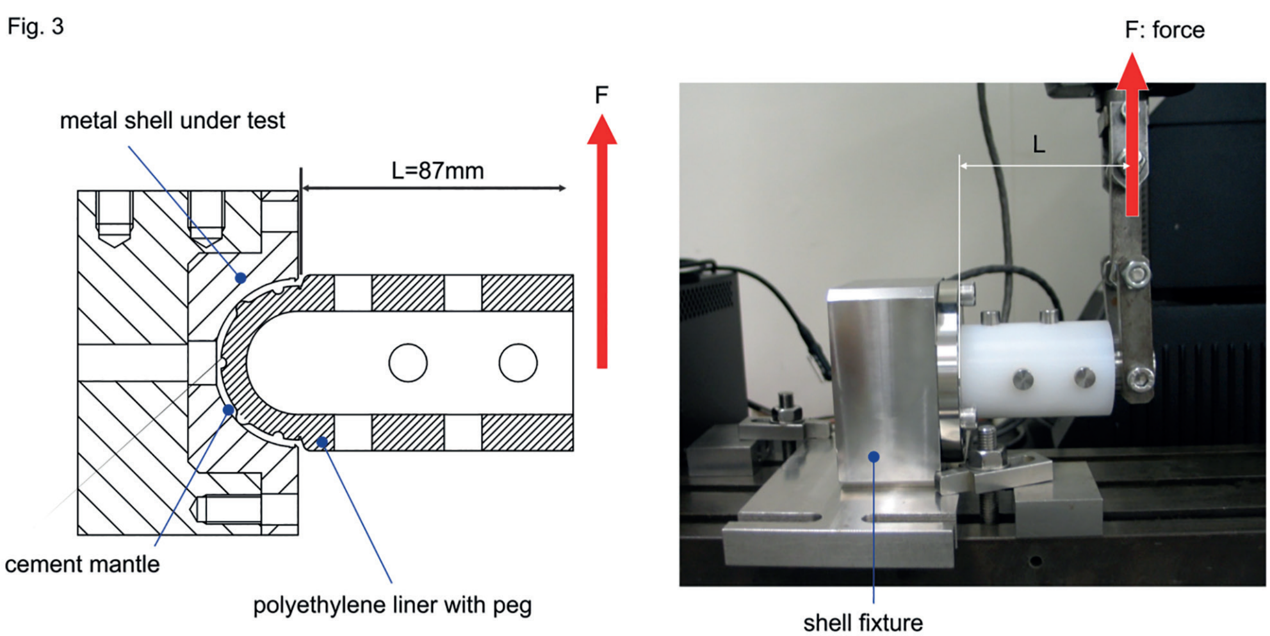



***Fig. 3.*** — Set-up of the testing device. Measurement method: A universal testing machine (Instron Model 112; Instron, Canton, MA, USA) was used to apply a rotational force at a rate of 5°/min to enable measurement of the interlocking force. Dissociation torque was calculated using the following formula from the lever-out distance (L) and the force (F): Torque [N·m] = F [N] × L [m].

Table I. — The interlocking force associated with different anchor hole depths and configurations

| Shell | No holes (N·m) | One, 1 mm hole (N·m) | One, 3 mm hole (N·m) | One, 6 mm hole (N·m) | Three, 3 mm holes, A (N·m) | Three, 3 mm holes, B (N·m) |
|---|---|---|---|---|---|---|
| 1 | 9.8 | 54.5 | 60.7 | 111.2 | 22.5 | 95.2 |
| 2 | 10.2 | 20.4 | 26.9 | 97.0 | 36.3 | 108.9 |
| 3 | 14.6 | 26.0 | 16.5 | 27.9 | 65.1 | 99.3 |
| Mean | 11.5 | 33.6 | 34.7 | 78.7 | 41.3 | 101.1 |
| σn-1 | 2.7 | 18.3 | 23.1 | 44.6 | 21.7 | 7.0 |
| Breaking point | Cement-shell | Cement-shell | Cement-shell | Cement-liner | Cement-shell | Cement-liner |

