J Anesth (2007) 21:459–466
DOI 10.1007/s00540-007-0545-7

Journal of
Anesthesia

Incidence of embolic events during acetabular prosthesis insertion in total hip arthroplasty, and effect of intramedullary decompression in preventing embolism: higher risk of embolism with one-piece type prosthesis

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Abstract
Purpose. In total hip arthroplasty (THA), there is a high risk of bone marrow embolism during femoral prosthesis insertion. However, the incidence during acetabular prosthesis insertion has received less attention. The first goal of this study was to determine the incidence of bone marrow embolism associated with acetabular prosthesis insertion. The second goal was to evaluate the effects of intramedullary decompression of the acetabulum in suppressing bone marrow embolism.
Methods. To achieve the first goal, we evaluated the effects of prosthesis insertion on the incidence of bone marrow embolism, and on respiratory and cardiovascular dynamics. For the evaluation of bone marrow embolism, images obtained by transesophageal echocardiography were rated using Pitto's classification. To achieve the second goal, patients undergoing THA with a one-piece type acetabular prosthesis were divided into a control group and an acetabulum-decompression group, and the effects of insertion were analyzed in the same fashion.
Results. In the 150 patients in the study, bone marrow embolism was rated as grade 0 in 9, grade 1 in 46, grade 2 in 61, and grade 3 in 34 patients. Patients rated as grade 2 and 3 exhibited significant reductions in blood pressure and Pa_{O_2} 5 min after acetabular prosthesis insertion. The results of multivariate analysis suggested that the incidence of bone marrow embolism was higher for the one-piece type prosthesis than for the two-piece type. Among the 60 patients who underwent THA with a one-piece type prosthesis, the incidence of bone marrow embolism was significantly lower in the decompression group.
Conclusion. As there are increasing indications for one-piece type acetabular prostheses in Japan, we must pay attention to the possibility of bone marrow embolism, not only during femoral prosthesis insertion but also during acetabular prosthesis insertion.

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Received: November 27, 2006 / Accepted: June 14, 2007

Key words Bone marrow embolism · Total hip arthroplasty (THA) · Acetabular prosthesis · Intramedullary decompression

Introduction

Total hip arthroplasty (THA) involves the risk of bone marrow embolism, which occasionally leads to cardiac arrest or death as a result of hypotension, hypoxemia, pulmonary hypertension, and other effects [1–6]. Regarding the mechanism of bone marrow embolism during THA, it is thought that the insertion of a prosthesis elevates the pressure in the bone marrow and pushes fat, bone marrow, thrombi, air, and other materials into the veins, causing obstruction of the right heart or the pulmonary artery. The insertion of a prosthesis on the femoral side using bone cement is thought to involve a particularly high risk of severe embolism [7–11].

However, the incidence of bone marrow embolism associated with the insertion of a prosthesis on the acetabular side has received less attention. We recently encountered several patients in whom reduction in blood pressure and Sp_{O_2} was observed following the insertion of certain types of prostheses on the acetabular side during THA. The first goal of the present study was to determine the incidence of bone marrow embolism associated with acetabular prosthesis insertion during THA and to examine factors affecting the onset of this complication, using transesophageal echocardiography. The second goal was to evaluate the effects of intramedullary decompression of the acetabulum in suppressing bone marrow embolism. To our knowledge, no previous study has examined the onset of bone marrow embolism associated with acetabular prosthesis insertion during THA and the effects of prosthesis

structure and type on the incidence of bone marrow embolism. This is the first report dealing with factor analysis of the influence of acetabular prosthesis insertion on the occurrence of bone marrow embolism and exploring a valid means of preventing its occurrence.

Patients, materials, and methods

This study was conducted under the authorization of the Ethics Committee of our facility. Informed consent was obtained in writing from each patient prior to the start of the study.

