CURRENT CONCEPTS REVIEW

Short Bone-Conserving Stems in Cementless Hip Arthroplasty

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- ➤ Short bone-conserving femoral stems in total hip arthroplasty were designed to preserve proximal bone stock.
- ➤ Given the distinct fixation principles and location of loading among these bone-conserving stems, a classification system is essential to compare clinical outcomes.
- ➤ Due to the low quality of currently available evidence, only a weak recommendation can be provided for clinical usage of certain stem designs, while some other designs cannot be recommended at this time.
- ➤ A high prevalence of stem malalignment, incorrect sizing, subsidence, and intraoperative fractures has been reported in a subset of these short stem designs.
- ➤ Stronger evidence, including prospective multicenter randomized trials comparing standard stems with these newer designs, is necessary before widespread use can be recommended.

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Cementless femoral fixation is now the fixation of choice for total hip arthroplasty in North America[1,2]. Despite excellent long-term results with most designs, stress-shielding and thigh pain may occur[3-6]. Short bone-conserving cementless stems have been introduced to preserve proximal bone stock and allow more physiological proximal loading[7,8]. The short prostheses available differ in geometries, design rationales, and outcomes[9,10].

Various factors influencing fixation of cementless prostheses, including metallurgy, coatings, and geometries, have been described[11]. The following classification system and outcomes summary can be used for comparing these newer stems to guide research and development.

Definition

Terms used for describing these stems include conservative, neck-sparing, short, and less invasive. As no exact definition exists, we categorized them by fixation principles and location of proximal loading. The femoral neck is often preserved, and fixation is achieved in the neck or proximal metaphysis. However, some have fixation extending below the lesser trochanter. Stem lengths range from 40 to 135 mm (see Appendix).

Classification System

There are four categories of stems: femoral neck only, calcar loading, lateral flare calcar loading, and shortened tapered

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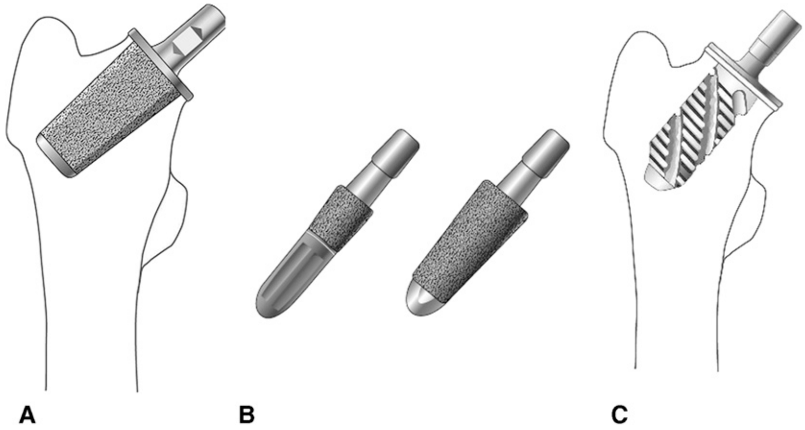

Fig. 1

Figs. 1-A, 1-B, and 1-C Type-1 stems. **Fig. 1-A** Type-1A neck-only prosthesis with a trapezoidal cross section. **Fig. 1-B** Type-1B neck-only prosthesis; the rounded stem geometry has splines for rotational stability. **Fig. 1-C** Type-1C neck-only prosthesis with threaded geometry for rotational stability.

(Figs. 1 through 4). We classified these as Types 1 through 4, with loading across the proximal part of the femur increasing sequentially. Types 1 and 2 were further subdivided by cross-sectional geometry.

Type 1: Femoral Neck Only

Type-1 stems have only femoral neck fixation. While the distal tip may extend beyond the intertrochanteric line, no fixation is achieved laterally. Primary stability occurs through cancellous

