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Short-term success of proximal bone stock preservation in short hip stems: a systematic review of the literature

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- Total hip arthroplasty is performed more frequently in younger patients nowadays, making long-term bone stock preservation an important topic. A mechanism for late implant failure is periprosthetic bone loss, caused by stress shielding around the hip stem due to different load distribution. Short stems are designed to keep the physical loading in the proximal part of the femur to reduce stress shielding. The aim of this review is to give more insight into how short and anatomic stems behave and whether they succeed in preservation of proximal bone stock.
- A systematic literature search was performed to find all published studies on bone mineral density in short and anatomic hip stems. Results on periprosthetic femoral bone mineral density, measured with dual-energy X-ray absorptiometry (DEXA), were compiled and analysed per Gruen zone in percentual change.
- A total of 29 studies were included. In short stems, Gruen 1 showed bone loss of 5% after one year ($n = 855$) and 5% after two years ($n = 266$). Gruen 7 showed bone loss of 10% after one year and –11% after two years. In anatomic stems, Gruen 1 showed bone loss of 8% after one year ($n = 731$) and 11% after two years ($n = 227$). Gruen 7 showed bone loss of 14% after one year and 15% after two years.
- Short stems are capable of preserving proximal bone stock and have slightly less proximal bone loss in the first years, compared to anatomic stems.

Keywords: anatomic stem; bone mineral density; bone stock loss; DEXA; periprosthetic bone loss; short stem; total hip arthroplasty

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Introduction

Nowadays, there is a higher incidence of younger and more active patients undergoing total hip arthroplasty (THA). In the Netherlands, between 17% and 19% of the patients receiving total hip arthroplasty are younger than 60 years.[1,2] Their biomechanical forces on the hip implant are higher compared to the more elderly with THA, increasing the long-term failure rate of hip implants.[3–6] Failure of hip implants can be caused by periprosthetic bone loss, leading to aseptic loosening or periprosthetic fractures. Stress shielding is one of the reasons for periprosthetic bone loss in cementless total hip arthroplasty,[7,8] as bone resorption occurs through changed physical loading in the femur.[9,10] Loss of bone stock can compromise the stability of hip stems,[11] emphasizing the importance of bone stock preservation around hip stems. Physical loading in most conventional hip stems is transferred from the proximal region of the femur to the femur shaft, decreasing bone mass around the greater trochanter and calcar region.[12,13]

Other types of implants, such as short and anatomical stem designs, are based on a more proximal anchoring principle. Short stems in total hip arthroplasty were designed to restrict the physical loading to the proximal part of the femur, thereby reducing periprosthetic bone loss.[14] However, there are a lot of designs with different implant characteristics. A clear definition of a short stem still lacks. A classification based on the osteotomy level is currently used,[15] but neglects the anchoring principle of the stem. Hip stems that are classified as short do not necessarily yield better proximal bone stock preservation compared to anatomical or conventional hip stems.

Dual-energy X-ray absorptiometry (DEXA) is a reliable and widely accepted tool to determine bone mineral density (BMD).[16–18] Measuring BMD around the total hip prosthesis provides information on the redistribution of the biomechanical forces in the femur as a result of implanted hip stems.[19] A review by Knutsen et al[13] gave insight into stress shielding around cemented and uncemented conventional hip stems, as all available data on bone remodelling were pooled. For uncemented conventional stems, the area of the greater trochanter and calcar region are most prone to bone loss. Results of proximal bone stock preservation for different types of short and anatomic stems have been published in recent years, with diverse outcomes, but there are no global data on their outcome. In this review, short-term results on BMD surrounding short stems were assessed in comparison with anatomic stems.

Methods

Inclusion criteria

Studies

A systematic literature search was performed to obtain all published data on bone mineral density (BMD) in total hip arthroplasty. Inclusion was limited to studies on BMD measurements surrounding proximal anchored femoral hip stems, with a follow-up period of at least one year after surgery. Studies on hip resurfacing and conventional hip stems were excluded. Prospective and retrospective cohorts, as well as comparative studies, were included.

Outcome measurement

Primary outcome was BMD loss in Gruen zone 1 (calcar region) and Gruen zone 7 (greater trochanter),[20] representing proximal loading zones, as these zones can be compared per different stem design. The outcome was described as the relative percentual change in BMD per follow-up moment relative to baseline. Baseline value was defined as the direct postoperative BMD (< 3 weeks). Data on BMD were collected for all Gruen zones (as mean BMD g/cm^2 or percentual change in BMD, with or without standard deviation). The studies that presented their data in mg/cm^2 or g/cm^2 were converted into percentual change of baseline BMD in each Gruen zone.

Gruen zones are defined areas around the hip stem to assess osteolysis. Originally, they were divided into seven zones for conventional stems, but are also appliable for short stems (Fig. 1). Gruen 1 begins on the proximal lateral side (greater trochanter) and Gruen 7 ends on the proximal medial side (calcar region). If studies used a different Gruen zone numbering, this was converted to the zones as depicted in Fig. 1.

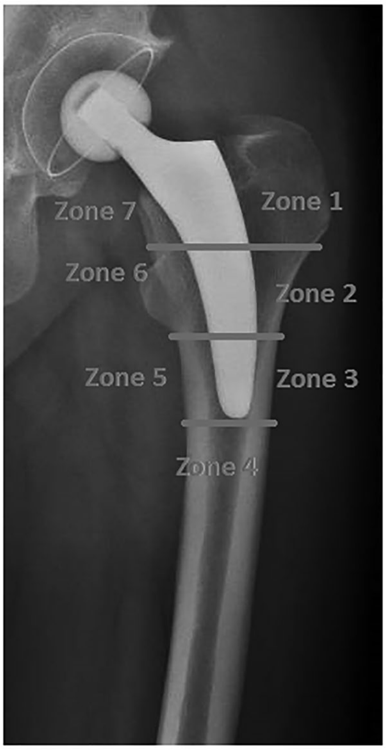


Fig. 1 Gruen zones in short hip stems.

Search strategy

To identify all suitable studies, the following search terms were used in Medline, PubMed and Embase: "hip arthroplasty OR hip replacement" and "short stem OR anatomic stem" and "dual-energy OR DEXA" between January 1990 and June 2020. More details of the search can be requested from the authors. The search was performed by two reviewers (PV and DH), independently. Language was restricted to English, German, French and Spanish. References of retrieved studies, potentially meeting the criteria, were also screened. Abstracts from congress, scientific meetings and unpublished reports were excluded.

Methods of review

Selection of studies

Studies were selected by reviewing the title and abstract to identify potentially relevant articles by two reviewers (PV and DH). Disagreement was resolved through discussion by the two reviewers, with a third reviewer (SW) as final vote with remaining discussions. The full text was retrieved and evaluated for definitive inclusion, when the title, keywords or abstract showed information on bone mineral density or DEXA in total hip arthroplasty.

Data extraction

Two authors (SW and JV) independently performed the data extraction. Predefined extraction forms were used to collect the following data from each study: author, year of publication, type of implant, manufacturer, whether the implant is still on the market, number of patients/hips, years of follow-up, and the patient demographics (such as age, gender and BMI). BMD data were collected in mg/cm^2, g/cm^2 or percentual change of BMD at baseline, all with the standard deviation if described. When available, additional Harris Hip Scores (HHS) were collected. In case of non-numerical presentation of BMD, the authors were contacted to retrieve numerical data.

All hip implants were defined as either short or anatomical hip stems. According to the classification system as used by van Oldenrijk et al[21] and described by Falez et al,[15] the short stems were classified as partial collum or trochanter sparing, and the anatomic stems as trochanter sparing or trochanter harming. Additionally, all stem types were categorized based on anchoring site as metaphyseal, metadiaphyseal or diaphyseal anchoring.[22] Follow-up was categorized as 1–3 months, six months, one year, two years, 3–5 years and 5–10 years.