To achieve goal 1 (analysis of the incidence of bone marrow embolism and factors affecting its occurrence), 150 patients (28 men and 122 women) with American Society of Anesthesiologists (ASA) status I or II undergoing scheduled primary THA were enrolled in the study. For these patients, surgery was conducted under general anesthesia combined with lumbar epidural anesthesia. Anesthesia was initiated with thiamylal (3–4 $mg \cdot kg^{-1}$) or propofol (1–2 $mg \cdot kg^{-1}$) and maintained with nitrous oxide (67%), sevoflurane (1.0%), and fentanyl (3–5 $\mu g \cdot kg^{-1}$). The use of epidural anesthesia was permitted after prosthesis insertion was finished, in order to eliminate circulatory changes induced by the epidural anesthesia. During surgery, the patient lay on his/her side with the affected leg above the intact leg, and 5 cmH_2O positive end-expiratory pressure (PEEP) was used. After tracheal intubation with 0.1–0.15 $mg \cdot kg^{-1}$ vecuronium, a 5.0/3.7-MHz probe (21364A; Philips Medical Systems, Andover, MA, USA) for transesophageal echocardiography (SONOS 1500 or SONOS 5500; Philips Medical Systems) was inserted. The right atrium and ventricle were observed in a four-chamber view [12–15]. The ultrasound images taken during prosthesis insertion were serially saved on a VCR, and examiners, without knowledge of patient characteristics or surgical procedure, assessed the grade of emboli on the basis of these images. Grading of emboli was performed in accordance with the classification of Pitto et al. [16,17]: grade 0 (no embolus), grade 1 (small numbers of fine emboli, below 5 mm in diameter), grade 2 (large numbers of emboli, below 5 mm in diameter), and grade 3 (emboli over 5 mm in diameter). To avoid artifacts, intravenous fluid administration was suspended during ultrasonography.

To evaluate the effects of bone marrow embolism on respiratory and cardiovascular dynamics, the radial artery was cannulated for invasive blood pressure measurement of systolic blood pressure (SBP), diastolic blood pressure (DBP), and mean blood pressure (MBP); and arterial blood gas analysis of Pa_{O_2}, Sa_{O_2} and Pa_{CO_2}. In addition, peripheral oxygen saturation (Sp_{O_2}), and end-tidal carbon dioxide pressure (Pet_{CO_2}) were monitored. Each parameter was measured immediately before and 5 and 10 min after the insertion of a prosthesis on the acetabular side. In all patients, ethylphenylephrine was administered when SBP fell below 80 mmHg, and the frequency of its use was recorded. If the anesthesiologists in charge judged it necessary to administer catecholamine (e.g., dopamine and epinephrine) for circulatory support, the use of such drugs was permitted and the frequency of their use was recorded.

Surgery on all patients was performed by the same team of orthopedic surgeons. The type and size of prosthesis to be used in each patient were determined at a preoperative conference of orthopedic surgeons. A two-piece type prosthesis with holes was used in 64 patients, a two-piece type prosthesis with one hole was used in 50 patients, and a one-piece type prosthesis without holes was employed in 36 patients. Bone cement was not used for fixation of the prosthesis in any of the patients. When a prosthesis with holes was used, additional fixation with screws was performed as needed, as judged intraoperatively by the orthopedic surgeons. The acetabular prosthesis used for THA is conventionally composed of two pieces (an outer metallic shell and an inner portion made of high-density polyethylene). The one-piece type prosthesis without holes is primarily used for surface-replacement type THA, of which the advantages are keeping the bone-head diameter physiological, making postoperative dislocation unlikely, remaining more bone, and making revision easier. After McMinn et al. [18] developed the Birmingham Hip Resurfacing System (Smith & Nephew, London, UK), which has a highly anti-abrasive metal-on-metal sliding surface, in 1996, the surface-replacement type of THA with this system yielded reliable results at several facilities [19,20]. At our facility, this system began to be used clinically in 1998. In young or middle-aged patients with diseases of the hip joint caused by dysplasia or congenital dislocation (which are frequently seen among Japanese) these conditions are a good indication for the surface-replacement type of THA, because the shape of femoral head can be better maintained and severe osteoporosis is not associated. Necrosis of the femoral head with moderate deformation and favorable ossein content is also an indication for the surface-replacement type of THA.