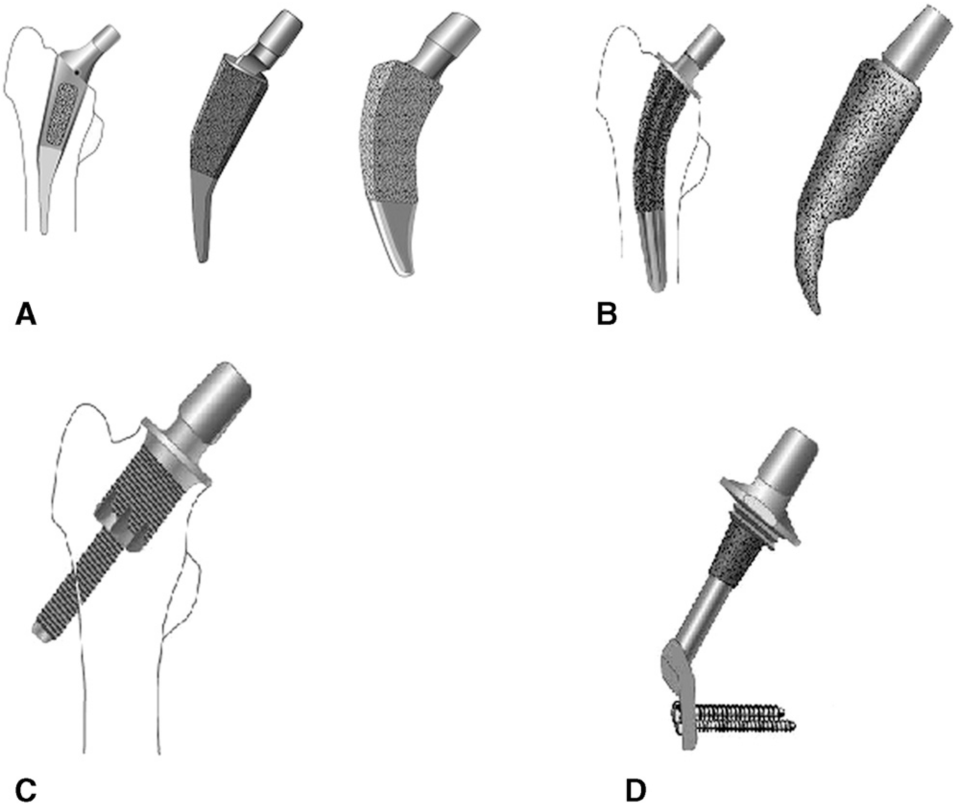

Fig. 2

Figs. 2-A through 2-D Type-2 stems are calcar-loading designs. **Fig. 2-A** Type-2A calcar-loading prosthesis with a trapezoidal cross section and wedge-tapered design. **Fig. 2-B** Type-2B calcar-loading stem with a rounded cross section and neck-preserving design. Ribs provide rotational stability. **Fig. 2-C** Type-2C neck-preserving stem with threaded geometry that passes through the lateral cortex for fixation and load sharing. **Fig. 2-D** Type-2D thrust plate design with primary fixation through the press-fit of the thrust plate in the femoral neck and compression achieved through the bolt that passes from the lateral cortex.

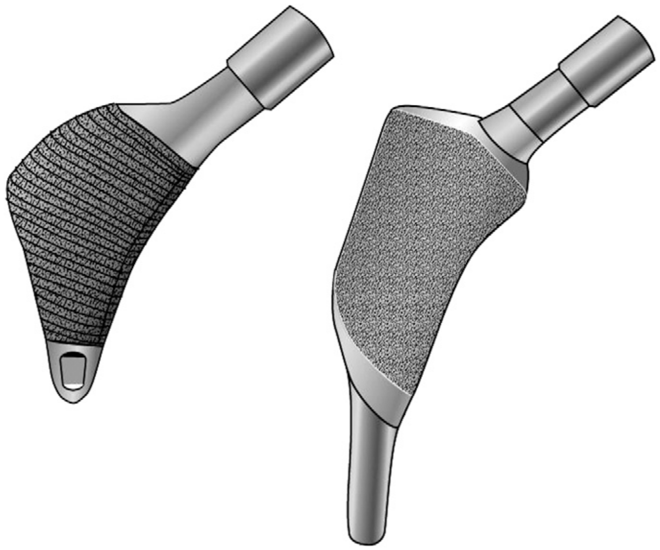

Fig. 3
Type-3 stems with a lateral flare design. The pronounced lateral flare is for enhanced fixation and load distribution.

bone compression[12-19]. These designs are subclassified by geometric shape: wedge, cylindrical, and threaded (Figs. 1-A, 1-B, and 1-C).

Type 1A (Wedge)
Type-1A implants have a wedge-shaped, trapezoidal geometry for rotational stability in the neck (Fig. 1-A). Some have a proximal collar for load distribution[8,14].

Type 1B (Cylindrical)
Cylindrical tapered stems have splines, which improve rotational stability (Fig. 1-B)[8,12-15,18]. The distal portion is narrower, and second-generation stems are shorter, to avoid distal offloading and neck stress-shielding. Some Type-1B designs incorporate a collar[8].

Type 1C (Threaded)
Type-1C implants are self-cutting, threaded, cylindrical designs (Fig. 1-C) with or without a collar[20]. The prototype was made from corundum-blasted titanium-vanadium alloy to increase porosity.

Type 2: Calcar Loading

These stems may extend to the metadiaphysis, transferring loads and achieving fixation in the calcar and the lateral proximal femoral cortex. Principles common to Type-2 designs are neck preservation, calcar loading, and metaphyseal cancellous bone impaction[21-34]. Neck preservation improves fixation by providing resistance to axial and varus forces. More physiological stress distribution is seen on the proximal medial cortex when >50% of the neck is preserved[35]. In these designs, the distal part engages the lateral endosteum or impacted cancellous bone, enhancing load transfer and resisting varus forces. The method of lateral engagement and the level of resection may vary. Although proximal loading is enhanced, stress-shielding can occur at the greater trochanter[35,36]. There are four subtypes of calcar-loading stems based on geometry (Figs. 2-A through 2-D).