Methodological quality

Methodological quality was assessed by use of the Methodological Index for Non-Randomized Studies (MINORS) criteria for quality assessment of the studies[23] by two authors (SW and PV) independently. Discrepancies were resolved by consensus.

Analysis

Descriptive statistics were used to present study details. BMD data were converted into overall weighted mean of bone loss, expressed in percentages, for short and anatomic stems. The standard error (SE) was calculated using the pooled standard deviations in percentages. A threshold of ten percent was defined by the authors as the clinically relevant cut-off value for bone loss in the proximal Gruen zones (G1 and G7); however, there is no known threshold. The review of Knutsen et al showed in different types of conventional hip stems a wide range of percentual bone loss, where after two years in non-cemented femoral stems there was bone loss of at least 10%. A hip stem was classified as bone stock preserving in case the bone loss was less than this threshold. Additionally, all short stems that are still on the market were selected and their course of bone loss during a two-year follow-up period was investigated.

Results

Selection procedure

In total, 681 references were found in the online databases, all published between January 1997 and June 2020. After removal, a total of 470 articles remained for reviewing titles, abstracts and keywords. Finally, 29 studies were included in this review (Fig. 2).

Study characteristics

The 29 included studies contained a total of 2095 patients (2265 hips). Details of the included studies are presented in Table 1. The population consisted of 56% male and 44% female patients, with an average age of 55 years (range, 17–83 years) and a mean body mass index (BMI) of 28.4 (range, 16.9–49.6). Eighteen different stem designs were found, of which nine were short stems and nine anatomic stems (Table 2). According to the level of osteotomy, the stems were classified as trochanter harming (seven stems),[24–30] trochanter sparing (seven stems)[25,26,31–40] and partial collum (four stems).[41–50] According to site of anchoring, the stems were classified as metaphyseal (three stems),[25,26,36,41,43,44,46,47] metadiaphyseal (seven stems)[24,26,37–42,45,48,51] or diaphyseal (eight stems)[25,27–30,33–36,52] anchoring. After patients who were lost to follow-up were excluded, 1796 hips remained to analyse. All included hip stems with their respective bone loss are depicted in Table 2. The bone loss in short and anatomic stems at one year follow-up is comparable in Gruen 7; however, there appears to be a difference in Gruen 1 at two-year follow-up (Fig. 3). The bone loss in all Gruen zones stabilized after three months, except for Gruen 7 which displayed a continuous bone loss until six months in the anatomic stems (Table 3).

Short stem

A total number of 1068 patients (1098 hips) were included in 19 studies (not including Meyer et al,[32] of whom 53.7% were male (n = 574/1068) and 46.3% were female (n = 494/1068). The average age was 55 years with a mean BMI of 25. Once patients who were lost to follow-up were excluded, a total of 915 hips remained. A mean total value in HHS of 94 at a minimal follow-up of one year (range, 1–10 years) was reported.

Gruen 1 showed a bone loss of 5% after one year (n = 855) and 5% after two years (n = 266). Gruen 7 was the most affected zone, with a bone loss of 10% after one year and 11% after two years (Table 3).

Anatomic stem

A total of 1027 patients (1167 hips) were included in 13 studies, of whom 56% were male (n = 597/1027) and 44% female (n = 430/1027). In this population, the mean age was 54 years with a mean BMI of 23. Lost to follow-up patients were excluded, leaving a total of 881 hips in this subgroup. The HHS had a mean total value of 96 points at a minimal follow-up of one year (range, 1–10 years).

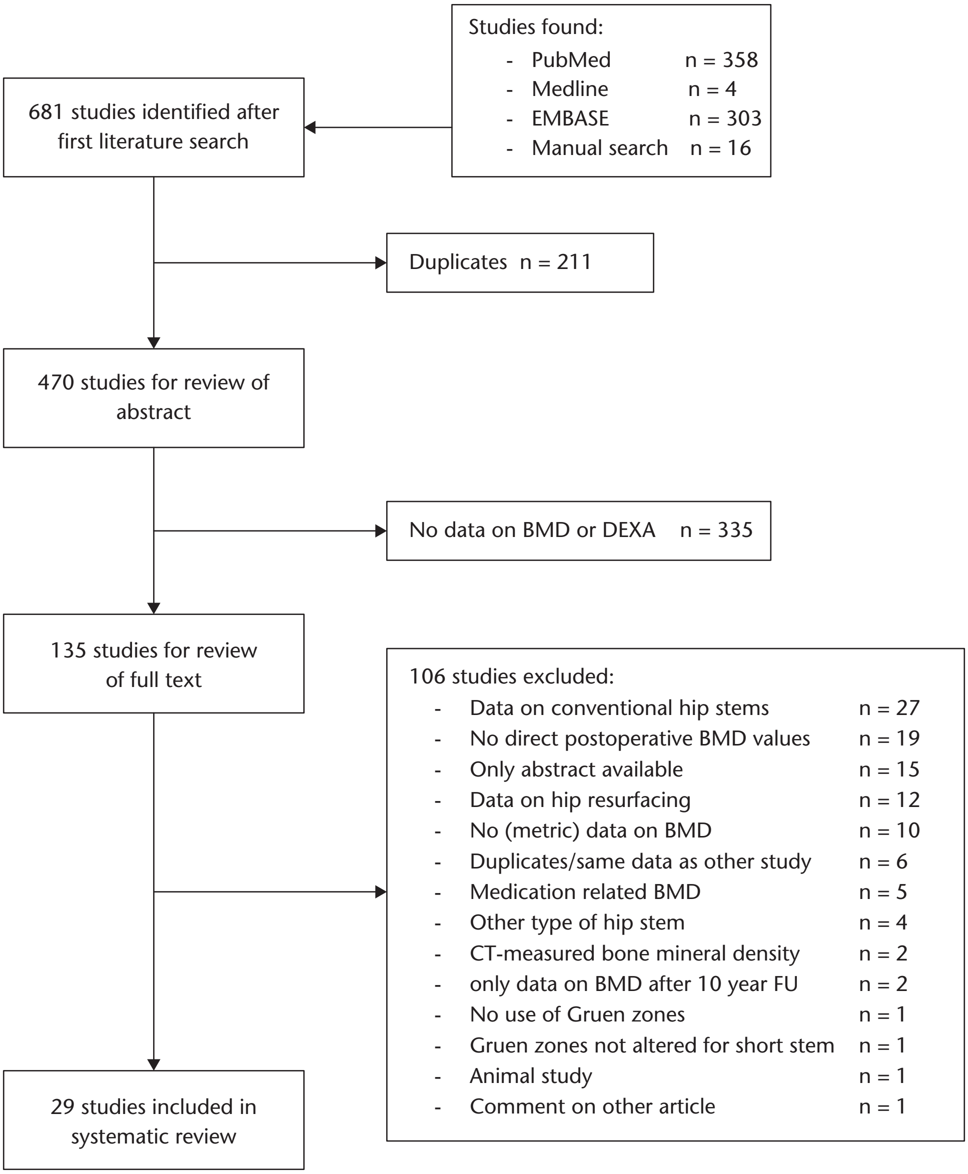


Fig. 2 Flowchart with selection of included studies.

Note. BMD, bone mineral density; DEXA, dual-energy X-ray absorptiometry; CT, computerized tomography; FU, follow-up.

Gruen 1 showed bone loss of 8% after one year (*n* = 731) and 11% after two years (*n* = 227). Bone loss in Gruen 7 was 14% after one year and 15% after two years (Table 3).

Osteotomy levels (Fig. 4)

Bone loss in Gruen 1 was, in both trochanter sparing and partial collum hip stems, less than 10%, with a slightly better preservation in trochanter sparing hip stems at one year follow-up. This was not seen at two-year follow-up. A difference of > 10% bone loss was found at two-year follow-up between trochanter sparing and partial collum hip stems in Gruen 7.

