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Factors Affecting Periprosthetic Bone Loss after Hip Arthroplasty

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Periprosthetic bone loss may lead to major complications in hip arthroplasty, including aseptic loosening, implant migration, and even periprosthetic fracture. Such a complication leads to revision surgeries, which are expensive, technically demanding, and result in a low satisfaction rate. Therefore, a study was conducted of the factors affecting the periprosthetic bone loss around the stem that caused these complications. Factors influencing periprosthetic bone loss include demographic factors such as age, sex, obesity, smoking, and comorbidity including diabetes and osteoporosis. The implant design and fixation method are also factors that are determined before surgery. In addition, there are surgical factors, such as surgical approach and surgical technique, and we wish to investigate the factors affecting periprosthetic bone loss around the stem by comparing the effects of postoperative rehabilitation protocols and osteoporosis drugs.

Key Words: Osteoporosis, Arthroplasty, Osseointegration

INTRODUCTION

As the elderly population gradually increases, the number of patients with hip fractures and osteoarthritis are steadily increasing[1,2]. Among the various treatment methods for patients with hip fracture or osteoarthritis, hip arthroplasty, one of the most effective treatments, relieves pain and restores the function of the hip joint[3,4]. Hip arthroplasty is a very useful treatment for patients; however, various complications such as infection, dislocation, and aseptic loosening can occur after hip surgery[5].

As the number of hip arthroplasties have shown a gradual increase, complications that occur after surgery have recently emerged as an important problem[6]. Among them, aseptic loosening of the stem is one of the most common complications requiring revision surgery[6,7]. The stress shielding that occurs between the implant and the bone after surgery causes periprosthetic bone loss (Fig. 1)[8], which eventually leads to periprosthetic fracture, stem migration, and loosening, which in turn requires revision surgery, which accounts for approximately 57-84% of revision surgery[9].

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In the case of revisional arthroplasty, compared to primary arthroplasty, it is not only technically difficult, but also has a higher cost and a higher complication rate, resulting in lower satisfaction for patients[6]. Therefore, we would like to review the various factors that can influence periprosthetic bone loss, which is the main reason for revision surgery. We classified the factors that affect periprosthetic bone loss after arthroplasty into three parts: preoperative, intraoperative, and postoperative (Fig. 2).

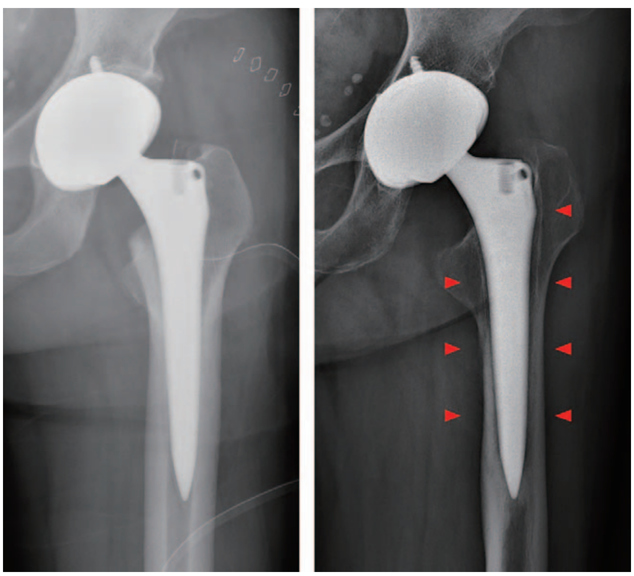

Fig. 1. Anteroposterior radiographs showing periprosthetic bone loss (arrows) due to stress shielding at 2 years after total hip arthroplasty.

METHODOLOGY

We searched electronic databases including PubMed and Embase, adopting the search strategy combining the terms "(age, sex, obesity, smoking, osteoporosis, diabetes, stem fixation, stem geometry, stem material, surgical technique, rehabilitation, bisphosphonate, denosumab) AND (aseptic loosening OR periprosthetic bone loss OR osseointegration)". Research articles and reviews published from January 1993 to October 2020 were considered.