To achieve goal 2 (evaluation of the effects of acetabular decompression in preventing bone marrow embolism), the 60 patients rated ASA I or II who underwent scheduled primary THA using a one-piece type acetabular prosthesis without holes were divided into a non-decompression group (control group; $n = 30$) and a decompression group ($n = 30$). These patients were prepared and assessed in the same fashion as for goal 1. In the control group, prosthesis insertion was carried out using the routine press-fit method. In the decompres-

sion group, acetabular reaming was immediately followed by the creation of a hole from the anterolateral part of the acetabulum into the marrow cavity of the acetabulum, using a 3-mm-diameter drill. A surgical aspiration tube was inserted through this hole and connected to an aspirator installed in the operating room to effect decompression within the marrow cavity at the time of prosthesis insertion. The aspiration pressure was about 0.5 MPa. In all patients, the prosthesis was fixed by the press-fit method, without the use of bone cement or screws.

Analysis of variance was used for intergroup comparisons. Multivariate analysis was used to evaluate factors affecting the occurrence of bone marrow embolism in the study for goal 1. The χ^2 test was employed for comparison of the incidence of bone marrow embolism in the study for goals 1 and 2. Statistical analyses were performed using JMP 5.1 (SAS Institute, Cary, NC, USA), and findings of $P < 0.05$ were considered significant.

Results

Incidence of bone marrow embolism and factors affecting it

Table 1 shows the background variables for the 150 patients enrolled in the study for goal 1. On transesophageal echocardiography during insertion of the acetabular prosthesis, embolism was rated as grade 0 in 9 patients, grade 1 in 46, grade 2 in 61, and grade 3 in 34 patients. None of the patients rated as grade 0 or 1 exhibited a significant change in blood pressure or abnormality in blood gas analysis. In grade 2 and 3 patients, significant decreases in SBP and Pa_{O_2} were observed following prosthesis insertion. Grade 3 patients also exhibited significant decreases in DBP, MBP, Sa_{O_2} and Sp_{O_2} following prosthesis insertion (Fig. 1 and Table 2). No significant changes in Pa_{CO_2} or Pet_{CO_2} were observed for any grade of embolism (Table 2). Of the 34 patients rated as grade 3, 11 required treatment with a vasopressor or catecholamine to deal with the decrease in blood pressure following prosthesis insertion (ethylphenylephrine was used in 9 patients, dopamine in 1, and epinephrine in 1). Of the 61 patients rated as grade

Table 1. Background of 150 patients in study for goal one

Age (years)	57.5 ± 12.6
Sex (male:female)	28:122
Height (cm)	155.7 ± 8.9
Weight (kg)	56.4 ± 10.9
BMI (kg/m^2)	23.2 ± 3.6
Operation time (min.)	127.9 ± 36.4
Blood loss (g)	572.5 ± 289.5
Type of prosthesis (no hole:one hole:multi pleholes)	36:50:64
Diameter of prosthesis (mm)	51.1 ± 3.5