Fig. 4

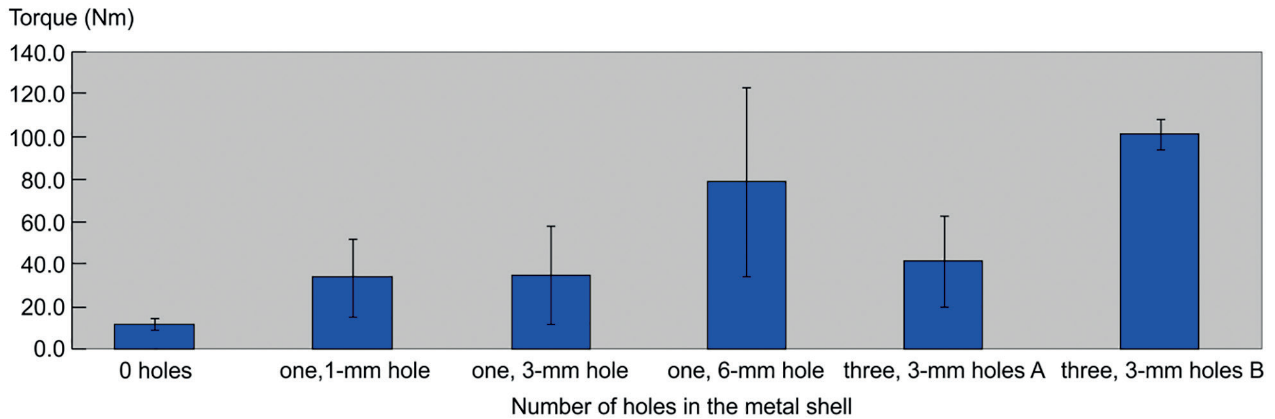



***Fig. 4.*** — Interlocking force associated with different anchoring configurations. In the 3-anchor groups, the interlocking force was greater for Pattern B, where the anchors were located distal to the application of dissociation force, than for Pattern A, where the anchors were installed peripherally.

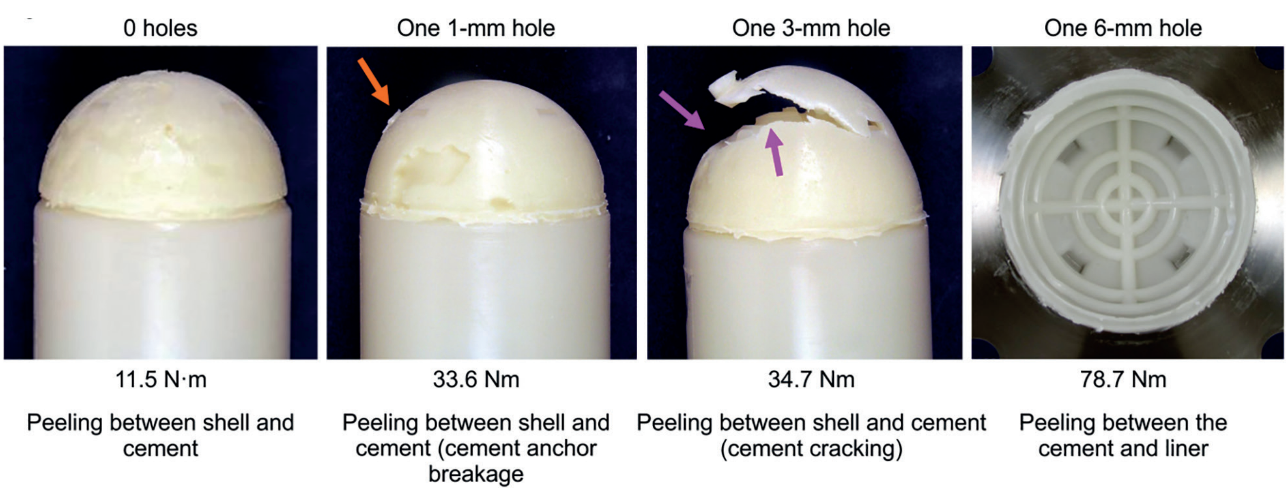



***Fig. 5*** — Consequences of the applied force on the breaking points associated with single anchor configurations. In models with anchor lengths of 1 mm and 3 mm, the breaking points were between the shell and cement; however, the breaking points were between the cement and liner in configurations with a 6 mm anchor length. This observation confirmed that strong adhesion between the shell and cement had been obtained in the 6 mm configuration.