PREOPERATIVE FACTORS

1. Demographic Factors

Age has already been reported as a well-known risk factor for revision arthroplasty in many studies[9-11]. According to Malchau et al.[12], patients under 55 years of age at the time of total hip arthroplasty (THA) surgery had the highest risk of revision surgery for aseptic loosening, and patients over 75 years of age had the lowest risk of revision surgery due to aseptic relaxation. The increased risk of revision surgery in the younger patient group is almost entirely attributable to higher levels of activity and higher load on the joints. However, it is still unknown whether other age-related factors affecting bone quality contribute to an increased risk of revision surgery in young patients. More basic research related to tissue regeneration or cell unit areas will be needed in order to understand the effect on age in periprosthetic bone modeling that occurs after implant insertion.

Several studies of sex-specific aseptic loosening have

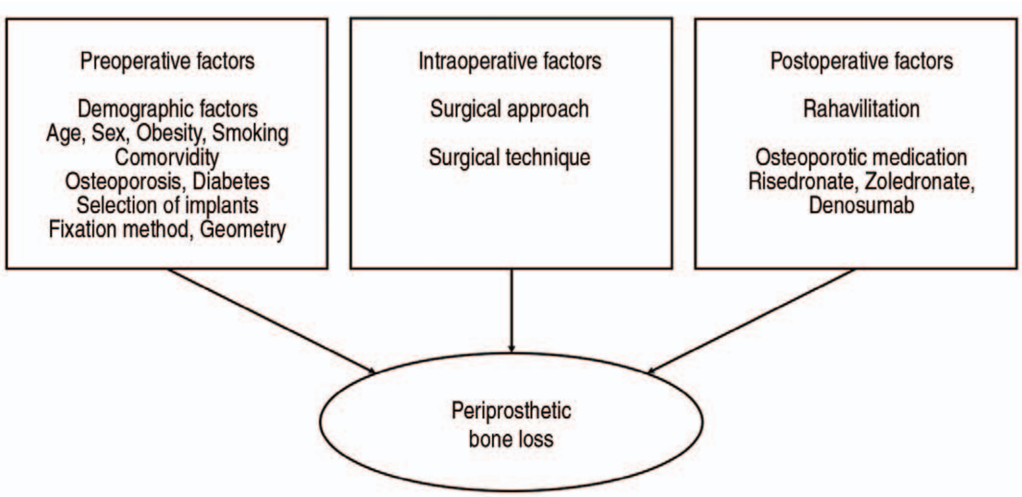

Fig. 2. Factors related to the periprosthetic bone loss around the stem.

been reported, but a completely consensus conclusion has not been reached. Most studies have reported that men have at least 1.5 to 2 times higher risk of revision surgery than women[10,11,13,14]. However, the study by Inacio et al.[15] reported that women have a 29% higher risk of revision surgery than men, and the Kaiser Permanente Joint Registry also reported that the risk of aseptic THA revision was higher in women than in men[16]. Sex differences are not simply due to anatomical and kinematic differences, and further studies are needed to determine how sex-related hormonal factors play a role in osseointegration throughout the lifespan. In particular, studies related to osteoporosis show that estrogen deficiency is traditionally considered the main cause of bone loss, but independent elements other than estrogen also affect bone quality, some of which are more related to fixation of implants during hip arthroplasty[17].

Obesity is known to be one of the factors causing poor outcomes in hip arthroplasty as well as in knee arthroplasty[16,18]. However, the evidence is contradictory in terms of the risk of an aseptic loosening[19,20] (Table 1)[21-25]. According to Ibrahim et al.[21] and McLaughlin and Lee[22], no difference in clinical and radiologic outcomes was observed between obese patients and non-obese patients. However, compared with previous studies, conflicting results have been reported in more recent research. Electricwala et al.[24] reported that obesity caused approximately 4.7 times more aseptic loosening or osteolysis, increasing the risk of early revision surgery. In addition, obesity has also been reported as an independent risk factor for early aseptic loosening[25]. The increasing early failure rate due to aseptic loosening of obesity might be related to mechanical stress in bone implant interfaces and increased joint reaction force proportional to individual weight.