In anatomic stems, the trochanter harming stems were bone stock preserving at one-year follow-up in Gruen 1, but this preservation was not seen at two-year follow-up. There is a difference between trochanter sparing stems in short and anatomic stems, in favour of the short stems.

Anchoring types (Fig. 5)

In short stems, metaphyseal anchoring was bone stock preserving in the two Gruen zones at one- and two-year

Table 1. Summary of included studies

Author, year	Patients/hips (*n*)	Age (mean)	M/F (*n*)	Body mass index (mean)	Follow-up (years)	Design	MINORS
Arabmotlag, 2003[52]	15/15	48	7/8	–	2	CTX	17/22
Boller, 2019[50]	39/39	51	13/26	28	2	Metha	12/16
	28/28	66	16/12	27	2	Metha	
Brinkmann, 2015[41]	24/24	59	12/12	27	1	Metha	16/22
	26/26	60	16/10	27		Nanos	
Ercan, 2016[42]	62/62	57	28/34	29	1	Minihip	10/16
Fokter, 2015[24]	19/19	60	8/11	28	1	Unibionix	16/22
Freitag, 2016[33]	57/57	57	36/21	30	1	Fitmore	19/22
Gasbarra, 2014[34]	33/33	62	15/18	24	1	Fitmore	16/22
Hayashi, 2016[70]	21/21	68	11/56	23	2	Trilock	12/16
Jahnke, 2014[43]	40/40	55	20/20	27	1	Metha	13/16
Kim, 2011[25]	50/60	54	22/28	26	3	Proxima	16/22
	50/60	52	24/26	25		Profile	
Kim, 2016[26]	201/221	53	118/83	30	10	Proxima	19/22
	400/530	53	264/136	29		IPS	
Kim, 2016[36]	200/200	53	138/62	30	12	Proxima	19/22
	200/200	53	138/62	30		Profile	
Leali, 2004[27]	10/10	65	4/6	–	3	Revelation	10/16
Lerch, 2012[44]	25/25	59	16/9	25	2	Metha	13/16
Meyer, 2019[32]*	54/54	–	–	–	5	Fitmore	–
Nysted, 2011[51]	43/43	55	18/28	–	5	Unique	16/22
	35/35	53	13/28	–		ABG-I	
Panisello, 2009[37]	56/56	60	27/29	28	5	ABG-I	19/22
	54/54	59	26/28	27		ABG-II	
Parchi, 2017[49]	20/20	54	11/9	–	4	Metha	12/16
Rahmy, 2004[38]	24/24	62	11/18	28	3	ABG-I	18/22
Salemyr, 2015[31]	26/26	62	11/15	27	4	Proxima	21/22
Shafy, 2016[45]	26/26	43	20/6	27	2	Minihip	12/16
Sluimer, 2006[28]	40/40	53	15/25	–	2	Omnifit-HA 1090	18/22
Steens, 2015[46]	20/20	49	12/8	26	5	ESKA cut 2000	14/16
Synder, 2015[47]	36/36	50	18/18	–	1	Metha	12/16
Vd Wal, 2006[40]	25/25	62	17/8	–	2	ABG-I	16/22
	26/26	60	12/14	–	2	ABG-II	
Vd Wal, 2008[39]	24/24	60	11/13	–	2	ABG-I	15/22
White, 2008[29]	27/27	37	14/13	25	5	Epoch	9/16
Wixson, 1997[30]	35/35	50	16/19	–	2	Custom made	9/16
Zeh, 2013[48]	25/25	60	15/10	29	1	Nanos	11/16

Note. MINORS, Methodological Index for Non-Randomized Studies.

*Study between two age groups.

**follow-up of Freitag et al, 2016[33].

follow-up. Metadiaphyseal anchoring also achieves this in Gruen 1, but not in Gruen 7. Comparing metadiaphyseal short stems and anatomic stems, both stems had equal bone loss in Gruen 1 and 7.

Short stem types (Fig. 6)

The progress of the different types of short stems that are still on the market in Gruen 1 and Gruen 7 over time varies. The total mean percentual changes in BMD of the short and anatomic stems were included as reference line, with the threshold of 10%.

At two years follow-up, the Metha (Braun, Hessen, Germany), Fitmore (ZimmerBiomet, Warsaw, USA) and Minihip (Corin group PLC, Circencester, United Kingdom) were bone stock preserving in Gruen 1 and 7. The Trilock (DePuy, Warsaw, IN) was bone stock preserving in Gruen 1, but this was not achieved in Gruen 7. The Nanos (Smith & Nephew, Marl, Germany) is bone stock preserving in Gruen 7 at one-year follow-up, but did have more than 10% bone loss in Gruen 1.

Discussion

This review compiled the available data on periprosthetic bone loss in short and anatomic hip stems and defined which type of stem is best capable of preserving bone stock. Overall one-year follow-up results revealed that short and anatomic stems are bone stock preserving in Gruen 1. Furthermore, only the short stem was bone stock preserving in Gruen 7 at one-year follow-up. In the rest of the follow-up moments, in both short and anatomic stems, there was more than 10% bone loss. Bone stock was preserved in the remaining Gruen zones in short and anatomic stems.

This review was restricted to short stems and anatomic stems; hip resurfacing stems were not included

Table 2. Classification and course of bone loss per hip stem design from baseline in Gruen 1 and 7 (in %)

Gruen 1	Type	Osteotomy	Anchoring	Studies (*n*)	*N*	3M	6M	1Y	2Y
ABG-I[35–38,51]	Anatomic	Trochanter sparing	Metadiaphyseal	5	164	–11	–11	–13	–12
ABG-II[35,38]	Anatomic	Trochanter sparing	Metadiaphyseal	2	80	–5	–7	–8	–9
Custom made Biomet[30]	Anatomic	Trochanter harming	Diaphyseal	1	31		–10	–17	–8
CTX[52]	Anatomic	Trochanter sparing	Diaphyseal	1	15				–2
Epoch[29]	Anatomic	Trochanter harming	Diaphyseal	1	12			–17	–19
ESKA cut 2000[46]	Short	Partial collum	Metaphyseal	1	30	–3		–1	
Fitmore[31,32,40]	Short	Trochanter sparing	Diaphyseal	3	90*	–3	0	–4	
IPS[33]	Anatomic	Trochanter harming	Metadiaphyseal	1	385			0	
Metha[41,43,44,47,49, 50]	Short	Partial collum	Metaphyseal	6	206	–9	–9	–8	–5
Minihip[42,45]	Short	Partial collum	Metadiaphyseal	2	88	–11	–12	–8	–3
Nanos[41,48]	Short	Partial collum	Metadiaphyseal	2	51	–9		–14	
Omnifit-HA 1090[28]	Anatomic	Trochanter harming	Diaphyseal	1	35	–11	–13	–14	–13
Profile[25,26]	Anatomic	Trochanter harming	Diaphyseal	2	60			–27	
Proxima[25,26,34, 39]	Short	Trochanter sparing	Metaphyseal	4	333	–6	–3	–1	–3
Revelation[27]	Anatomic	Trochanter harming	Diaphyseal	1	10	–1	–2	–4	
Trilock[33]	Short	Trochanter sparing	Diaphyseal	1	65	–6	–5	–3	
Unibionix[24]	Short	Trochanter harming	Metadiaphyseal	1	19	0	5	10	
Unique[51]	Short	Trochanter sparing	Metadiaphyseal	1	43	–10	–9	–10	–11
Gruen 7	**Type**	**Osteotomy**	**Anchoring**	**Studies (*n*)**	***N***	**3M**	**6M**	**1Y**	**2Y**
ABG-I [35–38,51]	Anatomic	Trochanter sparing	Metadiaphyseal	5	164	–12	–22	–23	–15
ABG-II[35,38]	Anatomic	Trochanter sparing	Metadiaphyseal	2	80	–5	–10	–16	–12
Custom made Biomet[30]	Anatomic	Trochanter harming	Diaphyseal	1	31		–17	–19	15
CTX[52]	Anatomic	Trochanter sparing	Diaphyseal	1	15				–34
Epoch[29]	Anatomic	Trochanter harming	Diaphyseal	1	12			–10	–12
ESKA cut 2000[46]	Short	Partial collum	Metaphyseal	1	30	–3		1	
Fitmore[31,32,40]	Short	Trochanter sparing	Diaphyseal	3	90*	–14	–6	–8	
IPS[33]	Anatomic	Trochanter harming	Metadiaphyseal	1	385			–6	
Metha[41,43,44,47,49, 50]	Short	Partial collum	Metaphyseal	6	206	–15	–11	–13	–3
Minihip[42,45]	Short	Partial collum	Metadiaphyseal	2	88	–11	–12	–9	–3
Nanos[41,48]	Short	Partial collum	Metadiaphyseal	2	51	–9		–8	
Omnifit-HA 1090[28]	Anatomic	Trochanter harming	Diaphyseal	1	35	–11	–13	–14	–13
Profile[25,26]	Anatomic	Trochanter harming	Diaphyseal	2	60			–33	
Proxima[25,26,34,39]	Short	Trochanter sparing	Metaphyseal	4	333	–11	–12	–7	–13
Revelation[27]	Anatomic	Trochanter harming	Diaphyseal	1	10	–4	–5	–5	
Trilock[33]	Short	Trochanter sparing	Diaphyseal	1	65	–9	–9	–14	
Unibionix[24]	Short	Trochanter harming	Metadiaphyseal	1	19	–12	–12	–15	
Unique[51]	Short	Trochanter sparing	Metadiaphyseal	1	43	–17	–20	–21	–24

