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Effect of Cavity Preparation and Bone Mineral Density on Bone-Interface Densification and Bone-Implant Contact During Press-Fit Implantation of Hip Stems

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Running title: Effects on Contact in THA

Author contribution statement: JB and PMH planned the presented study and performed the measurements. JB processed the experimental data, performed the analysis and wrote the manuscript. FL performed the surgery. AK and KP contributed to provide the specimens and to carry out the study. GMC and MMM aided interpreting the results and revised the manuscript. GMC supervised the project.

Abstract

Implant loosening and periprosthetic fracture are two major revision causes for uncemented hip stems. The chosen method of cavity preparation could play a key role for both failure mechanisms. The aim of this study was to determine the dependence of the broach type as well as patient bone mineral density (BMD) on densification and contact conditions at the bone-implant interface. Hip stems were implanted into cadaveric femora using compaction, blunt extraction or sharp extraction broaches with computed tomography scans performed prior to broaching, after broaching and after stem implantation. Proximal periprosthetic bone densification as well as press-fit, contact area and stem seating relative to the last broach were determined. Median bone densification was higher with the compaction and blunt extraction broaches compared to sharp extraction broaches (181 % and 177 %, respectively, $p=0.002$). The bone densification of femora prepared with compaction broaching increased with higher BMD ($R^2=0.185$, $p=0.036$), while stem seating decreased with higher BMD for all broach types ($R^2=0.259$, $p=0.001$). Incomplete seated prostheses were associated with smaller press-fit and bone-implant contact area ($R^2=0.249$, $p=0.001$; $R^2=0.287$, $p<0.001$). **Clinical Significance:** The results suggest that compaction broaching maximizes bone densification in patients with higher bone density. However, there appears to be an increased risk of insufficient stem seating in high-density bone that could limit the benefits for primary stability. For lower quality bone, the broach type appears to play a lesser role, but care must be taken to limit extensive stem seating which might increase periprosthetic fracture risk.

Keywords

Osseodensification, femoral bone preparation, bone-implant contact, press-fit, QCT analysis

1 Introduction

The usage of uncemented femoral hip prostheses has increased worldwide, accounting for 78.4 % of implanted stems in Germany and for more than 95.6 % of implanted stems in patients under 80 years in the United States in 2016 (1–3). Stem loosening is a major reported cause for revision in uncemented hip prostheses (16.4 %) and insufficient primary stability is suspected to play an important role in the failure scenario (2). In uncemented prostheses, primary stability is achieved through an interference-fit (4, 5) and can be improved by increasing the initial bone-implant contact (6). On the other hand, when the stresses caused by the interference-fit exceed the strength of the patient's bone, a periprosthetic fracture occurs. Periprosthetic fractures are currently the cause of approximately 12 % of all revisions in Germany and 13 % of early revisions in the United States (2, 3).

The ideal primary stability is achieved by optimizing the degree of press-fit vs. the risk of periprosthetic fracture. This can be a challenge for surgeons, due to the heterogeneous bone geometry and morphology among patients (7–11). As the age range of patients undergoing total hip arthroplasty (THA) becomes broader (12–14), bone quality differs among patients substantially.

Preparation of the cavity prior to implantation of uncemented prostheses is achieved through extraction (bone is removed to form the cavity) or compaction (bone is crushed to form the cavity) broaching. Each process could affect bone-implant contact differently depending on bone quality. Osseodensification is the result of breaking the trabeculae and compacting them like an autograft in the surrounding bone tissue. This compaction of trabecular bone has been found to enhance primary implant stability by reducing micromotion at the bone-implant interface and increasing fixation strength of the implant in the initial period before osseointegration takes place (15–20). This effect might originate from the spring-back effect of compacted trabecular bone (21, 22), and could be dependent on the BMD of the patient. While bone densification around implant components for a range of BMD has not been evaluated to date, for small sections of trabecular bone of human femoral heads, Damm et al showed a trend for increased bone densification during insertion of platens with different implant surface finishes with higher initial BMD (11). Results on bone compaction by preparation broaches in metaphyseal human femora of different bone mineral densities have not been presented to date.

The aim of this study was to determine how commercially available compaction and extraction broach types influence the press-fit implantation of a hip stem in patients with different bone quality. Specifically, the effects on the bone densification at the bone-cavity-interface, as well as the press-fit achieved, the bone-implant contact area and the position of the prosthesis in femora with differing BMD were assessed.

2 Materials and Methods

2.1 Cadaveric specimens

Donors were 32-88 years old (mean=59.6±18.4 y, m/f=26/18). The femora were excised and stored frozen below -20 °C until testing. The study was approved by the Ethics Commission of the Medical Association Hamburg (PV5098).

2.2 Broach types

Three different types of broaches were investigated: compaction, blunt extraction (both Corail, DePuy Synthes, Leeds, UK) and sharp extraction broaches (Summit, DePuy Synthes, Leeds, UK) (Figure 1, Table 1). Three sub-studies were performed: two studies with paired femora using one femora of each pair for compaction broaching and the other femur for either blunt (study 1) or sharp extraction broaching (study 2; N=8/group in each study). In the third study (study 3), unpaired femora were prepared with either compaction (N=8) or sharp extraction (N=4) broaches. A similar BMD for the groups was assured (see 2.4.1 for BMD analysis).