Type 2A (Trapezoidal)
Type-2A stems are collarless, trapezoidal, and double-tapered. Medially, they rest on the calcar. The curved or angulated distal end of the stem contacts the proximal lateral cortex, enhancing load transfer laterally, preventing varus tilting, and providing three-point fixation (Fig. 2-A)[22,29,30]. The stem is wedged in the sagittal and coronal plane. Multipoint cortical fixation supported by cancellous bone compaction provides the primary stability. Modifications include variations in cross-sectional shape, neck-resection levels, and circumferential coating[37,38].

Type 2B (Rounded)
Type-2B stems have an oval shape and can have longitudinal ribs that resist torsional forces (Fig. 2-B)[25,28-31,39]. The middle to distal part of the stem is held by impacted bone, and the rounded tip can extend to the metaphyseal-diaphyseal junction. Type-2B stems are neck-retaining, providing immediate triplanar stability and circumferential bone-prosthesis contact[24,40,41]. The distal third is straight or curved and may be smooth or porous. These stems are designed to contact the calcar and the lateral femoral cortex, providing primary stability and allowing uniform load transfer[39,42].

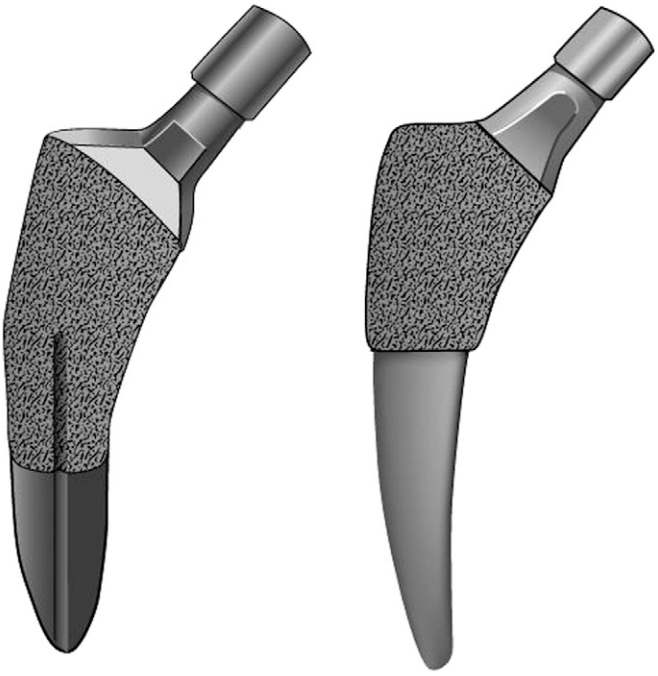

Fig. 4
The Type-4 stem is a shortened conventional design with primary fixation in the proximal femoral metaphysis.

Type 2C (Threaded)

Type-2C stems are metaphyseal loading, threaded, cylindrical designs with a collar (Fig. 2-C)[43-46]. The proximal portion engages the calcar endosteum. The distal portion has a smaller self-tapping diameter that penetrates the lateral cortex. The prototype finish was ceramic bead-blasted on all surfaces.

Type 2D (Thrust Plate)

Type-2D stems were conceived to load the femoral neck[31,33,47]. Modern designs have a collar and body connected by a bolt to a lateral plate. Compression of the bolt provides primary stability and load transfer to the neck as osseointegration occurs (Fig. 2-D)[32,33,47,48].

Type 3: Calcar Loading with Lateral Flare

Type-3 stems extend just beyond the metaphysis. With a tapered, trapezoidal geometry, and lateral flare, they achieve fixation in and transfer load to the calcar and lateral cortex[7]. The lateral flare conforms to the proximal femoral internal geometry to load the lateral aspect of the femur more physiologically (Fig. 3)[49]. This has demonstrated more effective load distribution proximally than other designs[35].

Type 4: Shortened Tapered Conventional Stems

Type-4 stems are rarely neck-preserving and often extend to the upper diaphysis. With their tapered-wedge design and proximal porous coating, they achieve fixation proximally. These are similar to conventional, proximally porous-coated tapered designs with a shorter length or reduced distal end of the stem (Fig. 4)[50-53]. Designed for proximal stress transfer, they may avoid proximal-to-distal mismatch seen with conventional designs in Dorr Type-A femora[54].

Results of Conservative Femoral Stems

Only the outcomes of studies with a mean follow-up of at least two years are reported.

Type 1A and Type 1C

Type-1A and 1C stems were in European clinical trials at the time of writing. To our knowledge, there is no study with a mean follow-up of at least two years.