Smoking is a known risk factor for poor outcomes not only for arthroplasty surgery, but for other surgery as well. Smoking increases the risk of aseptic loosening by three times, as shown by a meta-analysis by Teng et al.[26]. According to Kapadia et al.[27], former smokers (non-smokers within 30 days prior to surgery) showed no difference in complications compared to current smokers on an average 4-year follow-up. Therefore, it may be that the act of quitting smoking before surgery by smokers is not effective in lowering the risk of aseptic loosening. With regard to alcohol, heavy use of alcohol was associated with dislocation, but was not associated with aseptic loosening[28].

2. Comorbidity

Osteoporosis is the most common disease affecting bone quality in older people. In fact, several studies have reported a high prevalence of osteoporosis in patients with THA and total knee arthroplasty (TKA)[29-31]. Studies have shown that low bone mineral density (BMD), geometric changes in the proximal femur, and ageing may actually increase initial migration and delay osseointegration of cementless femoral stems[32]. However, little is known about the effect of low BMD on the results of arthroplasty and the effect of osteoporosis drugs, such as bisphosphonate, on the corre-

Table 1. BMI Studies with Hip Arthroplasty

Study	Publication year	No. of hips	Mean age (yr)	Mean F/U (yr)	Outcome
Ibrahim et al.[21]	2005	179	66.4 (33-86)	NR	No association between BMI and need for revision surgery (total obese: 3.6%, nonobese: 3.2%)
McLaughlin et al.[22]	2006	209	54 (20-77)	15 (10-19)	No statistically significant difference was identified between the obese and nonobese patients regarding clinical and radiologic outcomes or complications
Andrew et al.[23]	2008	1,059	NR (21-94)	NR (3-5)	Obese patients had no significant radiologic changes (P>0.05)
Electricwala et al.[24]	2016	257	67 (30-92)	NR	A significant difference in early revision THA for aseptic loosening/osteolysis in obese vs nonobese (56% vs 12%, P<0.001)
Goodnough et al.[25]	2018	684	65.4 (NR)	NR	The rate of primary THA failure for aseptic loosening before 5 years was 30% in obese and 18% in nonobese (P<0.023)

Values are presented as number only or mean (range).
BMI: body mass index, F/U: follow-up, NR: not reported, THA: total hip arthroplasty.

lation between implants and bones. Most studies on patients with osteoporosis are comparisons of the results of cemented stem and cementless stem, or how BMD values around the implant change depending on osteoporosis medication after arthroplasty. Considering the high prevalence of osteoporosis, further research on patients with osteoporosis before surgery will be needed.

In hip arthroplasty, diabetes has a significant impact on functional and surgical clinical outcomes; however, its long-term impact on the risk of aseptic loosening is mostly negative[33,34]. In the Kaiser Permanente Joint Registry, the presence of diabetes was a risk factor for aseptic loosening in TKA, but not in THA[9]. In other studies, diabetes increased the risk of revision surgery due to deep infection, but not aseptic loosening[35,36]. Therefore, the specific effect of diabetes-related hyperglycemia or insulin on osseointegration between bones and implants is not yet known.

3. Selection of Implants

In order to reduce bone loss, investigators have identified key design features that successfully reduce stress shielding. Several studies have shown that factors such as fixation method according to the use of cement, and geometry of stems have a significant influence on the change in BMD around the implant. Traditionally, the revision rate for cementless arthroplasty has been higher than that for cemented arthroplasty[37]. The risk of revision, including periprosthetic fracture, dislocation, and infection, is higher in cementless arthroplasty, but the results are slightly different only in terms of aseptic loosening[38]. In the case of using cemented stem under 65 years of age, the risk of revision of stem due to aseptic loosening was reported to be higher than that of using cementless stem[39]. According to Liu et al.[40], a cementless stem had a higher revision risk due to aseptic loosening than a cemented stem when followed for 5 years. Comparing the studies that measured the BMD values around the stem, which may affect aseptic loosening, according to the Gruen zone (Table 2)[41-44], in cementless stem, the BMD value decreased significantly in proximal areas such as Gruen zones 1 and 7. In contrast, in cemented stem, BMD values on the distal side tend to decrease significantly.