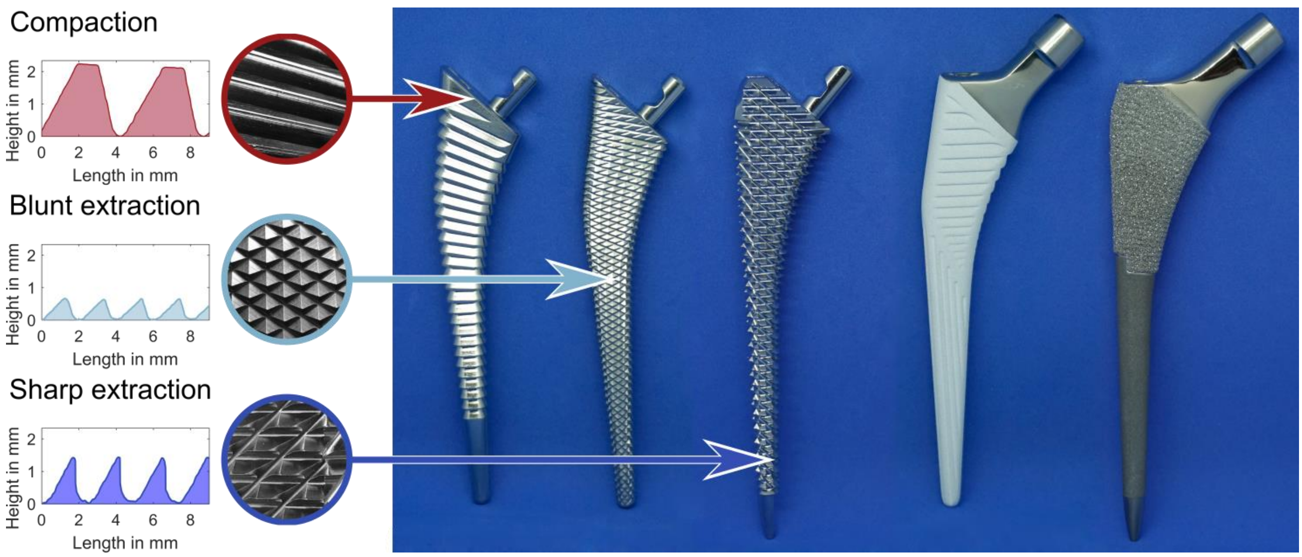

Figure 1: left: The three broach types investigated: Compaction, blunt extraction and sharp extraction (from left to right).

right: The two corresponding prostheses types: Corail and Summit (from left to right).

(All DePuy Synthes, Leeds, UK)

Table 1: Number of femora prepared with each broach type in the paired and single studies. In the paired studies, one femur in a pair was always prepared using compaction broaching whereas the other femur was prepared either with blunt or sharp extraction broaching.

	Paired	Single	Total
Compaction	16	8	24
Blunt extraction	8	-	8
Sharp extraction	8	4	12

2.3 Study setup

All femur preparations and stem implantations were performed by an experienced orthopaedic surgeon (more than 1000 THA surgeries). CT images were obtained before broaching (Philips Brilliance 16, 120kV) with a QRM Bone Density Calibration phantom (QRM GmbH, Möhrendorf, Germany) located beneath the samples. These were projected onto 2D planes (Matlab, The MathWorks, Inc., Nattick, MA, USA). The stem size for each femur was planned using digital templates (TraumaCad, Brainlab, Inc, Westchester, IL, USA). Subsequently increasing broach sizes were then used for cavity preparation and the ultimate size was determined by achieving a firmly sitting final broach. The prostheses were implanted according to the surgical instructions. QCT scans were performed after broaching with the final broach in place, after removal of the final broach and finally after stem implantation with the inserted stem, which, together with the initial scan, results in four scans. Scanning was performed with a slice thickness of 0.5 mm in studies 1 and 3 and with 1 mm in study 2.

2.4 Data analysis

All grey-value CT images were converted to BMD values [mgHA/cm^3] (Structural Insight 3, Department of Radiology, UKSH Kiel, Germany) and resampled to in-plane voxel sizes of 0.5 mm (Avizo 9.4, Thermo Fisher Scientific, Waltham, MA, USA).

2.4.1 Initial mean BMD within the proximal femur

The trabecular region within the proximal femur was segmented by wave propagation reaching the endosteal surface and eroded by 1.5 mm to exclude subcortical bone (Avizo 9.4, Thermo Fisher Scientific, Waltham, MA, USA). Each femur was then aligned to its femoral axis and the trabecular BMD of the proximal femur was evaluated within a volume ranging from the most proximal trabecular bone and extending distally to 10 mm below the lesser trochanter (23).