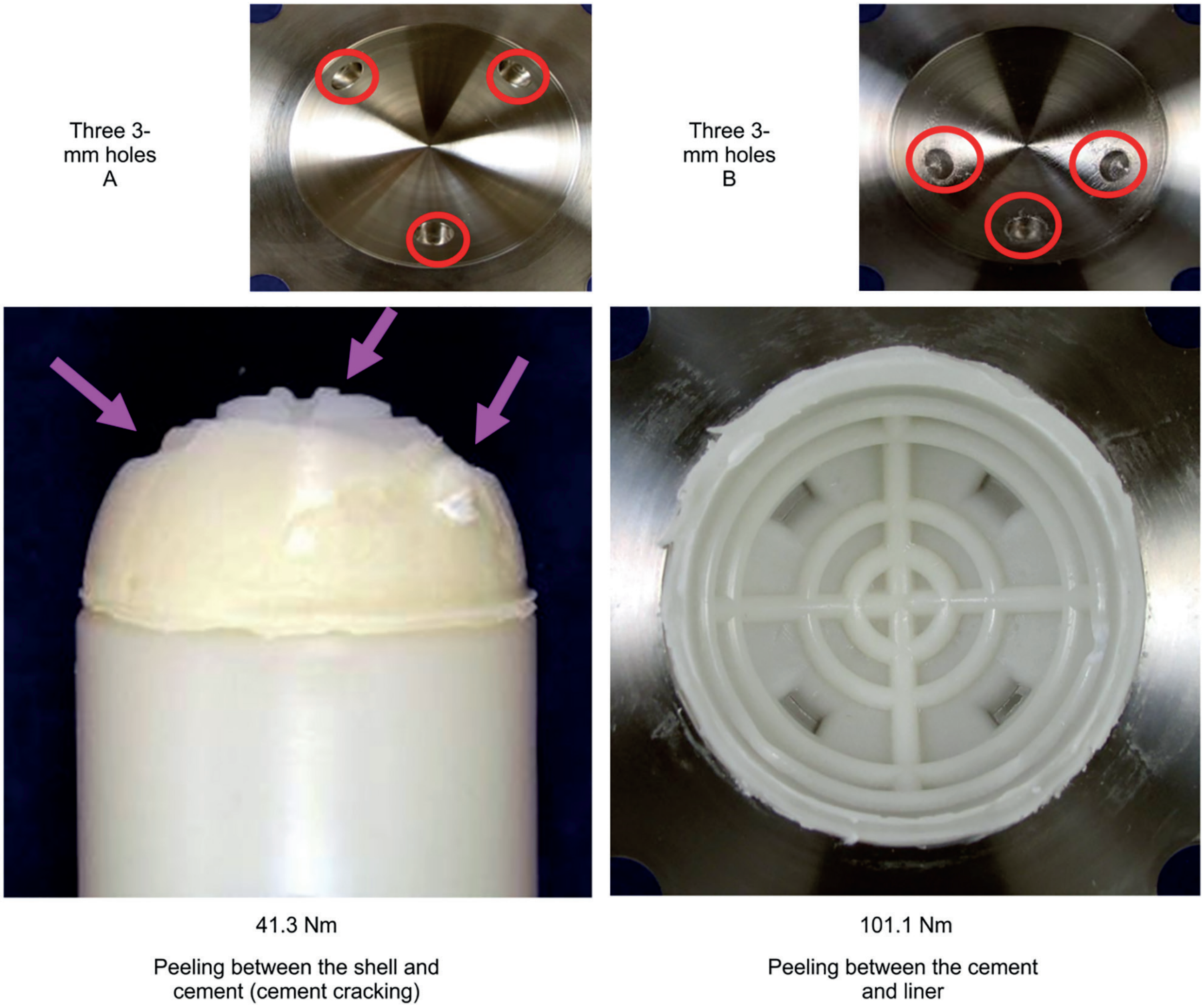



***Fig. 6.*** — Consequences of the applied force on the bone cement associated with different 3-anchor configurations. Cement cracking occurred in the 3 mm depth, 3-hole Pattern A group, and peeling occurred between the shell and cement. In the Pattern B group, peeling occurred between the cement and liner, indicating that strong adhesion between the shell and cement had been obtained.