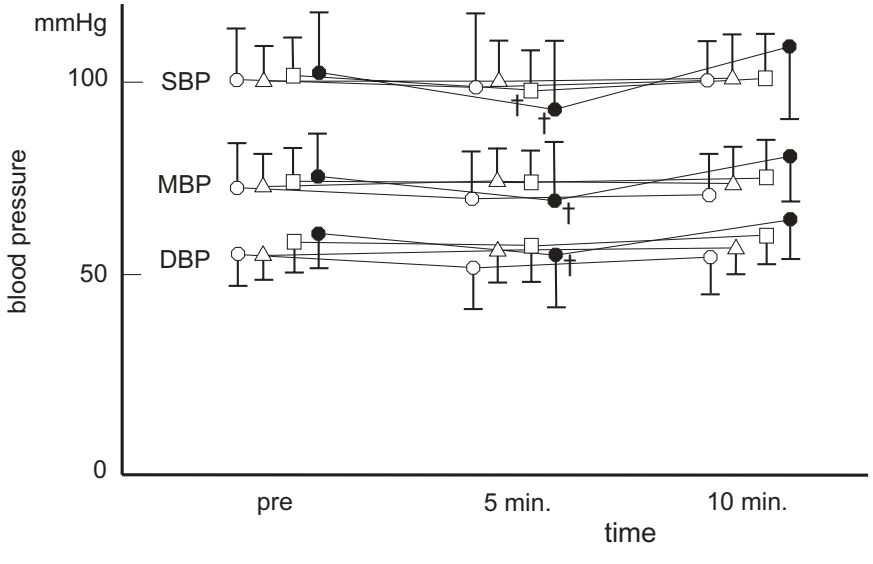

Fig. 1. The changes in systolic blood pressure (*SBP*), mean blood pressure (*MBP*), and diastolic blood pressure (*DBP*) before (pre-insertion; *pre*) and 5 and 10 min after acetabular prosthesis insertion. Values are given as means and SD. †Significantly different from pre-insertion value. *Open circles*, grade 0; *triangles*, grade 1; *squares*, grade 2; *closed circles*, grade 3

Table 2. Gas exchange data

	Pre-insertion	5 Min after insertion	10 Min after insertion
Pa_{O_2} (mmHg)			
Grade 0	137.5 ± 29.0	136.8 ± 33.7	136.0 ± 30.5
Grade 1	139.8 ± 26.3	137.6 ± 27.0	137.0 ± 25.1
Grade 2	142.4 ± 31.8	126.2 ± 35.2*	135.5 ± 31.0
Grade 3	144.9 ± 26.4	108.3 ± 26.7***	134.0 ± 30.3
Sa_{O_2} (%)			
Grade 0	98.8 ± 1.7	98.8 ± 1.9	98.8 ± 1.9
Grade 1	98.8 ± 0.8	98.8 ± 0.8	98.8 ± 0.8
Grade 2	98.8 ± 1.3	98.6 ± 0.9	98.8 ± 0.8
Grade 3	98.9 ± 0.6	98.3 ± 1.4*	98.8 ± 0.8
Sp_{O_2} (%)			
Grade 0	98.7 ± 1.8	98.4 ± 1.8	98.8 ± 1.8
Grade 1	98.7 ± 1.1	98.6 ± 1.0	98.8 ± 1.1
Grade 2	99.0 ± 0.9	98.7 ± 1.1	99.0 ± 0.9
Grade 3	99.0 ± 1.1	97.7 ± 2.2***	98.6 ± 1.7
Pa_{CO_2} (mmHg)			
Grade 0	36.2 ± 4.1	35.8 ± 3.5	36.0 ± 4.1
Grade 1	35.3 ± 3.5	35.4 ± 3.9	35.3 ± 4.0
Grade 2	36.0 ± 3.2	36.1 ± 3.0	36.2 ± 3.0
Grade 3	36.9 ± 3.6	37.4 ± 4.7	37.5 ± 4.3
Pet_{CO_2} (mmHg)			
Grade 0	28.8 ± 2.7	28.8 ± 2.6	29.0 ± 2.7
Grade 1	29.1 ± 3.1	28.9 ± 3.3	28.8 ± 3.2
Grade 2	29.4 ± 3.1	29.0 ± 2.7	29.3 ± 3.0
Grade 3	30.0 ± 3.4	29.7 ± 3.4	30.2 ± 2.9
$Pa_{CO_2} - Pet_{CO_2}$ (mmHg)			
Grade 0	7.4 ± 4.9	7.0 ± 4.4	7.0 ± 4.4
Grade 1	6.1 ± 2.4	6.6 ± 2.7	6.5 ± 2.9
Grade 2	6.6 ± 3.8	7.1 ± 3.4	6.9 ± 3.2
Grade 3	6.9 ± 3.3	7.7 ± 4.9	7.3 ± 4.6