2.4.2 Bone densification within the proximal femur

Volumes of interest (VOIs) of the cavity following broaching were segmented using a threshold of -250 mgHA/cm³ (Avizo 9.4, Thermo Fisher Scientific, Waltham, MA, USA, Figure 2). To analyze the area in the bone adjacent to the broached cavity, the cavity VOIs were then expanded into the trabecular bone using a dilation procedure to produce 10 ring volumes of interest (rVOIs) of 0.5 mm thickness each, thereby covering the bone surrounding the cavity to a depth of 5 mm. The rVOIs reached from the calcar to 10 mm below the lesser trochanter. The bone densification analysis in the rVOIs was performed excluding areas of air cavities and osteoma-like structures. To compare the situation before broaching to the situation after broaching, the rVOIs were transferred to the pre-broach image. This was accomplished by aligning the post-broach to the pre-broach image using entropy-based registration of the non-deformed cortices. The level of bone densification was then quantified by calculating the mean BMD within the rVOIs before and after broaching (Matlab, The MathWorks, Inc., Nattick, MA, USA). With this procedure, the BMD within the rVOIs was calculated on the original, untransformed images, thereby avoiding any errors from voxel interpolation of the grey values due to the resampling after transformation.

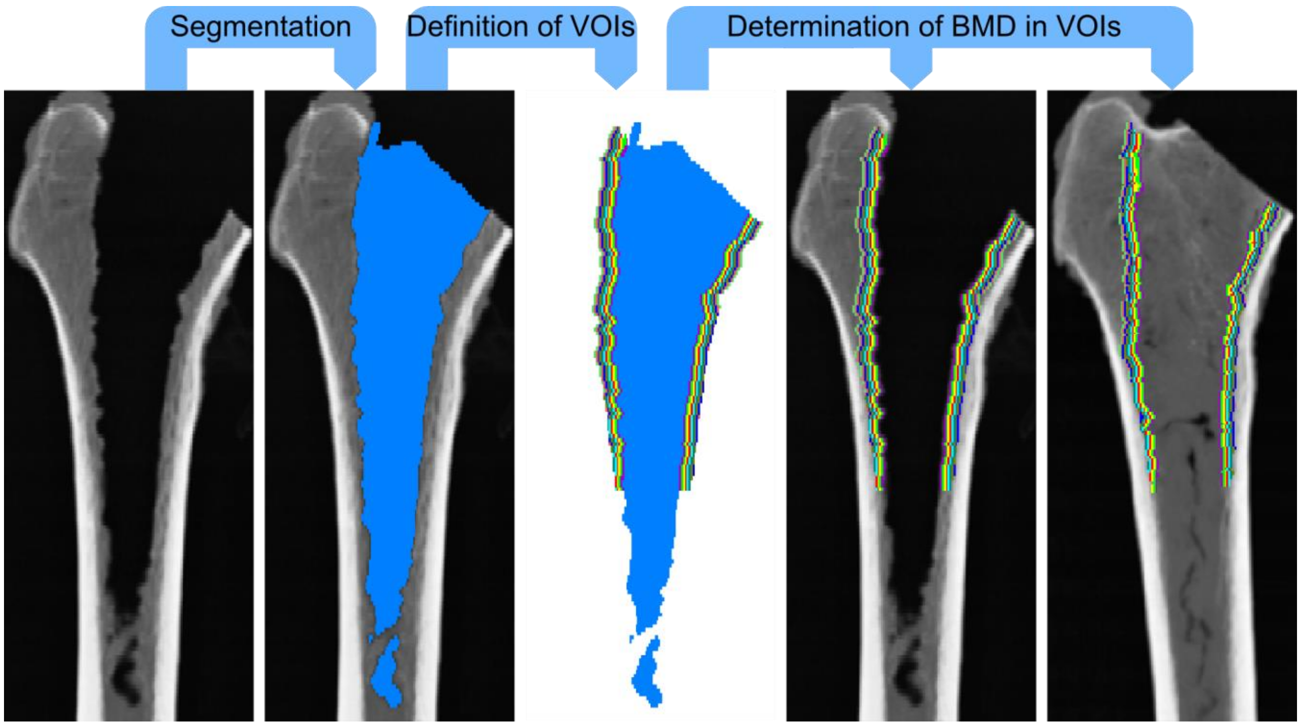

Figure 2: The steps for analyzing the densification at the bone cavity interface. From the post-broach CT, the air cavity (blue) was segmented to generate a cavity VOI. Radial rVOIs surrounding the cavity VOI and ending 10 mm below the lesser trochanter were defined and the BMD of the post-broach situation determined. The rVOIs were also transferred to the pre-broach image using image registration for the determination of the initial BMD in these regions.

2.4.3 Press-fit and contact area within the proximal femur

Due to small but significant metal artefacts from the titanium stems, the stem geometry could not be accurately depicted for calculation of stem seating, contact area and press fit from the CT images alone. Therefore, detailed surface data sets of the stems were collected with a 3D laser scanner (HandySCAN 700, Creaform, Lévis, Canada) and aligned with their respective segmented components in the CT scans using a threshold of 1500 mgHA/cm^3.

The areas of proximal bone-implant contact and proximal press-fit were determined by first aligning the image after stem insertion to the post-broach image with the segmented cavity surface by registration of the non-deformed cortices. Intersection lines of the cavity surface and the stem surface were generated, and the mesh partitioned to create two separate stem surface data sets, one for areas of press-fit and one for areas of non-contact.