Type 1B

We know of four reports with Level-IV evidence (see Appendix)[12-14,19]. In studies with the prototype design, the mean rate of survival, with revision for aseptic loosening as the end point, was 99.6% (range, 98.7% to 100%) at a mean of 2.8 years (range, 2.1 to 3.5 years)[12-14]. The mean Oxford hip score was 13.7 points; the best score reported was 12 points and the worst score was 48 points (the range of scores was not reported by Waller[19]). No dislocations, thigh pain, or intraoperative fractures were found[12-14]. There were two periprosthetic neck fractures (1.2% of 156 hips), while stress-shielding with distal spot-welding was seen in five (7.5%) of sixty-seven hips with a first-generation implant. Stem subsidence, malalignment, dislocation, incorrect stem-sizing, or neck resorption were not reported[12-14]. Waller, at a minimum follow-up of two years, reported that survival free of revision for aseptic loosening was 100% for fifteen total hip replacements with a different Type-1B stem[19].

Type 2A

Fourteen studies on three Type-2A stem designs with Level-IV evidence and one with Level-III evidence described outcomes in 1123 hips (Table I; see Appendix). The mean survival, with aseptic loosening as the end point, of the stem design reported by Wittenberg et al.[55] and others[37,38,56-58] was 99.4% (range, 98% to 100%) for 548 hips at a mean follow-up of 2.9 years (range, two to five years). Harris hip scores ranged from 90.4 to 97.6 points (mean, 94 points), while the mean prevalence of coronal stem malalignment in 326 hips with this design, from the data available, was 34% (range, 25% to 68%)[55,57]. Intraoperative fracture frequency in 390 hips in patients with this design ranged from 0% to 2.7% (mean, 1.5%), while the mean prevalence of subsidence of >2 mm in 548 hips was 4.2% (range, 0% to 14.6%)[37,38,55-58] (Table I). In one study of 250 hips, at a mean follow-up of 4.9 years, proximal stress-shielding occurred in 2.5% of the hips[55].

The mean aseptic survivorship of the stem in studies by Morrey et al.[29] and others[30,59-63], involving 503 hips in which the prototype design had been used, was 98.6% (range, 97.4% to 100%) at a mean of 5.1 years (range, 2.0 to 7.9 years) (Table I). Harris hip scores ranged between 90 and 96 points (mean, 93 points). The prevalence of coronal malalignment was 68% in forty-nine hips[61], and intraoperative fractures occurred in 4.4% (range, 0% to 7.1%) of 440 hips[29,30,60,61,63]. The prevalence of thigh pain was a mean of 1.6% (0%, 2%, and 2.7%) of 250 hips at mean of five years (range, 3.1 to 6.5 years) postoperatively[29,61,63]. The mean prevalence of proximal stress-shielding was 5.6% (range, 4.1% to 6.7%) in 238 hips at mean of 5.5 years (range, 3.1 to 6.8 years)[29,60,61]. The mean subsidence was 3% (range, 0% to 7%) in 302 hips[29,30,60-62].

Type 2B

There are twenty-four studies on Type-2B stems with Level-IV evidence (see Appendix). Kendoff et al.[64] and others[27,28,65-75] reported a mean survival rate of the stem, with aseptic loosening as the end point, of 99.3% (range, 96.6% to 100%) in 1394 hips with the prototype stem at a mean of 6.3 years (range, two to seventeen years) postoperatively (Table I; see Appendix). The mean Harris hip score for 761 hips with the data available was 93 points (range, 90 to 99 points)[28,64,68-70]. Intraoperative fractures ranged between 0% and 13.3% (mean, 2.6%) for 984 hips in nine reports. Coronal stem malalignment in 432 hips was a mean of 21.6% (range, 5.2% to 60%). In four studies involving 369 hips[68,69,72,73], the rate of stem subsidence of >2 mm ranged between 0% and 11%. The mean prevalence of improper stem-sizing described in four studies on 454 hips was 11% (range, 6.3% to 20%)[28,68,69,74]. These results underscore the fact that Type-2B stems require precise templating and accurate sizing to avoid complications. The mean prevalence of thigh pain reported in seven studies with 599 hips with data available was 2% (range, 0% to 11%)[27,28,59,69,71,72,74], and stress-shielding was 35% (range, 5.2% to 66%) for 414 hips[28,69,72,74].