* Significantly different from the pre-insertion value; ** significantly different from grade 0; *** significantly different from grade 1; **** significantly different from grade 2
The values are given as means and SD

Table 3. Partial correlations coefficients of main factors affecting grade of bone marrow embolism

	r^2	P value
Age	0.0023	0.9443
Sex	0.0700	0.8475
BMI	0.0002	0.9145
Operation time	0.0055	0.1392
Blood loss	0.0109	0.2635
Type of prosthesis	0.4210	<0.0001
Diameter of prosthesis	0.0017	0.007

2, only 4 required treatment with ethylphenylephrine. None of the patients rated as grade 0 or 1 required treatment with hypertensive agents.

On multivariate analysis involving patient age, sex, body mass index (BMI; weight × height^{-2}), operation time, volume of blood loss, type of prosthesis, and diameter of prosthesis used, only the type of prosthesis significantly affected the incidence of bone marrow embolism ($r^2 = 0.4210$; $P < 0.0001$; Table 3). When the incidence of bone marrow embolism was examined in relation to the type of prosthesis used, it was found to be significantly higher with the one-piece type prosthesis without holes than with any other type of prosthesis ($r = 0.5356$; $P < 0.0001$; Table 4).

Prophylactic effects of acetabular decompression

When the background variables of patients undergoing THA with the one-piece type prosthesis without holes were analyzed, no significant differences were noted between the control group and the decompression group (Table 5). In the control group, all patients were rated as grade 2 or 3, while in the decompression group, no patient was rated as grade 3 according to the classification of Pitto. The incidence of bone marrow embolism was significantly lower in the decompression group than in the control group ($r = 0.8034$; $P < 0.0001$; Table 6). In the control group, significant decreases in blood pressure, Pa_{O_2}, Sa_{O_2}, and Sp_{O_2} were noted after prosthesis insertion compared to levels before insertion. In the decompression group, no parameter differed significantly between pre-insertion

Table 4. Incidence of embolism graded with Pitto's classification

Type of prosthesis	Grade 0	Grade 1	Grade 2	Grade 3	Total
Two-piece with holes	9	39	14	2	64
Two-piece with hole	0	7	31	12	50
One-piece with no holes*	0	0	16	20	36
Total	9	46	61	34	150

$P < 0.0001$; $r = 0.5356$
Pitto's classification: grade 0, no embolus; grade 1, small numbers of fine emboli, below 5 mm in diameter; grade 2, large numbers of emboli, below 5 mm in diameter; grade 3, emboli over 5 mm in diameter
* Significantly different from other type of prosthesis

Table 5. Background of 60 patients in study for goal two

	Control group	Decompression group	*P*
Age (years)	55.0 ± 17.6	58.2 ± 17.1	NS
Sex (male:female)	9:21	7:23	NS
Height (cm)	158.6 ± 11.2	157.0 ± 9.6	NS
Weight (kg)	58.0 ± 12.0	59.7 ± 12.0	NS
BMI (kg/m^2)	22.9 ± 3.3	24.3 ± 4.0	NS
Operation time (min)	123.5 ± 28.6	118.2 ± 27.5	NS
Blood loss (g)	591.8 ± 251.7	634.8 ± 304.4	NS
Diameter of prosthesis (mm)	52.5 ± 3.5	51.3 ± 3.0	NS

Table 6. Incidence of embolism graded with Pitto's classification

	Grade 0	Grade 1	Grade 2	Grade 3
Control group	0	0	13	17
Decompression group	7	14	9	0