The region of interest (ROI) for the contact area and press-fit analysis was defined as the surface restricted by a plane 2 mm below the femoral neck resection level, a plane 17 mm below the stem shoulder, and a plane 10 mm below the lesser trochanter. The proximal limits were set to ensure that only bone contact was analyzed and not contact with surrounding soft tissue (Figure 3). Distance maps between the stem surface and cavity surface data sets were computed. The surface triangles that cross the intersection line could not be assigned to positive or negative overlap regions and were omitted. The press-fit was calculated for stem surface points outside of the cavity volume. The contact area was defined as the percentage of the stem surface outside of the cavity volume to the total stem surface in the ROI. The distribution of contact area was assessed by comparing the contact area on the anterior or posterior respectively medial or lateral sides.

2.4.4 Position of the implanted prosthesis

The final position of the implanted stem was determined relative to the final position of the last broach. This was accomplished by either obtaining surface data sets of the last broaches after removal with a 3D laser scanner and aligning them to the segmented broach from the CT scan with a threshold of 2000 mgHA/cm^3 (studies 1 and 2) or directly utilizing the surface scan of the implanted broach (study 3). To determine the position of the final broaches relative to the implanted prostheses, the CT scans or 3D laser scans containing the positions of the broaches were aligned to the CT scans containing the implanted stems by registration of the non-deformed cortices (studies 1 and 2) or aligning the surface data of the laser scans (study 3).

Stem seating was evaluated as the distance between the top edge of the stem coating of the aligned prosthesis and the connection plane of the final broach (Figure 3). Negative values signify a protruding stem and positive values a subsided stem.

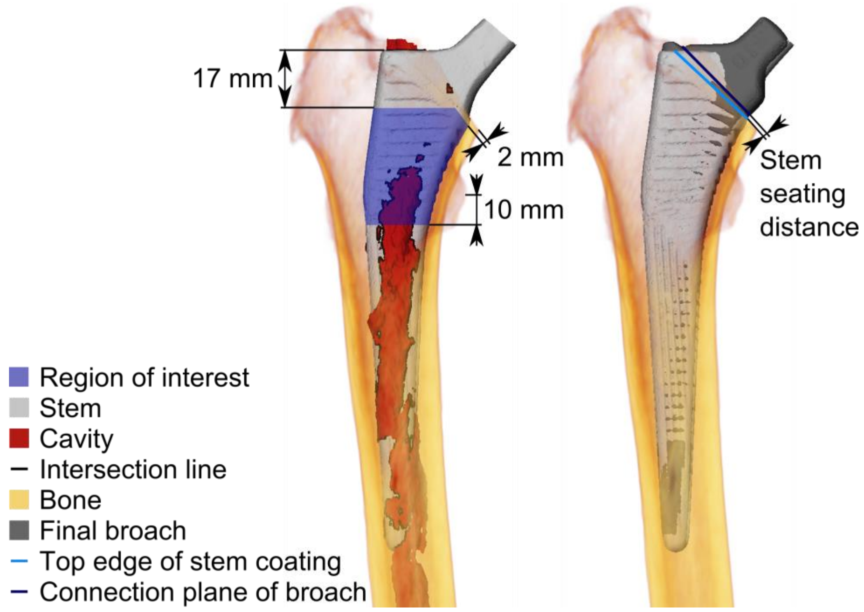

Figure 3: The region of interest for the contact area and press-fit analysis was defined between 2 mm below the neck resection level, 17 mm below the stem shoulder, and 10 mm below the lesser trochanter. The stem and cavity are depicted with their intersection line within the femur on the left (red areas indicate cavities), whereas the stem and final broach are shown on the right (light grey areas indicate areas of the prosthesis “outside” the final broach position). The stem seating distance was determined between the top edge of the stem coating and the connection plane of the final broach.

2.4.5 Statistical analysis

Statistical analysis was performed with IBM SPSS Statistics 22 (IBM Corp, Armonk, NY, USA). Spearman’s rho correlation analysis, Wilcoxon signed rank tests, Mann-Whitney U tests and Bonferroni adjustment for multiple comparisons were used. The Type I error level was set to $\alpha=0.05$.

3 Results

3.1 Influence of broach type

The initial BMD was similar between broaching groups (p=0.844; Table 2, Table 3). Bone densification showed a maximum in the rVOI at a distance of 1.5 mm from the cavity (Figure 4). Bone densification in this rVOI was significantly higher for compaction and blunt extraction broaching compared to sharp extraction broaching (p=0.001 and p=0.004, Table 3). No significant difference between compaction and blunt extraction broaching was observed (p=0.815).

Table 2: Tested femora with broach type, stem size, initial BMD and exclusion criteria for press-fit, contact area and stem seating analyses.

	Broach type	Stem size	Initial BMD [mgHA/cm³]	Exclusion criteria
Study 1	Compaction	13	184	
	Blunt extraction	13	193	
	Compaction	13	156	
	Blunt extraction	13	145	
	Compaction	10	234	
	Blunt extraction	10	228	
	Compaction	16	94	Calcar fracture
	Blunt extraction	16	108	
	Compaction	13	132	Incongruous sizing
	Blunt extraction	14	135	Incongruous sizing
	Compaction	12	141	
	Blunt extraction	12	146	
	Compaction	16	196	
	Blunt extraction	15	201	
	Compaction	18	99	
	Blunt extraction	18	96	
Study 2	Compaction	10	213	
	Sharp extraction	3	221	
	Compaction	11	211	
	Sharp extraction	3	210	
	Compaction	11	201	