It is also believed that the stem geometry plays an important role in the transfer of loads to the femur, consequently periprosthetic bone remodeling and osseointegration[45]. When comparing straight stem and tapered stem in the cementless group, it has been reported that there was less

Table 2. Change of Bone Mineral Density Ratio of Gruen Zone according to Fixation Method

Study	Publication year	Duration of follow-up (yr)	No. of hips	Stem	BMD ratio change (% changes in BMD)						
					Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7
Panisello et al.[41]	2006	3	54	Cementless ABG II stem	−5.57	+7.77	+3.44	−0.57	+1.52	+6.69	−15.92
Hayashi et al.[42]	2012	2	50	Cementless G2 stem	−3.0	−5	−2	−2	−2	−12	−14
Morita et al.[43]	2016	3	165	Cemented Exeter Universal stem	+2.9	−7.8	−5.0	−8.4	−4.9	−9.1	−10.3
Iwase et al.[44]	2019	5	60	Cemented polished tapered stem	+2.0	−9.9	−5.9	−11.1	−5.7	−13.8	−9.8

BMD: bone mineral density.

reduction in BMD around the stem in the straight stem[46]. In another study of the stem design, types 1, 2, and 3C stem were compared according to the classification by Khanuja et al.[47]; the Type 3C stem showed the least BMD reduction in the proximal medial femur area, and the Type 1 stem showed the least BMD decrease in the proximal lateral femur area[48]. In addition, a study based on the length of the stem was reported, and it was reported that the overall decrease in BMD value was less when using the short stem compared to the cementless standard femoral stem[49].

The stem material is also an important factor influencing periprosthetic femoral bone loss. The most common material used for cementless stems was Titanium alloy. Although it is not a direct comparative study, it was confirmed through systematic review that BMD decreased by 5.0% in a Titanium alloy stem and 12.8% BMD in a Cobalt Chromium stem, resulting in more maintenance of BMD in the Titanium alloy stem[46]. In addition to the stem, bearings are well known as an important factor influencing stem loosening. Ingrid et al. reported 10-year survival rates of 0.995, 0.990, and 0.894 for the metal-to-metal, metal-to-polyethylene, and metal-to-metal groups with respect to aseptic loosening[50]. Despite low wear, selection of metal-to-metal bearings in young and active patients is difficult with regard to the occurrence of aseptic loosening. Since these differences in fixation method or stem designs affect BMD values and stress shielding around the stem, the need for studies for successful stem development will continue.

INTRAOPERATIVE FACTORS

1. Surgical Approach

The surgical approach is the first factor influencing periprosthetic bone loss during surgery. In a comparison of the muscle-sparing anterolateral approach and the transgluteal approach, periprosthetic BMD decreased more in the transgluteal approach at 1 year postoperatively[51]. This might be due to changes in femoral load as a result of differences in damage on abducted muscles during surgery. Another recent study has shown the negative effect of the anterior approach on the risk of revision owing to aseptic loosening, compared to the non-anterior approaches[52]. In the surgical approach it is important to insert the implant in the correct position through good exposure, which reduces the risk of revision.

2. Surgical Technique

In addition to the stability of the stem, it is important to rasp and select the appropriate size of the stem in terms of bone ingrowth. To ensure proper fit of the components, excessive rasping causes mechanical and thermal damage to the bone and impairs bone growth[53]. Up to 30 mm of micromotion between stem and bone is useful for bone growth, but more than 150 mm may damage osseointegration of the titanium implant[53].

Hayashi et al.[54] reported that excessive femoral stem anteversion mismatch to the anatomical anteversion causes stem point contact with the cortical bone in the distal portion and affected proximal periprosthetic BMD loss after THA. When anteversion was not an anatomical location, BMD reduction occurred more in Gruen zones 1 and 7 than in other zones[55]. In addition, in a study of the change of BMD according to the alignment of the stem, the varus group showed a greater decrease in BMD in Gruen zones 1 and 7 compared to the neutral group, and in the valgus group there was a greater decrease in zone 7[41]. Choosing the proper size of the stem and inserting the stem with the appropriate anteversion to perform the correct fitting might be seen as the ability of the surgeon. Fender et al.[56] found that surgeons who performed less than 30 hip replacements annually had a four-fold greater risk of failure than surgeons who performed more than 60 hip replacements a year.