$P < 0.0001$; $r = 0.8034$

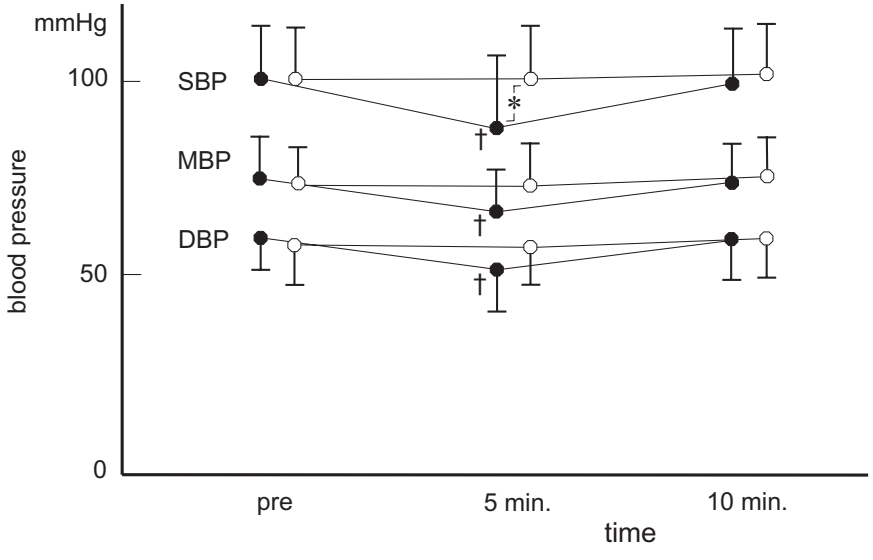

Fig. 2. The changes in systolic blood pressure (*SBP*), mean blood pressure (*MBP*), and diastolic blood pressure (*DBP*) before (*pre*) and 5 and 10 min after acetabular prosthesis insertion. Values are given as means and SD. †Significantly different from pre-insertion value; *significantly different from control group. *Open symbols*, decompression group; *closed symbols*, control group

and post-insertion measurements. The SBP, Pa_{O_2}, Sa_{O_2}, and Sp_{O_2} values at 5 min after prosthesis insertion were significantly lower in the control group than in the decompression group (Fig. 2 and Table 7). In terms of Pa_{CO_2} and Pet_{CO_2}, neither significant change following insertion nor intergroup differences were observed (Table 7). No patient in the decompression group required treatment with hypertensive agents, while 9 of the 30 patients in the control group required administration of ethylphenylephrine.

Table 7. Gas exchange data

	Pre-insertion	5 Min after insertion	10 Min after insertion
Pa_{O_2} (mmHg)			
Control group	140.7 ± 31.9	118.7 ± 36.6*	132.3 ± 32.6
Decompression group	150.7 ± 34.7	143.4 ± 35.7**	147.7 ± 35.6
Sa_{O_2} (%)			
Control group	99.0 ± 1.6	98.1 ± 1.3*	98.8 ± 0.7
Decompression group	99.2 ± 0.5	99.0 ± 0.9**	99.1 ± 0.6
Sp_{O_2} (%)			
Control group	98.9 ± 1.0	97.7 ± 2.1*	98.6 ± 1.4
Decompression group	99.1 ± 1.0	99.0 ± 1.2**	99.1 ± 1.0
Pa_{CO_2} (mmHg)			
Control group	36.9 ± 3.0	37.2 ± 3.7	37.5 ± 3.7
Decompression group	37.8 ± 3.7	37.6 ± 3.9	37.7 ± 3.9
Pet_{CO_2} (mmHg)			
Control group	32.3 ± 3.1	31.8 ± 2.8	32.2 ± 3.1
Decompression group	32.6 ± 3.0	32.2 ± 3.5	32.0 ± 3.0
$Pa_{CO_2} - Pet_{CO_2}$ (mmHg)			
Control group	6.6 ± 3.4	7.4 ± 4.4	6.9 ± 3.6
Decompression group	5.7 ± 4.2	5.8 ± 4.2	6.1 ± 4.3