	Sharp extraction	3	201	
	Compaction	11	173	
	Sharp extraction	3	167	
	Compaction	12	126	
	Sharp extraction	4	135	Calcar fracture
	Compaction	15	106	
	Sharp extraction	7	100	
	Compaction	12	87	
	Sharp extraction	4	84	
	Compaction	10	160	
	Sharp extraction	3	144	
Study 3	Compaction	11	110	
	Compaction	11	232	
	Compaction	11	119	
	Compaction	12	181	
	Compaction	13	140	
	Compaction	11	189	
	Compaction	11	143	
	Compaction	13	183	
	Sharp extraction	4	161	
	Sharp extraction	1	279	
	Sharp extraction	4	156	
	Sharp extraction	5	162	

Table 3: Initial BMD, bone densification, press-fit, contact area and stem seating for the different broach types (in median (interquartile range)). Asterisks (**) indicate significant differences (p<0.001) vs. the compaction broach, and hash (#) indicates significant differences (p<0.01) vs. the blunt extraction broach.

	Initial BMD [mgHA/cm³]	Bone densification [mgHA/cm³]	Press-fit [mm]	Contact area [%]	Stem seating [mm]
Compaction	158 (74)	47 (26)	0.71 (0.24)	42 (15)	-1.27 (2.34)
Blunt extraction	145 (84)	46 (45)	0.86 (0.51)	53 (17)	-0.49 (1.46)
Sharp extraction	161 (71)	26 (11) $^{**,\#}$	0.80 (0.34)	65 (17) $^{**,\#}$	-1.16 (1.65)

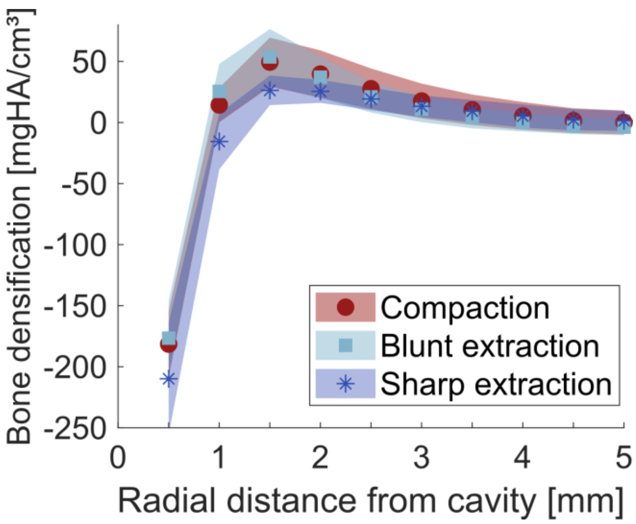

Figure 4: Bone densification in the 10 rVOI at distances of 0.5 to 5 mm from the cavity. Means and standard deviations are shown.

In two femora periprosthetic fractures occurred and in two femora the wrong stem sizes were implanted according to the final broach size used (Table 2). These femora were excluded from statistical press-fit, contact area and stem seating analyses. Press-fit as well as stem seating were similar for the three broach types (p=0.152 re. p=0.859). In contrast, contact area was higher after sharp extraction compared to compaction and blunt extraction broaching (p<0.001 re. p=0.008, Table 3). Blunt extraction broaching exhibited an increase of contact area with bone densification (R^2=0.863, p=0.003), which was not found for the other broach types (Table 4).

Table 4: Correlation between initial BMD, bone densification, press-fit, contact area and stem seating for compaction (C), blunt extraction (B) and sharp extraction (S) broach types. Results for each broach type are shown in the upper right triangle of the table, combined results for all broach types in the lower left triangle. Significant results are highlighted in bold characters.

	Initial BMD [mgHA/cm³]	Bone densification	Press-fit [mm]	Contact area [%]	Stem seating [mm]

		[mgHA/cm³]			
Initial BMD [mgHA/cm³]		**C: R^2=0.183, p=0.037** B: R^2=0.014, p=0.779 S: R^2=0.038, p=0.542	C: R^2=0.039, p=0.337 **B: R^2=0.797, p=0.007** S: R^2=0.224, p=0.142	C: R^2=0.008, p=0.699 B: R^2=0.011, p=0.819 S: R^2=0.060, p=0.467	C: R^2=0.163, p=0.062 B: R^2=0.563, p=0.052 **S: R^2=0.626, p=0.004**
Bone densification [mgHA/cm³]	R^2=0.037, p=0.212		C: R^2=0.155, p=0.070 B: R^2=0.082, p=0.535 S: R^2=0.215, p=0.151	C: R^2=0.090, p=0.175 **B: R^2=0.863, p=0.003** S: R^2=0.095, p=0.355	**C: R^2=0.222, p=0.027** B: R^2=0.005, p=0.879 S: R^2=0.132, p=0.272
Press-fit [mm]	**R^2=0.154, p=0.012**	R^2=0.060, p=0.127		**C: R^2=0.503, p<0.001** B: R^2=0.005, p=0.879 S: R^2=0.224, p=0.142	**C: R^2=0.308, p=0.007** B: R^2=0.413, p=0.119 S: R^2=0.002, p=0.894
Contact area [%]	R^2=0.008, p=0.594	R^2=0.084, p=0.070	**R^2=0.291, p<0.001**		**C: R^2=0.563, p<0.001** B: R^2=0.011, p=0.819 S: R^2=0.056, p=0.484
Stem seating [mm]	**R^2=0.259, p=0.001**	R^2=0.062, p=0.123	**R^2=0.249, p=0.001**	**R^2=0.287, p<0.001**	