In studies using a different Type-2B design[76-81], including those by Ender et al.[77,78,80] and others[76,79,81], the mean survival rate of the stem, with aseptic loosening as the end point, was

TABLE I Outcomes with Respect to the Stem Designs

Study by Stem Type	Name of Stem Design*	No. of Studies	No. of Hips	Mean Follow-up Time *(yr)*	Aseptic Survivorship of Stem†	Overall Survival†
Type 1B						
McMinn et al.[14] (2011) and others[12,13]#	BMHR	3	251	2.8	99.5	99.1
Waller[19]# (2012)	Silent Hip	1	15	2	100	NR
Type 2A						
Morrey et al.[29] (2000) and others[30,59-63]	Mayo	7	503	5.1	98.6	93.8
Wittenberg et al.[55] (2013) and others[37,38,56-58]	METHA	6	548	2.9	99.4	94.7
Ettinger et al.[23] (2011)	Nanos	1	72	5.2	99.8	97.9
Type 2B						
Kendoff et al.[64] (2013) and others[27,28,65-75]	CFP	14	1394	6.3	99.3	95.7
Ender et al.[77,78,80] and others[76,79,81-83]	CUT	8	651	5	92.9	87.7
Jerosch et al.[115]# (2012)	MiniHip	1	180	2.1	98	–
Budde et al.[116]# (2012)	Custom	1	15	3.1	93.4	86.7
Type 2C						
Carlsson et al.[44]# (2006)	GOT	1	53	3	96.3	92.5
Type 2D						
Ishaque et al.[83] (2009) and others[48,84-92,94-98]	TPP	16	1890	5.4	96.6	94
Munting et al.[93]# (1997)	Custom prosthesis	1	48	5.8	83.3	83.3
Type 3						
Kim et al.[100-103] and others[105]#	Proxima	5	595	4.2	100	99
Santori and Santori[104]# (2010)	Custom	1	129	8	100	96.2
Type 4						
Patel et al.[50,106] and others[53]#	Custom	3	294	3.7	100	98
Molli et al.[51]# (2012)	Taperloc Microplasty	1	269	2.5	99.6	98.9

*The BMHR (Birmingham Mid-Head Resection) was manufactured by DePuy; SILENT, by DePuy; the MAYO, by Zimmer; METHA, by Aesculap (Braun); NANOS, by Smith & Nephew; the CFP (Collum femoris preserving), by LINK; CUT, by Orthodynamics; MiniHip, by Corin; GOT (Gothenberg osseointegrated hip), by Astra Tech (Gothenburg, Sweden); TPP (thrust plate prosthesis), by Zimmer (Winterthur, Switzerland); Proxima, by DePuy; and Taperloc Microplasty, by Biomet. †The values are given as the mean percentage of hips. NR = not reported. ‡OHS = Oxford hip score. §PWB = partial weight-bearing, FWB = full weight- bearing, TWB = touch weight-bearing, TTWB = toe-touch weight-bearing, NWB = non-weight-bearing, and NS = not specified. #Limited data available to recommend routine use. **One report. ††Current data suggest that outcomes are inferior to standard stems. ‡‡In the studies by Kim et al.[100-102,104], the patients were instructed to use protected weight-bearing with crutches for the first six weeks and then were allowed full weight-bearing. In the study by Toth et al.[106], partial weight-bearing with crutches was recommended for four weeks postoperatively; thereafter, full weight-bearing with canes was allowed for an additional two weeks. §§In the study by Santori and Santori, patients were restricted to partial weight-bearing for the initial two postoperative weeks followed by full weight-bearing with two crutches for an additional two weeks and then a single crutch for an additional four weeks.

92.9% (range, 69.6% to 100%) in 651 hips at a mean of five years (range, three to eight years) postoperatively. Harris hip scores ranged between 85 and 98 points (mean, 92 points). The prevalence of intraoperative fractures was 0.6% (range, 0% to 2.4%), while coronal malalignment of the stem, reported in only one study involving ninety-nine hips[76], was 28%. The mean rate of subsidence of the stem of >2 mm was 3.4% (range, 0.8% to 7.7%). One study with ninety-nine hips noted a 27.3% prevalence of improper stem-sizing[76]. The mean prevalence of thigh pain in six studies was 2.9% (range, 1% to 5.1%), and proximal stress shielding, which was reported in one study involving thirty-nine hips, was 12.8%[82].

Type 2C

We know of one study on the Type-2C stem with Level-II evidence (see Appendix)[44]. A randomized controlled trial comparing the clinical outcomes for a Type-2C stem in twenty-four hips and a conventional cemented stem in twenty-nine hips found aseptic loosening or osteolysis in three (12.5%) of the twenty-four hips at the time of the three-year follow-up[44].

TABLE I (*continued*)

Mean Harris Hip Score‡	Intraop. Fracture†	Hip Dislocation†	Thigh Pain†	Stem Subsidence†	Malalignment†	Improper Sizing†	Neck Resorption†	Weight-Bearing Protocol§ (no. of studies)
92	0	0	–	–	–	–	0	PWB (3)
13.8 (OHS)	–	–	–	–	–	–	–	NS (1)
93	4.4	1.7	1.6	3	68.2**	3.3	5.6	FWB (2) and NS (5)
94	1.5	0	–	4.2††	33.7	14.6**	2.5	PWB (2), FWB (2), and NS (2)
98	0	0	2.8	NR	0	–	–	FWB (1)
93	2.6	0.8	2.0	2.9	21.6	10.9	24.6	PWB (7), TTWB (1), FWB (1), and NS (5)
92	0.57	0.83	2.8	3.4	28	27.3	12.8	NWB (3), PWB (2), FWB (2), and PWB/FWB (1)
96	–	0	–	1.7	–	–	–	NS (1)
94	0	0	–	0	0	–	–	NS (1)
98	0	1.9	–	–	–	–	4.1	PWB (1)
91	0.5	1.8	14.4	0	6.75	–	15	TWB (1), TTWB (1), PWB (3), FWB (3), NS (10)
98	–	–	0	0	–	–	–	NS (1)
90	1	1.4	0	0.2	9.5	–	–	PWB (5)‡‡
95	5.4	1.5	0	0	11	23.1	8.5	PWB (1)§§
93	0.2	3	0	0.2	5	–	14.5	FWB (3)
83	0.4	–	0	–	–	–	–	FWB (1)