* Significantly different from the pre-insertion value; ** significantly different from control group
The values are given as means and SD

Discussion

Insertion of a prosthesis into a long bone such as the femur involves the risk of development of bone marrow embolism, which occasionally leads to cardiac arrest or death as a result of hypotension, hypoxemia, pulmonary hypertension, and other effects [1–6]. Regarding the mechanism of this type of bone marrow embolism, it is thought that the insertion of a prosthesis elevates the pressure within the bone marrow and pushes fat, bone marrow, thrombi, air, and other materials out into the veins, causing obstruction of the right heart or the pulmonary artery. Insertion of a prosthesis on the femoral side using bone cement is thought to involve a particularly high risk of severe embolism [7–11]. However, the incidence of bone marrow embolism associated with the insertion of a prosthesis on the acetabular side has received less attention. The present study has revealed, for the first time, that the insertion of a prosthesis on the acetabular side can also induce bone marrow embolism accompanied by hypotension and reduction of arterial oxygen saturation. The shape of the acetabular prosthesis was found to significantly affect the occurrence of bone marrow embolism. In addition, insertion of the one-piece type prosthesis without holes was found to cause severe bone marrow embolism (grade 2 or 3 by Pitto's classification) accompanied by hypotension and reduced Pa_{O_2}. At our facility, this system began to be used clinically in 1998. However, we soon experienced some patients in whom reduction in blood pressure or Sp_{O_2} occurred following acetabular prosthesis insertion. These experiences motivated us to carry out the present study.

With the use of the one-piece type prosthesis for surface replacement THA, the inner plane directly forms a sliding surface with the femoral prosthesis. For this reason, this prosthesis has no hole for screw fixation. The press-fit method is indispensable for fixing this type of prosthesis in the acetabulum. McMinn et al. [18] recommend 1- to 3-mm under-reaming of the acetabulum to increase the reliability of fixation of this prosthesis. Assuming that the bone marrow embolism observed after acetabular prosthesis insertion develops by the same mechanism as that following femoral prosthesis insertion, the one-piece type prosthesis without holes could, for three reasons, have a higher risk of inducing severe bone marrow embolism than the conventional two-piece type prosthesis: (1) bone marrow decompression through the screw holes is not expected at the time of insertion of the one-piece type; (2) under-reaming of the acetabulum increases the tightness between the acetabulum and the prosthesis, and the loophole of intramedullary pressure is lost; and (3) the surgeon is required to drive the prosthesis with greater force because the press-fit method is indispensable for fixing. The two-piece type prostheses currently used have either one or multiple holes. The two-piece type prosthesis with one hole has no loophole to reduce intramedullary pressure, because the hole is used for retention of the prosthesis at the time of insertion. However, under-reaming is not performed and screw fixation after insertion is possible for the two-piece type prostheses. These are probably the reasons why the incidence of bone marrow embolism with the two-piece type prosthesis with one hole was intermediate between that for the one-piece type prosthesis and

that for the two-piece type prosthesis with multiple holes.

To test the validity of the assumption mentioned above, we incorporated decompression of the bone marrow during prosthesis insertion and evaluated its effects on the incidence and severity of bone marrow embolism (goal 2). Vacuum drainage in the femur for decompression of bone marrow during prosthesis insertion has already been reported to be successful, though a vacuum method for use in the acetabulum has not yet been reported [21,22]. Decompression significantly reduced the incidence of grade 2 and grade 3 embolism (by Pitto's classification) to 30%. No case of grade 3 embolism was seen in the decompression group. At the same time, adverse effects of prosthesis insertion on respiratory and cardiovascular dynamics decreased markedly. These findings demonstrate the validity of our assumption concerning the mechanism of occurrence of bone marrow embolism following acetabular prosthesis insertion, i.e., that bone marrow embolism following acetabular prosthesis insertion is due to elevated intramedullary pressure, and that its incidence and severity can therefore be reduced by decompression during prosthesis insertion.