*Number of patients of two studies (Freitag[33] and Gasbarra[34] as Meyer[32] et al is a follow-up study of Freitag.[33]

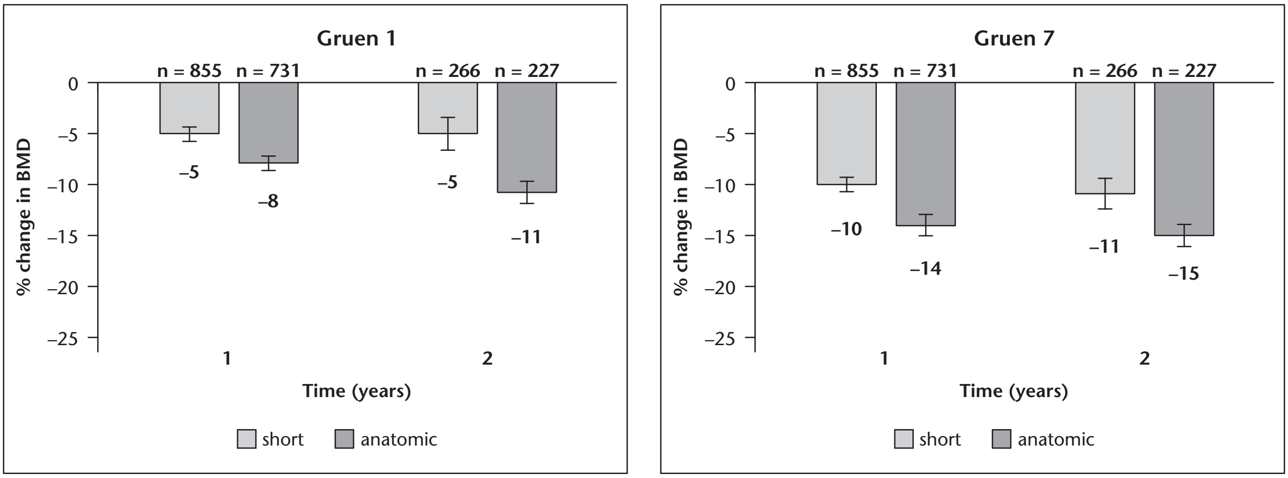


Fig. 3 Percentual bone loss per type of hip stem in Gruen 1 and 7, with pooled standard error.

Note. BMD, bone mineral density.

Table 3. Mean percentual change in bone mineral density in short and anatomic stems as a proportion from baseline (< 3 weeks postoperative)

Short	Time (months)	3	6	12	24	36–60	60–120
Nr of hips (G1, G7)		397 (12)	456 (12)	855 (18)	266 (7)	335 (4)	221 (3)
Nr of hips (G2–G6)		371 (11)	430 (11)	582 (16)	240 (6)	117 (3)	63 (2)
Gruen 1		–7	–8	–5	–5	1	–2
Gruen 2		–7	–5	–4	–1	–9	–7
Gruen 3		–1	–1	0	1	–2	–4
Gruen 4		–4	–4	–2	–1	–5	–6
Gruen 5		–3	–2	–2	0	0	–3
Gruen 6		–5	–1	1	2	–4	0
Gruen 7		–12	–11	–10	–11	–13	–15
Anatomic	**Time (months)**	**3**	**6**	**12**	**24**	**36–60**	**60–120**
Nr of hips (G1, G7)		155 (5)	245 (6)	731 (9)	227 (8)	504 (4)	631 (5)
Nr of hips (G2–G6)		155 (5)	245 (6)	257 (7)	227 (8)	59 (2)	157 (3)
Gruen 1		–9	–10	–8	–11	–13	–2
Gruen 2		–7	–4	–5	–6	–7	4
Gruen 3		–5	–4	–2	–2	–5	–1
Gruen 4		–4	–5	–1	–1	–2	–1
Gruen 5		–4	–1	–2	–1	–1	3
Gruen 6		–6	–4	–4	–3	–5	3
Gruen 7		–10	–17	–14	–15	–13	–25

Between brackets number of studies.