3.2 Influence of initial BMD

Bone densification increased with initial BMD for compaction broaching (R^2=0.183, p=0.037, Figure 5, Table 4), but not for blunt or sharp extraction. Higher initial BMD resulted in a lower press-fit (R^2=0.154, p=0.012), especially in the blunt extraction group (R^2=0.797, p=0.007, Figure 5, Table 4), but not in the two other groups. A similar relationship was detected for stem seating (R^2=0.259, p=0.001), where the sharp extraction broach showed the highest correlation (R^2=0.626, p=0.004, Figure 5, Table 4).

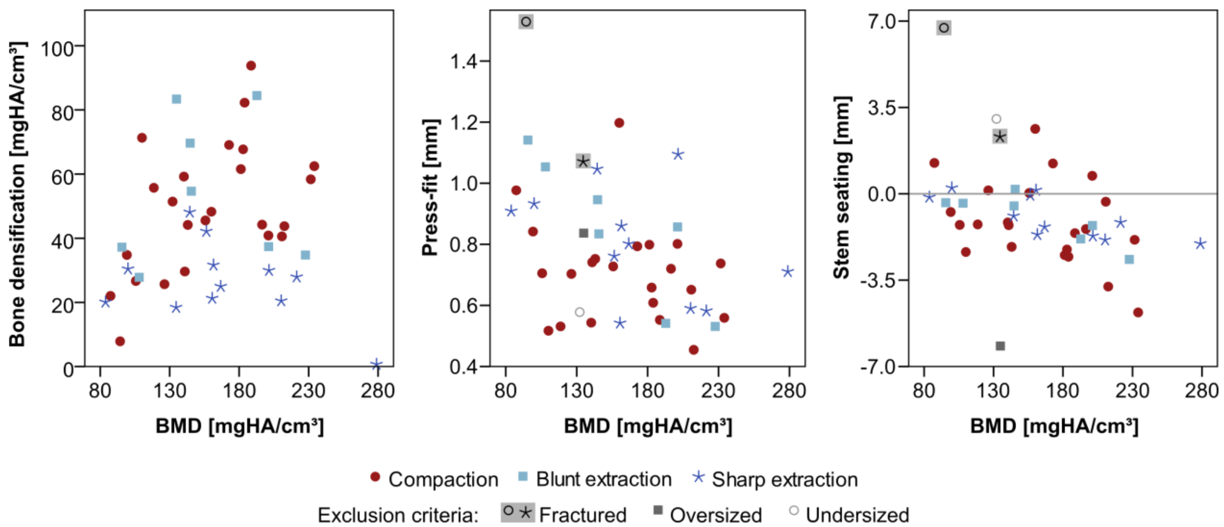

Figure 5: Bone densification, press-fit and stem seating vs. initial mean BMD. High BMD was associated with increased bone densification for compaction broaching

(R^2=0.183, p=0.037). Both, press-fit and stem seating decreased with initial BMD (R^2=0.154, p=0.012 and R^2=0.259, p=0.001). Negative stem seating values signify a protruding, positive a subsided stem. From the statistics excluded femora are depicted in grey values.

3.3 Contact parameters

The contact area increased with press-fit (R^2=0.291, p<0.001), which was pronounced for the compaction broaching group (R^2=0.503, p<0.001, Figure 6, Table 4). Press-fit increased with increased stem seating (R^2=0.249, p=0.001), particularly for compaction broaching (R^2=0.308, p=0.007, Figure 6, Table 4). A similar relationship was seen between contact area and stem seating (R^2=0.287, p<0.001), especially for the compaction broach (R^2=0.563, p<0.001, Figure 6, Table 4).