In the present study, it is interesting that there were no significant changes in Pet_{CO_2} and Pa_{CO_2}, although SBP and Pa_{O_2} were significantly decreased. Byrick et al. [23] pointed out the limit of capnography as a parameter for detecting bone marrow embolism, because there were no significant changes in Pet_{CO_2} or Pa_{CO_2}, although there was a significant rise in pulmonary artery pressure, and decreases significant in SBP and Pa_{O_2} when an artificial bone was inserted into a femur and marrow embolism was generated in their experiment using dogs. Moreover, other experiments, by Elmaraghy et al. [24] and Orsini et al. [25] and another experiment by Byrick et al. [26], also reported insignificant changes in Pa_{CO_2} as compared with significant changes in circulatory parameters and a significant change in lung oxygenation ability. These findings are different from the condition of clinical air emboli or the influence of experimental air emboli in which the reduction of Pet_{CO_2} works as the most sensitive index. Byrick et al. [23] suggested differences in the diameters and parts of the blood vessels occluded by bone marrow embolism and by air emboli as reasons for these differing findings. They also reported that 92% of the emboli were less than 50 μm, and 99% were less than 75 μm in diameter. Furthermore, it was reported by Young et al. [27], who checked the gas exchange area dogs, using beads of several different diameters as emboli, that there was little influence on the ventilation/perfusion ratio with beads of 50 to 100 μm as compared with beads of 150- to 500-μm. Because the bone marrow embolism occurring during THA occludes thinner blood vessels as compared with air emboli, Byrick et al. [26] considered that there was comparatively little influence of bone marrow emboli on gas exchange ability although these emboli caused a significant rise in pulmonary pressure and a significant decrease in SBP, and as a result, there were insignificant changes in Pet_{CO_2} and Pa_{CO_2}. However, they also made reference to the influence of the absolute quantity of an embolism, and mentioned that capnography was a useful monitor at the time a large bone marrow embolism was generated. Thus, it is important for us to recognize that changes in blood pressure and Sp_{O_2} may be observed before changes in Pet_{CO_2} when a bone marrow embolism occurs during THA [23,26].

In the present study, significant effects on respiratory and cardiovascular dynamics were exerted by bone marrow embolism 5 min after prosthesis insertion, but these effects were alleviated to insignificant levels 10 min after insertion, suggesting that the risk of persistent bone marrow embolism is low in most cases. However, because the patients we studied had normal respiratory and cardiovascular function at the start of surgery, and one-third of them required treatment with hypertensive agents and circulatory assistance with catecholamine after prosthesis insertion, it is clear that adequate prophylactic monitoring is required to deal with potentially risky patients, and that, even in patients without significant risk, careful anesthesiological management of cardiovascular dynamics is needed during prosthesis insertion.

THA using a one-piece type acetabular prosthesis without holes has not yet been widely performed in Japan. In the future, THA using a two-piece type prosthesis will still be the main method; however, the number of THAs using a one-piece type prostheses will increase in Japan with the results reported from domestic and foreign facilities. When this procedure is used, it is essential for anesthesiologists to monitor closely cardiovascular and respiratory changes brought about by bone marrow embolism during acetabular prosthesis insertion, though bone marrow embolism has been conventionally considered to occur only during femoral prosthesis insertion. As operative procedures and tools advance, anesthesiologists are required to get ready to cope with previously unknown risks.

Conclusion

Following the insertion of a prosthesis on the acetabular side during THA, some patients developed bone marrow embolism accompanied by a reduction in blood pressure and pulmonary oxygenation. The incidence of severe bone marrow embolism was particularly high in patients in whom a one-piece type prosthesis without holes was used. Decompression of the medullary cavity

was found to be useful in preventing bone marrow embolism. In view of the increasing indications for one-piece type acetabular prostheses in Japan, our experience demonstrates the need for anesthetic management considering bone marrow embolism not only during femoral prosthesis insertion but also during acetabular prosthesis insertion.

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