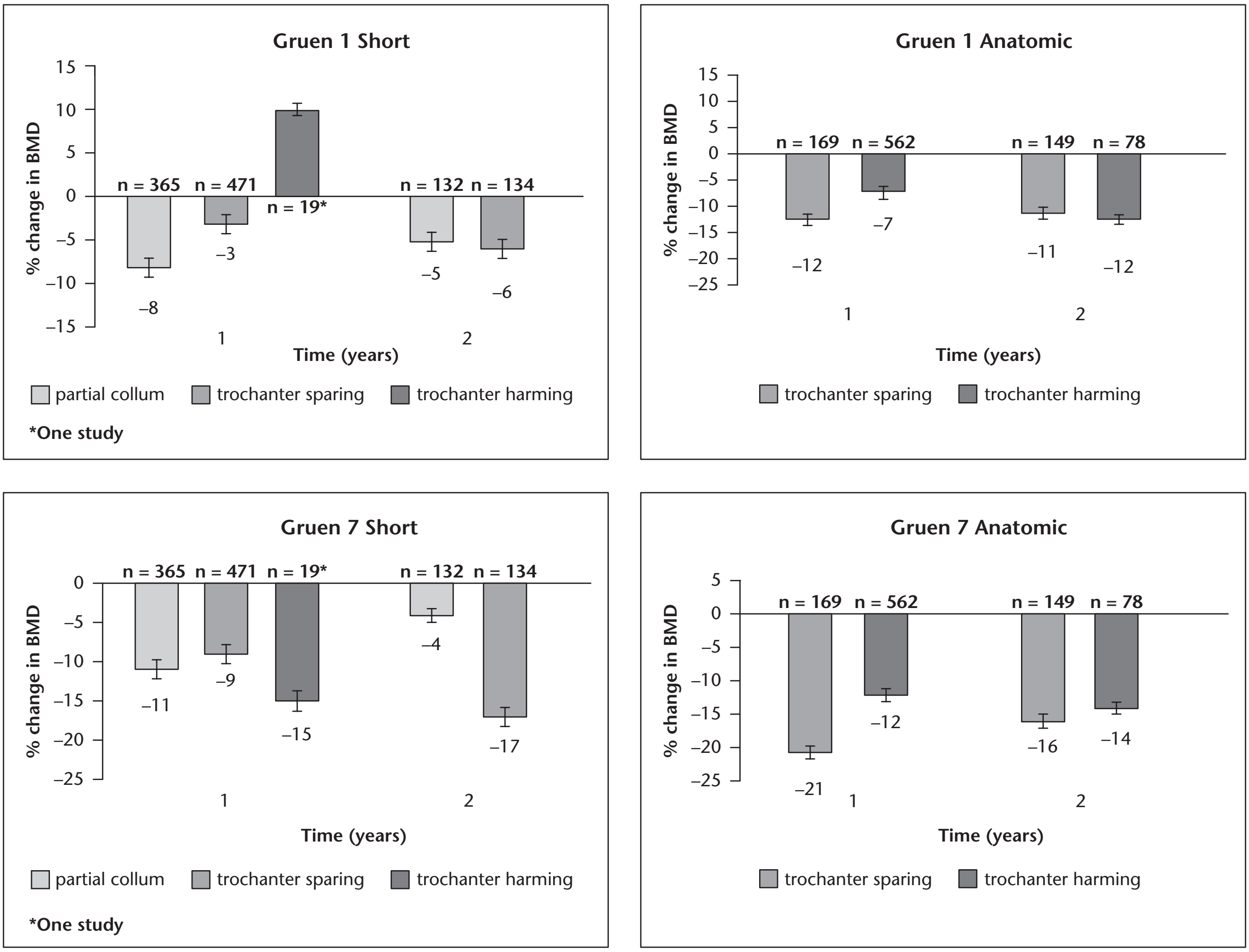


Fig. 4 Percentual bone loss in type of osteotomy in Gruen 1 and 7 (short and anatomic), with pooled standard error.

Note. BMD, bone mineral density.

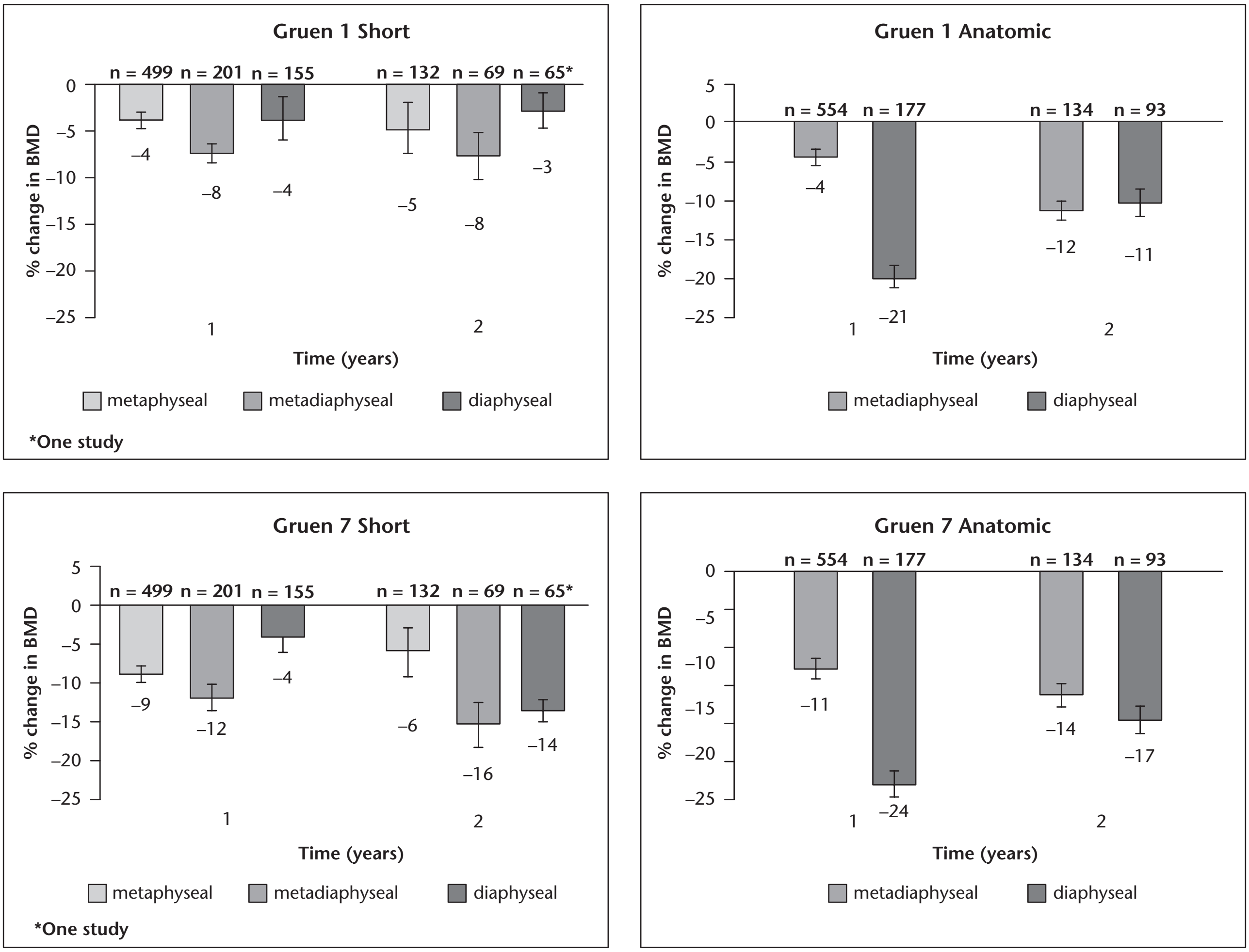
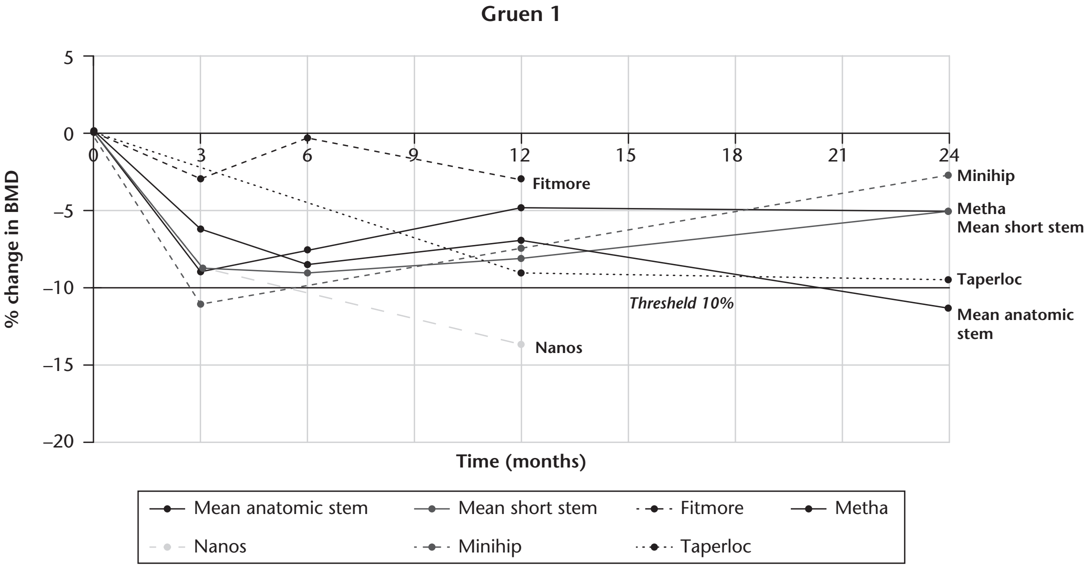


Fig. 5 Percentual bone loss in type of anchoring in Gruen 1 and 7 (short and anatomic), with pooled standard error.
Note. BMD, bone mineral density.

due to different physical loading and anchoring principles. Uncemented conventional hip stems were covered in the review by Knutsen et al.[13] All measurements were obtained with DEXA scans, a widely used and reliable technique for measurement of periprosthetic bone loss.[17,53] The focus of interest in this review were Gruen 1 and 7, as these two zones are most representative for proximal loading of the femur and where periprosthetic bone loss is mainly observed.[13,54,55] These two zones are also the most comparable between different stem designs, as stem length defines the length of the Gruen zone for Gruen 2 until Gruen 6, but is less important for Gruen 7 (the calcar/lesser trochanter region) and Gruen 1 (greater trochanter region).