Two of the revisions due to aseptic loosening occurred within two years, and a third was done for neck resorption and component fracture at one year. The remaining hips had a mean Harris hip score of 98 points (range, 80 to 100 points). None of the patients with a conventional stem had aseptic loosening.

Type 2D

There were seventeen reports on Type-2D stems in 1938 hips (two studies had Level-III evidence and fifteen had Level IV; see Appendix)[48,83-98]. At the time of follow-up between two and twelve years (mean, 5.6 years), Ishaque et al.[83,99] and others[48,83-92,94-98], using the prototype design, reported the survival rate of the stem free of revision for aseptic loosening, which was between 92.6% and 100% (mean, 96.6%) for 1890 hips with data available. The Harris hip scores ranged from 73 to 98 points (mean, 92 points). The mean prevalence of intraoperative fractures was 0.5% (range, 0% to 2.2%) for studies involving 1674 hips, while coronal malalignment was between 6% and 7.5% in two reports involving 111 hips[84,92]. In five studies involving 508 hips, resorption of the femoral neck or greater trochanter occurred in 7.5% to 21.5% (mean, 15.3%) of the hips[48,84,88,90,94], and thigh pain occurred at a mean frequency of 7% (range, 0% to 19.5%) in the 539 hips with data available[48,84,86,88,90,94].

Type 3

We identified six reports on 724 hips with two Type-3 stem designs (one study with Level-II evidence, one with Level-III evidence, and four with Level-IV evidence; see Appendix)[100-105].

At mean of 4.2 years (range, 2.2 to 5.6 years), Kim et al.[100-103] and others[105] reported a 100% rate of stem survival, with aseptic loosening as the end point, with a second-generation design. Harris hip scores ranged from 86 to 96 points (mean, 90 points). The prevalence of neck stress-shielding ranged between 50% and 100% in three of these studies. The mean prevalence of coronal plane malalignment and intraoperative fracture was 9.5% (range, 5.4% to 24.3%) and 1% (range, 0% to 2.4%), respectively, in studies involving 595 hips. The prevalence of stem subsidence of >2 mm was 0.2% (range, 0% to 0.8%). Incorrect stem sizing was not reported in any study, and the mean dislocation rate was 1.4% (range, 0% to 2.4%).

Santori and Santori, using the prototype design on 129 hips, reported 100% stem survival, with aseptic loosening as the end point, at a mean of eight years[104]. The mean Harris hip score was 95 points (range, 76 to 100 points). They reported incorrect sizing in thirty hips (23%). There was no thigh pain, which they attributed to rigid torsional and axial stability and an absence of contact between the stem tip and cortex. However, in the study by Kim et al.[102], 9% of the patients (six of seventy hips) complained of discomfort around the greater trochanter.

Type 4

There are four reports on two Type-4 stem designs, involving 563 hips (one study with Level-III evidence and three with Level-IV evidence; see Appendix)[50,51,53,106]. Three studies, using a shortened version of a standard stem, described a mean survival rate of 100%, with aseptic loosening as the end point, at a mean follow-up of 3.7 years (range, 2.7 to 5.5 years; Table I)[50,53,106]. Harris hip scores for studies involving 294 hips[50,53,106] ranged from 88 to 96 points (mean, 93 points). Thigh pain did not occur in two studies and was not reported in the third. Moreover, none of the three reports provided data about stem-sizing with this design. The prevalence of periprosthetic fractures ranged from 0% to 0.6% (mean, 0.3%) for the three studies involving 294 hips. In two studies involving 129 hips with this design[50,106], the mean prevalence of stem malalignment was 0% and 9.9%, while the mean rate of stem subsidence was 0% and 0.6%.

Molli et al.[51], using a different Type-4 design, reported a survival rate of 99.6%, with aseptic loosening as the end point, at a mean of 2.5 years (range, 0.8 to 5.2 years). The mean Harris hip score was 83 points at the time of follow-up, and an intraoperative fracture rate of 0.4% was found in this study.

Discussion

There is growing interest in bone-conserving short stems to preserve bone and provide physiologic loading to the proximal part of the femur[107]. This may reduce stress-shielding, although migration and fracture may result if loading becomes excessive[77,108].