anchoring bone (*10*). Subsequently, Heck and LaPorte also performed revision surgeries involving similar procedures (*7, 6*). Beaule et al. performed a study involving 32 hip joints with a mean follow-up of 8.6 years, and observed a 5-year joint survival rate of 78% (*7*). Furthermore, Beaule et al. noted that 6 joints required revision surgery within a mean of 29.7 months, with the acetabular construct being the cause of revision in 4 cases. Another study followed 22 patients for a mean of 70 months; when cases of dislocation were excluded, the 60-month survival rate was found to be 81% (*8*). Four of these patients needed revision surgery, with 2 patients requiring revision surgery due to loosening of the acetabular shell. Blakey et al. have reported on failures following this approach, noting that breaking points were within the cement-liner interface (*2*). A study involving 23 joints, where a cross-linked liner was used, did not demonstrate any recurrent osteolysis or loosening over a mean duration of 6 years (*17*). The authors of this study roughened the inner surface of the acetabular shell using a carbide or high-speed burr (*4*).

A number of reports have examined roughening of the liner surface or shell as a means of obtaining greater fixation. A laboratory study that examined a method involving the roughening of either the inner surface of the shell or the outer surface of the liner (*11*), before they were cemented with a 2–4 mm mantel, showed that the liner had an interlocking force that was 3–4 times stronger when using a cementless method. Another group reported that a liner undersized relative to the inner diameter of the shell provided a greater fixation force than that provided by a cementless liner or an oversized liner (*3*). The same study also revealed that cement fixation with an unmodified, oversized liner, provided weaker interlocking force than that provided by a conventional cementless liner. However, an oversized liner, in which circumferential grooves were created, had a greater interlocking force than that provided by the cementless liner (*8*). Haft et al. also found that the torsional or "lever-out" strength of a joint with a grooved liner was superior to that associated with an untextured liner, and that the construct strength was the greatest when the liner groove was shaped to resist applied loading (*10*). Similarly, a study involving 50 test samples found that cemented liners had strengths equivalent to that of a standard locked liner in a lever-out test, but yielded superior results in a torsion test (*7*). The same study also indicated that increased fixation strength was associated with the cement-liner interface when the outer surface of the polyethylene liner was roughened (*7, 15*). Mountney et al. also suggested that reinforcing the cement-liner interface may expose the liner to other interfacial failures (*15*).

With respect to the influence of haemo-dynamic parameters on bone and cement fixation, reduction of bleeding from the bone is necessary in order to obtain favourable micro-interlock anchoring between bone and cement. Forms of environmental management, such as temperature and cement storage temperature ; drilling; creation of a containment space, such as a space for a bone spur resection or bone grafting; creation of an anchoring hole; bone preparation, including pulsed cleaning and drying; aspects of cement filling, such as vacuum mixing or continuous cement pressurisation; and a flared cement polyethylene cup, have been used to improve micro-interlock anchoring. In addition, improved compression procedures have been used and experimentally verified. Indeed, fixation of a polyethylene liner within a well-fixed shell requires a special environment that is requisite of cement. For the cement-liner interface, a 2–4 mm cement layer is necessary; therefore, an undersized liner is selected and a groove with a given depth is formed in the outer surface of the liner to provide increased fixation strength. Conversely, for the shell-cement interface, roughening of the inner surface of the metal shell may be performed by a high-speed burr; however, this is technically difficult and requires careful monitoring to avoid the formation of metallic wear particulates. Indeed, for shells lacking screw holes implanted in prior surgery, the primary technique for improving the strength of the shell-cement interface is roughening with a high-speed burr; elsewhere, however, this should be avoided. Using screw holes in a metal shell provides a simple and practical solution that increases the fixation strength (Fig. 7). In this study, we aimed to evaluate the influence of placement, length, and quantity of cement anchors when the polyethylene liner is fixed to a metal shell with cement.