By maintaining a greater part of the postoperative physical loading in the metaphysis, the trochanter region has less bone stock loss in short (-5%) and anatomic (-8%) stems one-year postoperatively than uncemented conventional stems (–9.8%), as shown in the review by Knutsen et al.[13] In the calcar region it is more difficult to preserve bone stock in uncemented conventional stems (–19%).[13] Short stems (-10%) show better bone stock preservation one year after implantation compared to uncemented conventional stems. The more proximal anchoring anatomic stems (-14%) also provide a smaller amount of bone loss than uncemented conventional stems in the calcar region.

The present study had some limitations. This review has focused only on the classification of the hip stem, thereby neglecting implant-specific characteristics such as geometry, coating, stiffness and material that are also associated with BMD.[13] The IPS (anatomic) and Unibionix stem (short) both show remarkable bone stock preservation in Gruen 1, the Unique stem (short) displays bone loss of more than 20% in Gruen 7 and the Profile stem (anatomic) has bone loss of more than 20% in both Gruen zones. These results are not in line with other results of the same type of hip stems in their category, indicating



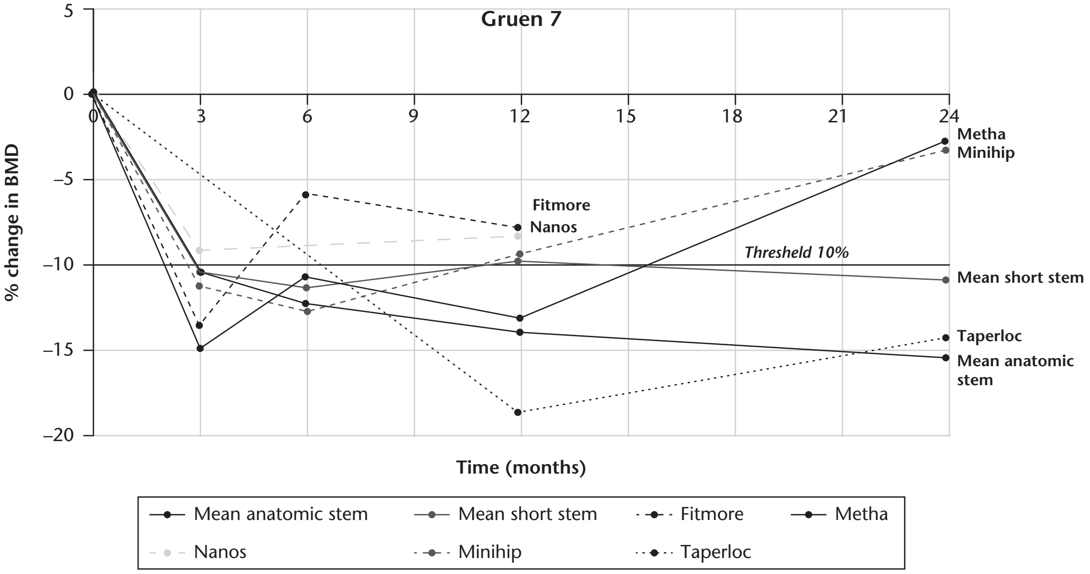


Fig. 6 Bone loss in % per short stem design (still on the market) in Gruen 1 and 7 over time, with the total mean per stem included. Threshold of 10% bone loss added.

Note. BMD, bone mineral density.

that other implant-specific characteristics play an important role. Unfortunately, stem positioning and osteotomy level were not mentioned in most studies, therefore their effect on BMD could not be assessed in this review. But it could be an explanation between two different results in the same type of hip stem (Metha), where one study describes bone loss of 23% in Gruen 7 and another 8%. A study by Brinkmann et al[56] showed a different straining distribution in stems which were placed in a varus or valgus alignment.

Most studies reported data on BMD direct postoperatively in both Gruen zones 1 and 7; however, 19 studies did not. They compared follow-up BMD to the preoperative BMD ($n = 5$), the BMD of the contralateral side ($n = 3$), the BMD value without Gruen zones ($n = 4$) or made no comparison at all ($n = 7$). Therefore, these studies were excluded from this review. A threshold of 10% bone loss was chosen as clinically relevant in this review as reference value for all short hip stems, thereby making a stem bone stock preserving when it shows less than 10% bone loss.

However, there is no known threshold for how much bone loss is of clinical significance for implant failure. Long-term survival in hip stems can be affected by bone loss in Gruen 1 and 7, but in case of sufficient anchoring in the other (more distal) Gruen zones, implant stability can be maintained. As conventional stems have a higher percentage of bone loss, most stems also have excellent long-term survival, as seen with the 13A Orthopaedic Data Evaluation Panel (ODEP) rating for the CLS and Exeter for example. However, if the femoral component fails in the long term due to aseptic loosening, this is often accompanied with (proximal) bone stock loss and mostly seen in Gruen 1 and Gruen 7. As revision surgery in total hip arthroplasty is rising, due to a higher incidence of younger and more active patients with total hip arthroplasty,[57–61] this loss can pose more difficulty during revision surgery[62] and influence the type of hip stem as femoral replacement.[63] The chance of complications, such as fractures, and the difficulty of the revision is theoretical lower when there is still sufficient bone stock.[64] Especially in patients who have a chance of re-revision in THA, maintaining bone stock seems to play an important role.[65]

The majority of the studies concerned follow-up data limited to the first postoperative year. Since bone activity is a continuous process, medium- and long-term bone remodelling is important for better understanding of the effect that short stems have on the physical loading.[26,66,67] Especially since the patient population is in a stage of life where bone stock will naturally decline due to age, reduced activity and hormonal shifts.[68] Nevertheless, the promising course of bone remodelling in this review around the short stem during the first two postoperative years could yield information on bone stock preservation in the long term.[12,69]

Both classification systems based on osteotomy level as well as anchoring site revealed varying amounts of bone loss within their classification among short and anatomical stems. This could indicate that positioning of the stem can play a role in bone remodelling.[56,70] For instance, the Nanos stem can be placed in a varus or valgus position, depending on the hip anatomy of the individual patient in terms of the femoral offset. Osteotomy level can therefore be either partial collum or trochanter sparing while maintaining the anchoring site. Classification on just osteotomy level could not be accurate enough. Therefore, classification according to type of anchoring should be described in further research when describing the effect of the hip stem on femoral bone loss.

Conclusion

This study contributes to the understanding of periprosthetic bone mineral density in short stem hip arthroplasty. Short stems are capable of preserving bone stock by maintaining the postoperative physical loading in the metaphysis. Though there is still loss of bone, this is slightly reduced in short stems compared to anatomic stems. Whether this effect is clinically relevant and remains in the long term is yet to be established.

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REFERENCES

1. **Arthroplasty in the Picture Annual Report of the Dutch Arthroplasty Register (Landelijke Registratie Orthopedische Implantaten) 2014.** *www.lroi-rapportage.nl* (date last accessed 21 October 2021).
2. **Landelijke Registratie Orthopedische Implantaten (LROI) ©2016 Online LROI-Rapportage 2015.** www.lroi-rapportage.nl (date last accessed 21 October 2021).
3. **Swarup I, Marshall AC, Lee YY, Figgie MP.** Implant survival and patient-reported outcomes after total hip arthroplasty in young patients with developmental dysplasia of the hip. *Hip Int* 2017;26:367–373.
4. **Swarup I, Sutherland R, Jayme C, Burket JC, Figgie MP.** Total hip arthroplasty in young patients with post-traumatic arthritis of the hip. *Hip Int* 2017;27:546–550.
5. **Swarup I, Shields M, Mayer EN, Hendow CJ, Burket JC, Figgie MP.** Outcomes after total hip arthroplasty in young patients with osteonecrosis of the hip. *Hip Int* 2017;27:286–292.
6. **Santaguida PL, Hawker GA, Hudak PL, Glazier R, Mahomed NN, et al.** Patient characteristics affecting the prognosis of total hip and knee joint arthroplasty: a systematic review. *Can J Surg* 2008;51:428–436.
7. **Alm JJ, Mäkinen TJ, Lankinen P, Moritz N, Vahlberg T, Aro HT.** Female patients with low systemic BMD are prone to bone loss in Gruen zone 7 after cementless total hip arthroplasty. *Acta Orthop* 2009;80:531–537.