Clinical outcomes for these newer stems have not been thoroughly defined. Comparison with well-performing conventional stems is necessary prior to routine use of this technology. We classified these stems on the basis of fixation principles and location of proximal femoral loading and further subcategorized them by geometry. The goal was to have a basis for comparison. Because of subtle variations in coatings, materials, and geometries, even stems within a particular subtype may have dissimilar outcomes. Although no data exist to suggest superiority, low-level evidence at short to mid-term outcomes for designs used by Morrey et al.[29], Wittenberg et al.[55], and Kendoff et al.[64] has shown survivorship comparable with that of conventional stems (Table I).

We identified 142 clinical and nonclinical studies on twenty-five stems (see Appendix). There is a paucity of studies with Level-I and Level-II evidence and a lack of long-term follow-up. Of the seventy studies describing outcomes with a mean follow-up of at least two years, sixty-three studies were Level IV; five, Level III; and two, Level II. For the remaining seventy-two studies that were not included in our analysis, most authors reported only short or mid-term follow-up data with small sample sizes and no controls, and data on many variables were not available uniformly.

The patient groups in the reports in the present study were young, with a mean age of fifty-three years (range, thirty-six to seventy-nine years). This may reflect the desire of the surgeons to conserve bone in younger individuals and may underestimate the risk of complications, such as fracture and subsidence, among elderly patients with osteopenia. Although these stems are used for various underlying diagnoses, most authors have refrained from using them in patients with marked proximal femoral deformity or high-grade dysplasia. The three common diagnoses were osteoarthritis (51%), osteonecrosis (26%), and hip dysplasia (11%) (see Appendix). Additional data are needed before these stems can be recommended for routine use.

These designs require technical expertise and are less forgiving than standard stems for implant malalignment, sizing, and neck resection. However, of seventy studies, only fourteen described preoperative templating in their protocols, without providing details. Seven of these fourteen templating studies were on Type-2B stem designs. We found only two studies on the accuracy of templating, both for Type-2A stems[109,110]. Schmidutz et al. found no differences in the templating accuracy for short stems compared with conventional stems ($p = 0.76$)[109]. Wedemeyer et al. reported a strong correlation between the templated and intraoperative measurements and a weak correlation with the offset, neck-shaft angle, and leg-length correction[110]. Further evidence is needed on the accuracy of sizing with the various designs.

Broaching techniques with these designs are technically more demanding, which can explain the higher prevalence of malalignment. This also increases the risk of intraoperative fractures and stem subsidence. Variable subsidence and stress-shielding rates among the different designs underscore that stress-loading in the proximal part of the femur differs with stem design, length, and geometry. Studies evaluating the role of preoperative templating and intraoperative imaging are needed in the future.

Despite potential improvement in proximal loading, stress-shielding in the calcar and greater trochanter remains a problem at short to intermediate-term follow-up for most designs[111-113]. Zeh et al. studied twenty-five hips in twenty-five patients with Type-2A designs and found decreased density in the Gruen zones 1 (15%), 2 (5%), and 7 (12%) at one year[111]. Lazarinis et al. studied twenty-seven patients with a Type-2B stem and reported significant bone loss in the Gruen zones 2 (13%), 6 (19%), and 7 (31%) at one year ($p < 0.001$)[112].

How the extent and type of surface coatings affect the clinical outcomes of various designs remains unknown. Intuitively, with neck-only designs having a limited area for bone

TABLE II Grades of Recommendation*

Grade	Description
A	Good evidence (Level-I studies with consistent findings) for or against recommending intervention.
B	Fair evidence (Level-II or III studies with consistent findings) for or against recommending intervention.
C	Conflicting or poor-quality evidence (Level-IV or V studies) not allowing a recommendation for or against intervention.
I	There is insufficient evidence to make a recommendation.

*Adapted from Wright et al.[114].

contact, circumferential coating throughout the length of the stem is warranted. Full-length coating may not be necessary for other types. Level-IV evidence has suggested that grit-blasted porous-coated stems with fiber-mesh pads or stems with a dual coat of microporous titanium with hydroxyapatite or calcium phosphate may have better survivorship at approximately three to six years of follow-up[27-29,38,55-58,64-75,103]. However, definite conclusions about the optimal coatings cannot be made.

In forty-eight studies describing postoperative protocols, 52% noted that patients were allowed partial weight-bearing postoperatively. Full weight-bearing was allowed for only 31% of the studies (Table I). However, all four studies on Type-4 stems indicated that the patients were allowed full weight-bearing postoperatively.