Our study revealed that the strength of the shell-cement interface increases when a long cement anchor is used in a screw hole. To aid in describing the effect of screw length on fixation force, a model has been provided in Figure 8a. When a balancing formula was used to find the force (Ra) applied to the anchor hole insertion point, where LA1 and LB2

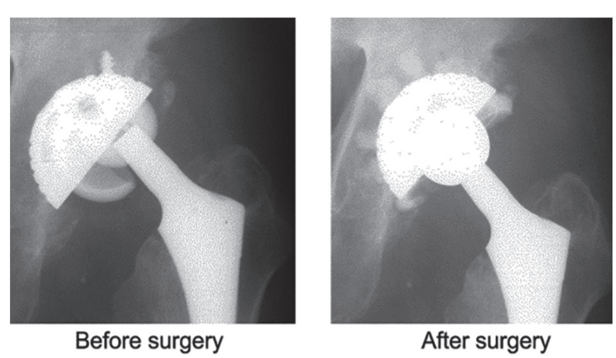



***Fig. 7.*** — Revision surgery due to liner dissociation. Radiographic appearance of a joint before (a) and after (b) revision surgery, in which the new liner was cement-fixed within the shell.

were assumed to be the same distance, we noted that the shorter cement anchor (Ra2) experienced greater stress than Ra1, and was regarded as having led to the breakage of the cement anchor (Fig. 8b). However, the metal thickness around the screw holes differed from 3–6 mm, due to the different types of shell. Moreover, since the thickness of the bone at the rear of a screw hole also varies, limiting the length of the cement anchor when using a screw hole is required during actual surgery. This study also revealed that creating as many anchors as possible is effective in raising the shell-cement interface fixation strength in a metal shell with 2 or more screw holes. The arrangement of the screw holes also needs to be chosen carefully. Three-anchor groups were designed with different patterns : Pattern A involved 3 anchors positioned close to the fulcrum (an action point), while Pattern B involved positioning the anchors distal to the action point. Therefore, these patterns had different interlocking forces, with Pattern A exhibiting greater force in the centre when the total force being applied to the action points was broken down into central and circumferential components (Fig. 9). As such, cement anchors farther from the fulcrum have greater interlocking force, in order to decrease the central force component that is typically responsible for failure of the cement-metal interface. Thus, Pattern B, in which the cement anchors were distal to the point of application of the dissociation force, had an enhanced interlocking force. Therefore, screw hole(s) should be placed distant from the fulcrum when the cement anchors are created.

In comparison, Tradonsky et al. described the torque between the polyethylene liner and the metal shell used in cementless fixation. Their results did not show a significant difference between the interlocking forces of other cementless liners (*16*), including those with a single cement anchor. The differences in these results may stem from the fact that the present study was conducted in vitro (the interposition of body fluids may cause changes in the interlocking forces, in vivo), the model and design used, the type of cement used, and the cementing technique employed. Given the degradation of bone cement over time, the interlocking force may be lower in vivo. Therefore, increasing the number and/or length of cement anchors with screw holes during surgery should be considered to increase fixation between the cement and metal shell. This study revealed that cement anchors created in screw holes provide greater interlocking force when they are located further from the fulcrum. This information lacks application in cases where the location of the screw hole is restricted, when the screw cannot be removed, or when it has penetrated into the pelvic cavity. We suggest that installing anchors with posterior screw holes into the metal shell would be more useful than using anterior screw holes, when anterior neck-metal shell impingement is expected.

In the present study, a number of limitations may be noted. Notably, no evaluation of the rotational torque of the shell-cement interface according to the thickness of the anchors was performed. Similarly, no investigation was performed to evaluate outcomes associated with the use of a cement anchor when cancellous bone was present on the rear side of the metal shell. It is difficult to create a model where the shell is sufficiently osseointegrated to the bone; however, it is assumed that results would be similar to those of this study if such a model was created. Additionally, this study has not addressed the application of additional grooves in the polyethylene liner. Because this study solely focused on the influence of cement anchors at the cement-shell interface, and this requires significant fixation at the cement-liner interface, we used a single complicated groove pattern that was concentric relative to the cup hemisphere (parallel to the equator) with a number of transverse grooves. It is possible that outcomes of the testing, specifically for those models that exhibited peeling between the cement and liner interface, may have been affected by the patterning of the liner.