POSTOPERATIVE FACTORS

1. Rehabilitation

Despite the debate that early weight-bearing may jeopardize the bone ingrowth needed for stability, the postoperative rehabilitation of cementless hip arthroplasty has shifted to early mobilization with full weight-bearing. Wolf et al. reported that there were no statistically significant differences in BMD in any of the Gruen zones at 5 years postoperatively between full weight bearing and partial weight bearing groups[57]. In young patients with high activity, it has been reported that weight bearing as tolerated reduces stem migration or loosening[58], but most papers recommend performing full weight-bearing immediately after surgery[59,60].

2. Osteoporotic Medication

In order to reduce periprosthetic bone loss after hip arthroplasty, studies on various types of osteoporosis drugs have been conducted, and are still in progress. Alendronate has a beneficial effect on preserving the periprosthetic bone for a short-term period after hip arthroplasty[61,62]. However, the current studies have not provided sufficient evidence that the positive effects that appeared during the early period after surgery persist for a long-term period after surgery[63]. A meta-analysis for risedronate indicated that postoperative reduction of periprosthetic BMD in the risedronate group was significantly lower than that in the placebo group in zones 1, 2, 3, 4, 6, and 7[64]. However, another randomized controlled trial study has reported that risedronate has no effect on periprosthetic bone loss as a result of four years follow-up after hip arthroplasy[65]. Another study reported that among osteoporosis drugs, zoledronate showed the optimal efficacy at six and 12 months in preventing periprosthetic bone loss in the calcar region after hip arthroplasty[66]. Huang et al.[67] reported that administering zoledronate increased BMD value around the proximal femur two years after surgery. Denosumab, another osteoporosis treatment, has been shown to be effective in restoring normal BMD levels, especially in the Gruen zone 7[68].

Significant research has been conducted on drugs to prevent periprosthetic bone loss; however, the optimal time to initiate osteoporotic medication in patients with hip arthroplasty is not known, especially considering the periprosthetic changes during the early months. It is also unclear whether local administration is more efficacious than systemic use, particularly in patients with normal BMD. It is also unclear whether the drug is effective in preventing periprosthetic bone loss, especially in patients with normal BMD. Therefore, it is expected that more participants and longer follow-up studies are needed in order to accurately determine the effectiveness of osteoporosis treatment in this regard.

CONCLUSION

So far, we have investigated the factors affecting periprosthetic bone loss after hip replacement. The factors are summarized as follows (Table 3). Among these, we believe that the application of adjustable factors during hip arthroplasty can contribute to reducing bone loss around the implant after surgery.

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CONFLICT OF INTEREST

The authors declare that there is no potential conflict of interest relevant to this article.

Table 3. Factor Affecting Periprosthetic Bone Loss

Period	Category	Outcome
Preoperative	Demographic factor	Highly active patients under the age of 55 are a risk factor. In recent studies, obesity is a risk factor. Smoking cessation
	Comorbidity	Osteoporosis decreases the osseointegration of the stem. Diabetes increased the risk of revision surgery due to deep infection, but not aseptic loosening.
	Selection of implants	In cementless stem, the BMD value decreases in the proximal area, and in cemented stem decreases in the distal area. Periprosthetic BMD reduction was greater for tapered stem than straight stem. Short stem showed less BMD reduction than standard stem.
Intraoperative	Surgical approach	Periprosthetic BMD decreased more in transgluteal approach than in anterolateral approach.
	Surgical technique	Excessive anteversion or misalignment of stem leads to further reduction in proximal periprosthetic BMD.
Postoperative	Rehabilitation	Most studies recommend performing full weight-bearing immediately after surgery.
	Osteoporotic medication	Zoledronate showed the optimal efficacy at 6 and 12 months in preventing periprosthetic bone loss in calcar region.

BMD: bone mineral density.

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