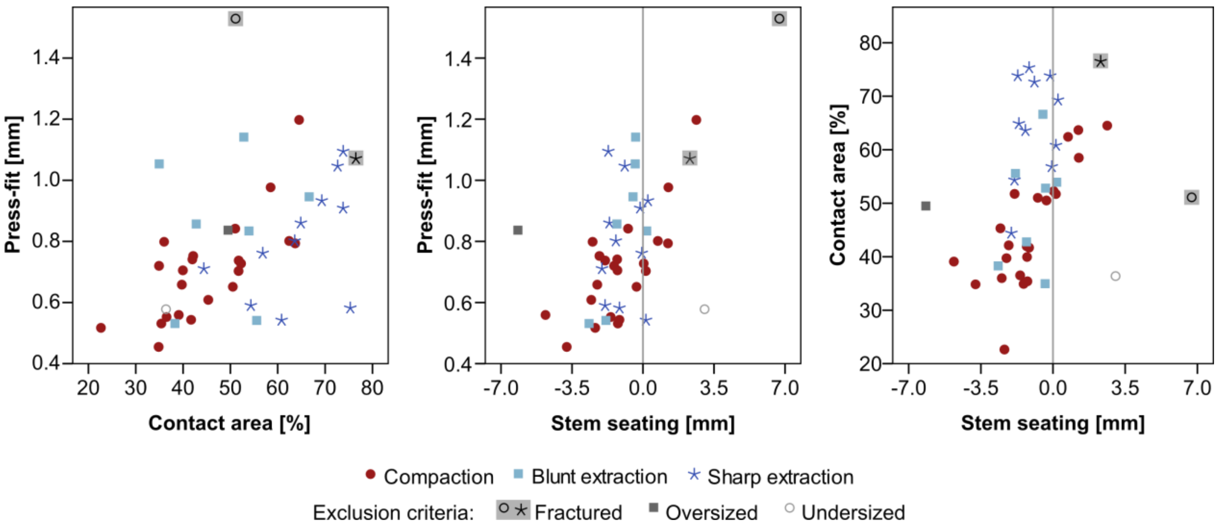

Figure 6: Relation between the contact parameters press-fit, contact area and stem seating. Negative stem seating values signify a protruding, positive a subsided stem. Press-fit increased with contact area (R^2=0.291, p<0.001) and both, press-fit and contact area increased with stem seating (R^2=0.249, p=0.001 and R^2=0.287, p<0.001). From the statistics excluded femora are depicted in grey values.

More contact area was observed on the posterior implant side (34/44 femora; 77 %) compared to the anterior side (5/44 femora; 11 %). Contact on the medial (20/44 femora; 45 %) and lateral sides (11/44 femora; 25 %) was more similarly distributed. Consequently, more bone-implant gaps were seen on the anterior side. Examples for stems with high (67 %), medium (52 %) and low (35 %) contact areas are shown in Figure 7.

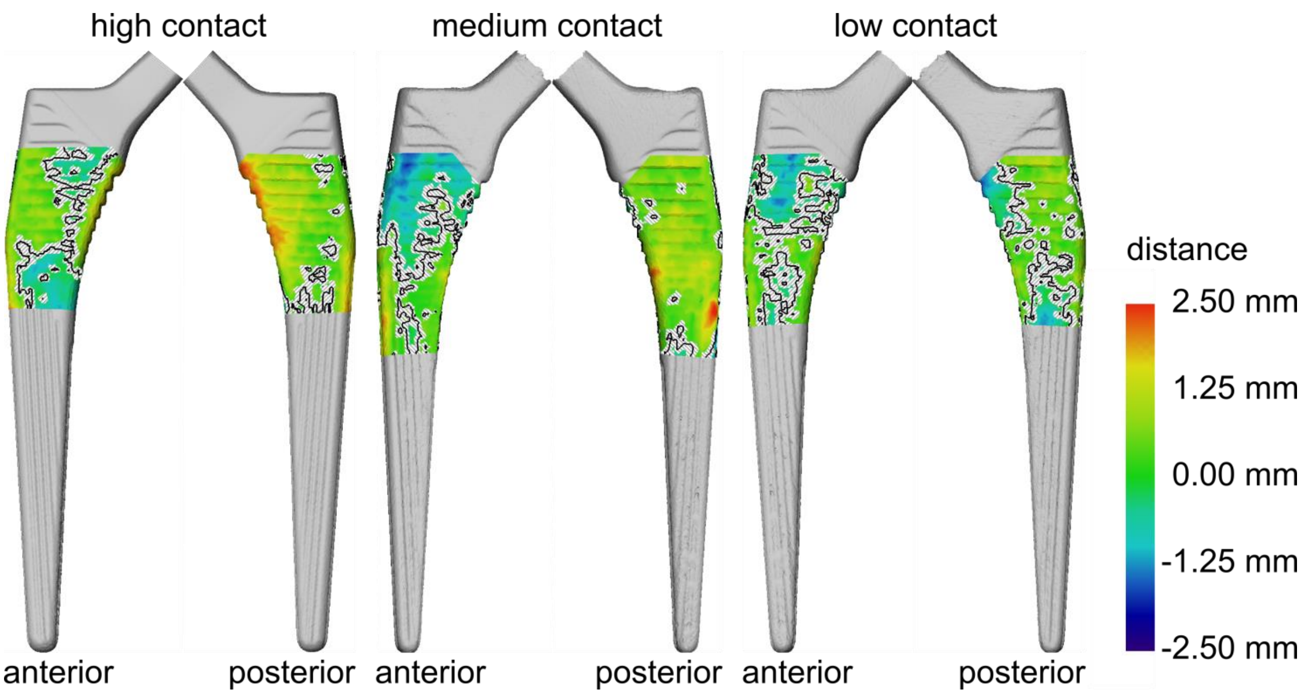

Figure 7: Contact between stem and bone (positive distance values represent press-fit, negative values no contact) exemplary shown for a high (67 %), medium (52 %) and low (35 %) contact case. The black line represents the intersection between cavity and stem surfaces, the surrounding grey shaded areas indicate non-analyzed transition zones of approximately 0 mm distance.

4 Discussion

Densification of periprosthetic bone has been shown to improve primary stability (15–20), suggesting that broach type could play an important role in implant longevity.