## CONCLUSIONS

In cases of stable cementless acetabular metal shells with poor bone stock requiring revision, especially in elderly patients, it is possible to use bone cement to fix a new liner. In this context, it is necessary to be acutely aware of the cement-shell interface, as a means of obtaining sufficient initial fixation. The application of a cement anchor

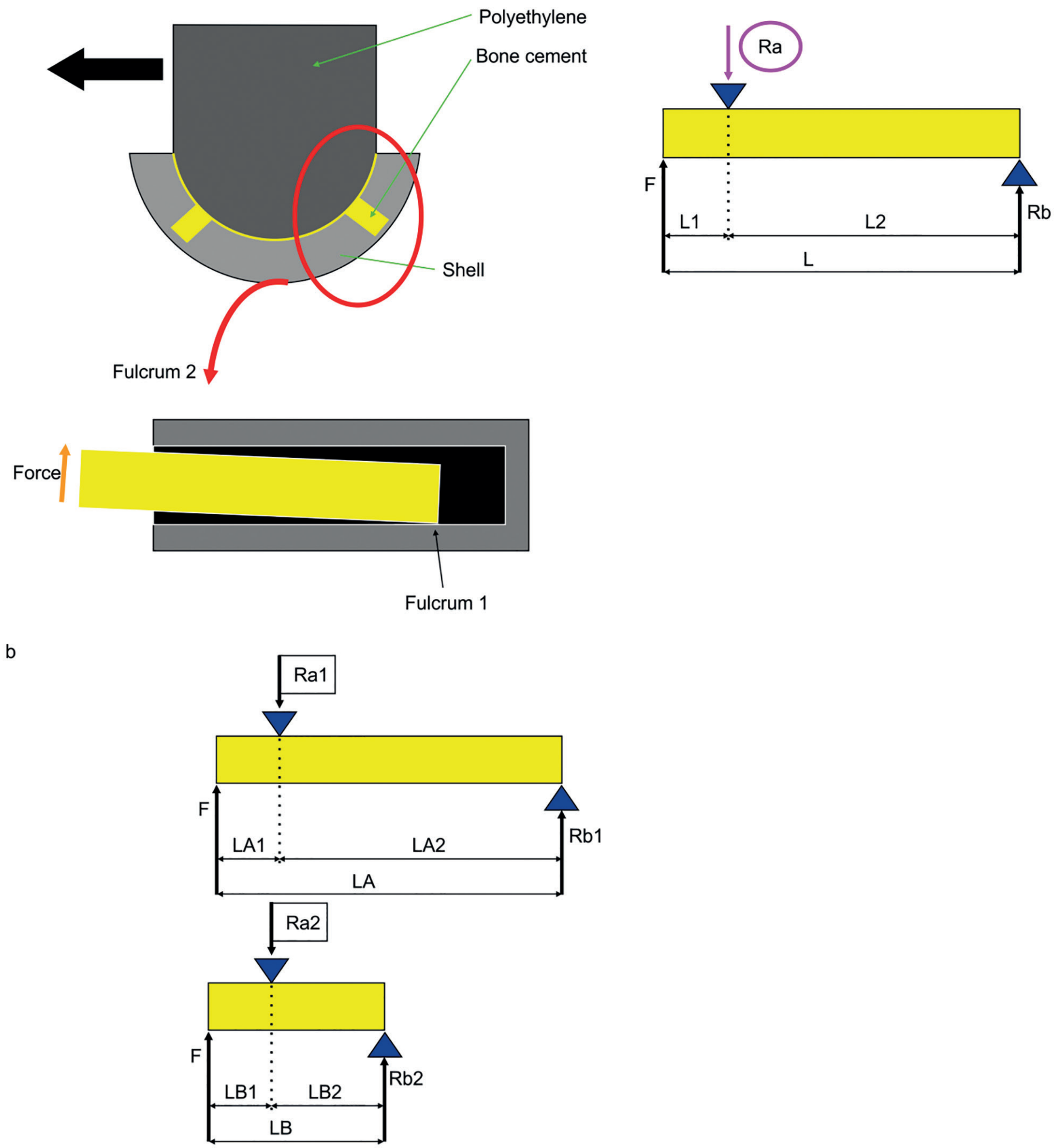



Fig. 8. Diagrammatic representation of models, showing the forces and force calculations. (a) Image of a model indicating anchor depth and fixation force. Equilibrium equations $F + Rb = Ra$, $F \cdot L + Ra \cdot L2 = 0$, $Ra = L/L2 \cdot F$, $Rb = L2-L/L2 \cdot F$

(a) Shorter anchors had a greater force applied due to Ra; thus, breakage of the cement anchors was more likely. $LA1 = LB1Ra1 = LA/LA2 \cdot F$, $Ra2 = LB/LB2 \cdot F$, $LA/LA2 < LB/LB2$

through a screw hole is considered clinically useful for increasing the mechanical strength of the shell-cement interface. This study has shown that the quantity, placement, and length of cement anchors may affect the interlocking strength of the interface.