8. Sköldenberg OG, Bodén HSG, Salemyr MO, Ahl TE, Adolphson PY. Periprosthetic proximal bone loss after uncemented hip arthroplasty is related to stem size: DXA measurements in 138 patients followed for 2–7 years. *Acta Orthop* 2006;77:386–392.

9. Rosenthall L, Bobyn JD, Tanzer M. Bone densitometry: influence of prosthetic design and hydroxyapatite coating on regional adaptive bone remodelling. *Int Orthop* 1999;23:325–329.

10. Tanzer M, Kantor S, Rosenthall L, Bobyn JD. Femoral remodeling after porous-coated total hip arthroplasty with and without hydroxyapatite-tricalcium phosphate coating: a prospective randomized trial. *J Arthroplasty* 2001;16:552–558.

11. Parchi PD, Cervi V, Piolanti N, et al. Densitometric evaluation of periprosthetic bone remodeling. *Clin Cases Miner Bone Metab* 2014;11:226–231.

12. Roth A, Richartz G, Sander K, et al. Verlauf der periprothetischen Knochendichte nach Hüfttotalendoprothesenimplantation. Abhängigkeit von Prothesentyp und knöcherner Ausgangssituation. *Orthopade* 2005;34:334–344.

13. Knutsen AR, Lau N, Longjohn DB, Ebramzadeh E, Sangiorgio SN. Periprosthetic femoral bone loss in total hip arthroplasty: systematic analysis of the effect of stem design. *Hip Int* 2017;27:26–34.

14. Albanese CV, Santori FS, Pavan L, Learmonth ID, Passariello R. Periprosthetic DXA after total hip arthroplasty with short vs. ultra-short custom-made femoral stems: 37 patients followed for 3 years. *Acta Orthop* 2009;80:291–297.

15. Falez F, Casella F, Papalia M. Current concepts, classification, and results in short stem hip arthroplasty. *Orthopedics* 2015;38:S6–S13.

16. Cohen B, Rushton N. Accuracy of DEXA measurement of bone mineral density after total hip arthroplasty. *J Bone Joint Surg [Br]* 1995;77-B:479–483.

17. Bloebaum RD, Liau DW, Lester DK, Rosenbaum TG. Dual-energy X-ray absorptiometry measurement and accuracy of bone mineral after unilateral total hip arthroplasty. *J Arthroplasty* 2006;21:612–622.

18. Martini F, Lebherz C, Mayer F, Leichtle U, Kremling E, Sell S. Precision of the measurements of periprosthetic bone mineral density in hips with a custom-made femoral stem. *J Bone Joint Surg [Br]* 2000;82-B:1065–1071.

19. Kroger H, Miettinen H, Arnala I, Koski E, Rushton N, Suomalainen O. Evaluation of periprosthetic bone using dual-energy X-ray absorptiometry: precision of the method and effect of operation on bone mineral density. *J Bone Miner Res* 1996;11:1526–1530.

20. Gruen T, McNeice G, Amstutz H. 'Modes of failure' of cemented stem-type femoral components: a radiographic analysis of loosening. *Clin Orthop Relat Res* 1979;141:17–27.

21. van Oldenrijk J, Molleman J, Klaver M, Poolman RW, Haverkamp D. Revision rate after short-stem total hip arthroplasty: a systematic review of 49 studies. *Acta Orthop* 2014;85:250–258.

22. McTighe T, Keggi J, David Stulberg S, Keppler L, Brazil D, McPherson EJ. Total hip stem classification system. *Reconstr Rev* 2014;4:24–28.

23. Slim K, Nini E, Forestier D, Kwiatkowski F, Panis Y, Chipponi J. Methodological Index for Non-Randomized Studies (MINORS): development and validation of a new instrument. *ANZ J Surg* 2003;73:712–716.

24. Fokter SK, Sarler T, Strahovnik A, Repše-Fokter A. Results of total hip arthroplasty using a bionic hip stem. *Int Orthop* 2015;39:1065–1071.

25. Kim YH, Choi Y, Kim JS. Comparison of bone mineral density changes around short, metaphyseal-fitting, and conventional cementless anatomical femoral components. *J Arthroplasty* 2011;26:931–940.e1.

26. Kim YH, Park JW, Kim JS. Metaphyseal engaging short and ultra-short anatomic cementless stems in young and active patients. *J Arthroplasty* 2016;31:180–185.

27. Leali A, Fetto JF. Preservation of femoral bone mass after total hip replacements with a lateral flare stem. *Int Orthop* 2004;28:151–154.

28. Sluimer JC, Hoefnagels NHM, Emans PJ, Kuijer R, Geesink RGT. Comparison of two hydroxyapatite-coated femoral stems: clinical, functional, and bone densitometry evaluation of patients randomized to a regular or modified hydroxyapatite-coated stem aimed at proximal fixation. *J Arthroplasty* 2006;21:344–352.

29. White SP, Lee MB, Galpin J, Learmonth ID. Ten-year results of a bone-preserving low-modulus composite total hip replacement stem. *Hip Int* 2008;18:81–87.

30. Wixson RL, Stulberg SD, Van Flandern GJ, Puri L. Maintenance of proximal bone mass with an uncemented femoral stem analysis with dual-energy x-ray absorptiometry. *J Arthroplasty* 1997;12:365–372.

31. Salemyr M, Muren O, Ahl T, et al. Lower periprosthetic bone loss and good fixation of an ultra-short stem compared to a conventional stem in uncemented total hip arthroplasty. *Acta Orthop* 2015;86:659–666.

32. Meyer JS, Freitag T, Reichel H, Bieger R. Periprosthetic bone mineral density changes after implantation of a curved bone preserving hip stem compared to a standard length straight stem: 5-yr results of a prospective, randomized DXA-analysis. *J Clin Densitom* 2019;22:96–103.

33. Freitag T, Hein MA, Wernerus D, Reichel H, Bieger R. Bone remodelling after femoral short stem implantation in total hip arthroplasty: 1-year results from a randomized DEXA study. *Arch Orthop Trauma Surg* 2016;136:125–130.

34. Gasbarra E, Celi M, Perrone FL, et al. Osseointegration of Fitmore stem in total hip arthroplasty. *J Clin Densitom* 2014;17:307–313.

35. Hayashi S, Nishiyama T, Fujishiro T, et al. Maintenance of periprosthetic bone mineral density with a cementless three dimensional straight tapered stem. *Hip Int* 2011;21:163–167.

36. Kim YH, Park JW, Kim JS. Ultrashort versus conventional anatomic cementless femoral stems in the same patients younger than 55 years. *Clin Orthop Relat Res* 2016;474:2008–2017.

37. Panisello JJ, Canales V, Herrero L, Herrera A, Mateo J, Caballero MJ. Changes in periprosthetic bone remodelling after redesigning an anatomic cementless stem. *Int Orthop* 2009;33:373–379.

38. Rahmy AIA, Gosens T, Blake GM, Tonino A, Fogelman I. Periprosthetic bone remodelling of two types of uncemented femoral implant with proximal hydroxyapatite coating: a 3-year follow-up study addressing the influence of prosthesis design and preoperative bone density on periprosthetic bone loss. *Osteoporos Int* 2004;15:281–289.