The results of this study support previous work suggesting that bone densification is design- and BMD-dependent (11). This is evident in the observed reduced densification with sharp extraction broaching as well as the positive association between bone densification and initial BMD with compaction broaching. In specimens with relatively low BMD typical for osteoporotic bone (less than 115 mgHA/cm³) (23), all broach types resulted in similar bone densification. For specimens with higher BMD, compaction and blunt extraction broaching increased the amount of densified bone, although not significant for blunt extraction broaching (Figure 5). Compaction and blunt extraction broaching may such increase implant stability in patients with relatively good bone quality. A negative impact on the fracture risk during broaching for patients with low bone quality is not expected since local hoop stresses are likely not increased due to minor periprosthetic bone densification. Patients with low quality bone therefore might neither profit nor suffer from preparation with densifying broaches.

The bone-implant contact area was enhanced in the sharp extraction group, suggesting that the different stem geometry for the sharp extraction broach (Summit vs. Corail system), could play a major role. The Corail stem is more rectangular shaped in the cross-section, whereas the cross-section of the Summit stem has a more elliptical shape. If a Corail stem is inserted with a slight rotational offset from the final broach, parts of the surfaces would be prevented from bone contact. This effect would be less pronounced with an elliptical transverse cross-section such as that offered by the Summit stem. The achieved contact areas for all broach types in this study are comparable to other proximal contact stems, where contact areas of 40-60% have been reported (24, 25). Contact area increased with bone densification for the blunt extraction broach only. The exact mechanism for this is not clear, but the small tooth height of the blunt extraction broaches may cause trabecular spaces to be filled up with the bone debris from broaching (26, 27). This may result in enhanced long-term stability of the prosthesis, since bone debris plays a supporting role in osseointegration (28).

Contact area was distributed roughly equally between the medial and lateral sides with more pronounced contact on the posterior vs. anterior side of the implant for both stem designs. The distinct medial and lateral contact has been previously observed by Gortchacow et al, who also found larger gaps on the anterior and posterior sides of straight stems (29). However, other groups have shown more contact on the anterior than the posterior side (30), and therefore this variable may be highly dependent on the surgeon's technique, whereas distinct medial and lateral contact is found in all studies.

High initial BMD was associated with a more protruding stem compared to the final broach, which likely resulted from increased resistance to impaction with denser bone. This effect might be enhanced after osseodensification due to more pronounced bone recoil (21, 22), although no significant relationship between densification and stem seating was observed in this study. The correlation to initial BMD explains 25.9 % of the seating variance, highlighting the influence of other factors such as implantation force and the orientation or the position of the implant in the femur. The amount of stem seating in this study is similar to other stem designs (around ±2 mm (34)).

Stem seating could have implications for periprosthetic fracture risk in patients with low bone quality. For both stem designs, press-fit and contact area were positively associated with stem seating, which is likely due to the wedge- and taper-shape geometries. As stem seating, and therefore press-fit, was highest in bones with low BMD, this could compound the heightened fracture risk in osteoporotic bone. Collared prostheses could be beneficial in patients with diminished bone quality by limiting the stem seating thereby reducing the achieved press-fit. The femora excluded from the analysis due to fracture support this: in these cases the stems seated deeply due to the low bone mineral density, resulting in high press-fits which may have caused the fractures. The oversized stem sat proud of the bone, whereas the undersized stem sank in during implantation, which resulted in values of press-fit and contact area comparable to the analyzed cohort. However, the discrepancies between the implanted stem position and the templated one would impede the restauration of the natural joint center clinically.

A limitation in this study is the sample size for the paired femora study design, which was limited by donor availability and created differences between broach types. This may have contributed to correlations not reaching significance. Another limitation involves the method to calculate the contact area. Superimposition of the cavity and implant CT scans may have underestimated the amount of contact area since axial stem insertion during implantation causes additional bone deformation and densification and may distribute bone mass further (11). Furthermore, the contact area analysis was rather conservative since surface triangles in the transition zone were not regarded as contact which excluded areas of "line-to-line" contact without overlap. The resolution of the CT scans was improved between the studies, which resulted in reduced slice thickness (from 1 mm to 0.5 mm) but limited the direct comparability between the studies. The sample size of relevant broach types was therefore extended by an additional study (study 3). However, the in-plane voxel size of 0.5 mm is maintained throughout all studies which plays an important role in densification and contact parameter analyses. Due to the limitation of the given voxel size the contact parameters were not used as an ideal measure of absolute values within this study rather to compare results of different broach types with ranging bone mineral density. The broaches differed not only in the tooth design but also in the macroscopic geometry adapted to the respective stem design. Future studies should address these influencing factors separately. This study included excised femora, which disregarded the influence of surgical access and damping of surrounding soft tissue. Within this study only one surgeon was analyzed to exclude intersurgeon variability as a factor due to a limited sample size. Future work should incorporate different surgeons and surgical approaches to give further insight in different contact distributions.

5 Conclusion

Compaction and blunt extraction broaches were both shown to densify the proximal periprosthetic bone in high BMD specimens. BMD played a major role for the contact situation between bone and implant: In femora with low BMD, the stem sat deeper, resulting in enhanced press-fit and contact area within the proximal femur but possibly increasing risk of periprosthetic fracture. The choice of the broach type and the positioning of the stem play an important role for the bone-implant contact situation and its implication for primary stability. In bone with high BMD, the ideal implant position was not reached. This could result in an increased risk of implant loosening. The results apply predominantly to the specific broach and stem types investigated. Other designs following similar broaching and implantation philosophies most likely will lead to comparable findings.

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