## REFERENCES

1. **Beaulé PE, Ebramzadeh E, Le Duff M, Prasad R, Amstutz HC.** Cementing a liner into a stable cementless acetabular shell : the double-socket technique. *J Bone Joint Surg Am* 2004 ; 86-A : 929-934.
2. **Blakey CM, Biant LC, Kavanagh TG, Field RE.** Failure of cement-in-shell acetabular liner exchange. *Hip Int* 2010 ; 20 : 120-122.
3. **Bonner KF, Delanois RE, Harbach G, Bushelow M, Mont MA.** Cementation of a polyethylene liner into a metal shell. Factors related to mechanical stability. *J Bone Joint Surg Am* 2002 ; 84-A : 1587-1593.
4. **Ezzet KA.** Cementing acetabular sockets into metal-backed acetabular components and antiprotrusio cages : a technical tip. *J Arthroplasty* 2007 ; 22 : 609-611.
5. **Haft GF, Heiner AD, Dorr LD, Brown TD, Callaghan JJ.** A biomechanical analysis of polyethylene liner cementation into a fixed metal acetabular shell. *J Bone Joint Surg Am* 2003 ; 85-A : 1100-1110.
6. **Heck DA, Murray DG.** In vivo construction of a metal-backed, high-molecular-weight polyethylene cup during McKee-Farrar revision total joint arthroplasty. A case report. *J Arthroplasty* 1986 ; 1 : 203-206.
7. **Hofmann AA, Prince EJ, Drake FT, Hunt KJ.** Cementation of a polyethylene liner into a metal acetabular shell : a biomechanical study. *J Arthroplasty* 2009 ; 24 : 775-782.
8. **Jiranek WA.** Acetabular liner fixation by cement. *Clin Orthop Relat Res* 2003 ; 417 : 217-223.
9. **Khanuja HS, Aggarwal A, Hungerford MW, Hungerford DS, Jones LC, Mont MA.** Cementing polyethylene liners into non-modular acetabular components in revision total hip arthroplasty. *J Orthop Surg (Hong Kong)* 2010 ; 18 : 184-188.
10. **Kim WC, Amstutz HC, O'Carroll PF, Hedley AK, Coster I, Schmidt I.** Porous ingrowth in canine resurfacing hip arthroplasty : analysis of results with up to a 2-year follow-up. *Hip* 1984 ; 211-243.
11. **Kummer FJ, Adams MC, Dicesare PE.** Revision of polyethylene acetabular liners with a cemented polyethylene cup : a laboratory study. *J Arthroplasty* 2002 ; 17 : 1055-1057.
12. **LaPorte DM, Mont MA, Pierre-Jacques H, Peyton RS, Hungerford DS.** Technique for acetabular liner revision in a nonmodular metal-backed component. *J Arthroplasty* 1998 ; 13 : 348-350.
13. **Mauerhan DR, Peindl RD, Coley ER, Marshall A.** Cementation of polyethylene liners into well-fixed metal shells at the time of revision total hip arthroplasty. *J Arthroplasty* 2008; 23 : 873-878.
14. **Meldrum RD, Hollis JM.** The strength of a cement acetabular locking mechanism. *J Arthroplasty* 2001 ; 16 : 748-752.
15. **Mountney J, Garbuz DS, Greidanus NV, Masri BA, Duncan CP.** Cementing constrained acetabular liners in revision hip replacement : clinical and laboratory observations. *Instr Course Lect* 2004 ; 53 : 131-140.
16. **Tradonsky S, Postak PD, Froimson AI, Greenwald AS.** A comparison of the disassociation strength of modular acetabular components. *Clin Orthop Relat Res* 1993 ; 296 : 154-160.
17. **Wang JP, Chen WM, Chen CF, Chiang CC, Huang CK, Chen TH.** Cementation of cross-linked polyethylene liner into well-fixed acetabular shells : mean 6-year follow-up study. *J Arthroplasty* 2010 ; 25(3) : 420-424.