Two prosthetic designs reported by Ender et al. and others[76-83] (a Type-2B design with a macroporous metal surface) and by Ishaque et al. and others[48,83-92,94-98] (a Type-2D thrust plate design) showed a lower mean survival rate free of revision for aseptic loosening (93% and 97%, respectively) and a higher mean prevalence of thigh pain (3% and 7%) compared with the designs reported by Morrey et al.[29] and others[59-62] (Type-2A) and Kendoff et al.[64] and others[27,28,65-75] (a Type-2B design) (98.6% and 99.3% survivorship with aseptic loosening as the end point) at an intermediate-term follow-up of five to seven years (Table I). Despite better aseptic survivorship of the stem with these latter designs, the high mean prevalences of stem subsidence (3% and 3%, respectively), coronal malalignment (68% and 22%), and intraoperative periprosthetic fractures (4.4% and 2.6%) are concerning. Thigh pain was noted to occur with stem designs used by Ishaque et al.[83] and Ender et al.[80]. This may be secondary to less physiological stress transfer to the proximal part of the femur than commonly believed.

The Type-3 designs used by Kim et al.[100-103] had a mean 9.5% rate of coronal malalignment and a mean 1% prevalence of intraoperative fractures, with the majority being calcar fractures, which also raises concern. The lowest prevalences of periprosthetic fractures were those for Type-4 stems (mean, 0.2%; range, 0% to 0.6%)[48,83-92,94-98]. Data on stress-shielding is equivocal and was not consistently reported. Additional studies are needed to assess the effect of stress-shielding and stem malposition on functional outcomes for these designs.

For stem Types 1A, 1B, and 1C; the Type-2A stem designs reported by Ettinger et al.[23]; Type 2C; Type 3; and Type 4, there is insufficient evidence to recommend routine use (Tables II and III)[114]. Moreover, less optimal functional outcomes have been reported for Type-3 stems, with three of five studies having Harris hip scores of <90 points. Braun and Sabah[56] reported 15% (seven) of forty-eight hips with stem subsidence of 2 to 10 mm, despite a survivorship of 98%, free of revision for aseptic loosening, at a mean follow-up of 2.4 years with the Type-2A stem design used by Wittenberg et al.[55] and others[37,38,55-58]. A weak recommendation can be provided for this design because of conflicting evidence in the literature. Moreover, only a weak recommendation for use can be provided for stem designs used by Morrey et al.[29] and by Kendoff et al.[64] because of poor-quality evidence (Table III)[114]. Nevertheless, excluding stem designs with no more than five studies

TABLE III Recommendations for Use of Short Bone-Conserving Designs

Grade*	Recommendation
I	For Types-1A, 1B, and 1C; Type-2A designs used by Ettinger et al.[23]; Type-2C designs; and Types 3 and 4, there is lack of evidence to recommended routine use at present.
C	For the Type-2A design used by Wittenberg et al.[55], because of conflicting evidence in literature, only a weak recommendation can be made for its use.
C	For the Type-2A design used by Morrey et al.[29] and others[30,59-63] and the Type-2B design used by Kendoff et al.[64] and others[27,28,65-75], a weak recommendation can be made for its use.
C	For Type-2D stems used by Ishaque et al.[83] and others[48,83-92,94-98], there is weak recommendation against use at present.

*Grades are based on the system described by Wright et al.[114].

and <500 patients, it appears that stems used by Morrey et al.[29], Wittenberg et al.[55], and Kendoff et al.[64] have a better rate of survival free of revision for aseptic loosening compared with others. These stems may be preferable in situations in which preexisting implants preclude the use of conventional femoral stems. However, the potential risks of intraoperative fractures, malalignment, and improper sizing need to be considered.

These designs are often marketed for minimally invasive surgery. However, only six of seventy studies described the use of these techniques. No substantial differences were seen in the dislocation rates compared with standard stems. Little data exist on the outcomes of revision of short stems; each will pose distinct challenges, given differences in the type and location of fixation.

Although short bone-conserving stem designs are conceptually appealing, concerns for stem subsidence, malalignment, intraoperative fractures, and lack of intermediate to long-term data should deter universal adoption of these stems in total hip arthroplasty until further high-level evidence and longer follow-up are available. Nevertheless, short to intermediate-term data suggest that continued research with some of these designs is worthwhile. Encouraging outcomes with certain designs must be evaluated in the context of commercial funding and conflicts of interests. Currently, only two randomized controlled studies have compared the outcomes of standard stem and short stem designs: one with a Type-2C design, which is no longer available, and the other with a Type-3 stem[43,102]. Well-designed trials should aim for a thorough comparison of radiographic results, complication and survival rates, as well as quality-of-life assessments.

Appendix

eA Tables showing various short stem and conservative implants currently marketed or in clinical trials; demographics and complications associated with stem types 1B, 2, 3, and 4; the design, approach, conflict of interest, funding and survivorship free of revision for aseptic loosening of stem types 1B, 2A, 2B, 2C, 2D, 3, and 4; and the distribution of diagnosis and weight-bearing protocols in studies on stem types 1B, 2A, 2B, 2C, 2D, 3, and 4 are available with the online version of this article as a data supplement at jbjs.org. ■

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