39. van der Wal BCH, Rahmy AIA, Grimm B, Heyligers IC, Tonino AJ. Preoperative bone quality as a factor in dual-energy X-ray absorptiometry analysis comparing bone remodelling between two implant types. *Int Orthop* 2008;32:39–45.

40. van der Wal BCH, Rahmy AIA, Grimm B, Blake GM, Heyligers IC, Tonino AJ. The influence of implant design on periprosthetic bone remodelling of two types hip stems. *Hip Int* 2006;16:8–17.

41. Brinkmann V, Radetzki F, Delank KS, Wohlrab D, Zeh A. A prospective randomized radiographic and dual-energy X-ray absorptiometric study of migration and bone remodeling after implantation of two modern short-stemmed femoral prostheses. *J Orthop Traumatol* 2015;16:237–243.

42. **Ercan A, Sokkar SM, Schmid G, Filler TJ, Abdelkafy A, Jerosch J.** Periprosthetic bone density changes after MiniHip TM cementless femoral short stem: one-year results of dual-energy X-ray absorptiometry study. *SICOT J* 2016;2:40.

43. **Jahnke A, Engl S, Altmeyer C, et al.** Changes of periprosthetic bone density after a cementless short hip stem: a clinical and radiological analysis. *Int Orthop* 2014;38:2045–2050.

44. **Lerch M, von der Haar-Tran A, Windhagen H, Behrens BA, Wefstaedt P, Stukenborg-Colsman CM.** Bone remodelling around the Metha short stem in total hip arthroplasty: a prospective dual-energy X-ray absorptiometry study. *Int Orthop* 2012;36:533–538.

45. **Shafy TA, Sayed A, Abdelazeem AH.** Study of the bone behavior around a neck preserving short stem implant: bone densitometric analysis over a span of two years. *SICOT J* 2016;2:31.

46. **Steens W, Boettner F, Bader R, Skripitz R, Schneeberger A.** Bone mineral density after implantation of a femoral neck hip prosthesis: a prospective 5 year follow-up. *BMC Musculoskelet Disord* 2015;16:192.

47. **Synder M, Krajewski K, Sibinski M, Drobniewski M.** Periprosthetic bone remodeling around short stem. *Orthopedics* 2015;38:S40–S45.

48. **Zeh A, Pankow F, Röllinhoff M, Delank S, Wohlrab D.** A prospective dual-energy X-ray absorptiometry study of bone remodeling after implantation of the Nanos short-stemmed prosthesis. *Acta Orthop Belg* 2013;79:174–180.

49. **Parchi PD, Ciapini G, Castellini I, Mannucci C, Nucci A-M, Piolanti N, Maffei S, Lisanti M.** Evaluation of the effects of the Metha® short stem on periprosthetic bone remodelling in total hip arthroplasties: results at 48 months. *Surg Technol Int* 2017;30:346–351.

50. **Boller S, Jahnke A, Augustin L, Ahmed G, Rickert M, Alexander B.** Age-related osseointegration of a short hip stem: a clinical and radiological 24 months follow-up. *Arch Orthop Trauma Surg* 2019;139:405–410.

51. **Nysted M, Benum P, Klaksvik J, Foss O, Aamodt A.** Periprosthetic bone loss after insertion of an uncemented, customized femoral stem and an uncemented anatomical stem: a randomized DXA study with 5-year follow-up. *Acta Orthop* 2011;82:410–416.

52. **Arabmotlagh M, Hennigs T, Rittmeister M.** Femoral periprosthetic bone remodelling after implantation of custom made anatomic and standard straight stem hip prostheses. *Z Orthop Ihre Grenzgeb* 2003;141:519–525.

53. **Cohen B, Rushton N.** Accuracy of DEXA measurement of bone mineral density after total hip arthroplasty. *J Bone Joint Surg [Br]* 1995;77-B:77–479.

54. **Grochola LF, Habermann B, Mastrodomenico N, Kurth A.** Comparison of periprosthetic bone remodelling after implantation of anatomic and straight stem prostheses in total hip arthroplasty. *Arch Orthop Trauma Surg* 2008;128:383–392.

55. **Boyle C, Kim IY.** Comparison of different hip prosthesis shapes considering micro-level bone remodeling and stress-shielding criteria using three-dimensional design space topology optimization. *J Biomech* 2011;44:1722–1728.

56. **Brinkmann V, Radetzki F, Gutteck N, Delank S, Zeh A.** Influence of varus/valgus positioning of the Nanos® and Metha® short-stemmed prostheses on stress shielding of metaphyseal bone. *Acta Orthop Belg* 2017;83:57–66.

57. **Duncan CP, Masterson EL, Masri BA.** Impaction allografting with cement for the management of femoral bone loss. *Orthop Clin North Am* 1998;29:297–305.

58. **Goff TAJ, Bobak P.** Femoral impaction allografting for significant bone loss in revision hip arthroplasty. *Hip Int* 2017;27:281–285.

59. **Abdel MP, Roth PV, Harmsen WS, Berry DJ.** What is the lifetime risk of revision for patients undergoing total hip arthroplasty? A 40-year observational study of patients treated with the Charnley cemented total hip arthroplasty. *J Bone Joint Surg [Br]* 2016;98-B:1436–1440.

60. **Cnudde PHJ, Nemes S, Bülow E, Timperley AJ, Whitehouse SL, Kärrholm J, et al.** Risk of further surgery on the same or opposite side and mortality after primary total hip arthroplasty: a multi-state analysis of 133,654 patients from the Swedish Hip Arthroplasty Register. *Acta Orthop* 2018;89:386–393.

61. **Kärrholm J, Mohaddes M, Odin D, Vinblad J, Rogmark C, Rolfson O.** *Swedish Hip Arthroplasty Register annual report 2017*. Gothenburg: Swedish Hip Arthroplasty Register, 2018.

62. **DeRogatis MJ, Issack PS.** Total femoral replacement as a salvage operation for the treatment of massive femoral bone loss during revision total hip arthroplasty. *JBJS Rev* 2018;6:e9.

63. **Sculco PK, Abdel MP, Lewallen DG.** Management of femoral bone loss in revision total hip arthroplasty. *Hip Int* 2015;25:380–387.

64. **Glassman AH, Bobyn JD, Tanzer M.** New femoral designs: do they influence stress shielding? *Clin Orthop Relat Res* 2006;453:64–74.

65. **Sheth NP, Melnic CM, Rozell JC, Paprosky WG.** Management of severe femoral bone loss in revision total hip arthroplasty. *Orthop Clin North Am* 2015;46:329–342, ix.

66. **Götze C, Ehrenbrink J, Ehrenbrink H.** Bleibt der Krafteinfluss der Kurzschaftprothese auf den methaphysären proximalen Femur begrenzt? Osteodensitometrische Analysen der NANOS®-Schaftendoprothese. *Z Orthop Unfall* 2010;148:398–405.

67. **Thorey F, Hoefer C, Abdi-Tabari N, Lerch M, Budde S, Windhagen H.** Clinical results of the Metha short hip stem: a perspective for younger patients? *Orthop Rev (Pavia)* 2013;5:e34.

68. **Boskey AL, Coleman R.** Critical reviews in oral biology and medicine. *J Dent Res* 2010;89:1333–1348.

69. **Venesmaa PK, Ger HPJK, Miettinen HJA, Jurvelin JS, Suomalainen OT, Alhava EM.** Monitoring of periprosthetic BMD after uncemented total hip arthroplasty with dual-energy X-ray absorptiometry: a 3-year follow-up study. *J Bone Miner Res* 2001;16:1056–1061.

70. **Hayashi S, Hashimoto S, Kanzaki N, Kuroda R, Kurosaka M.** Stem anteversion affects periprosthetic bone mineral density after total hip arthroplasty. *Hip Int* 2016;26:260–264.