The cemented optimys stem: A computational study of line-to-line and undersized stems with experimental verification

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Introduction

The optimys short stem has been introduced to be an alternative to conventional total hip arthroplasty stems, with the aim to preserve the proximal bone stock (Figure 1). At present the short stem is advised only for patients with good bone quality [1].

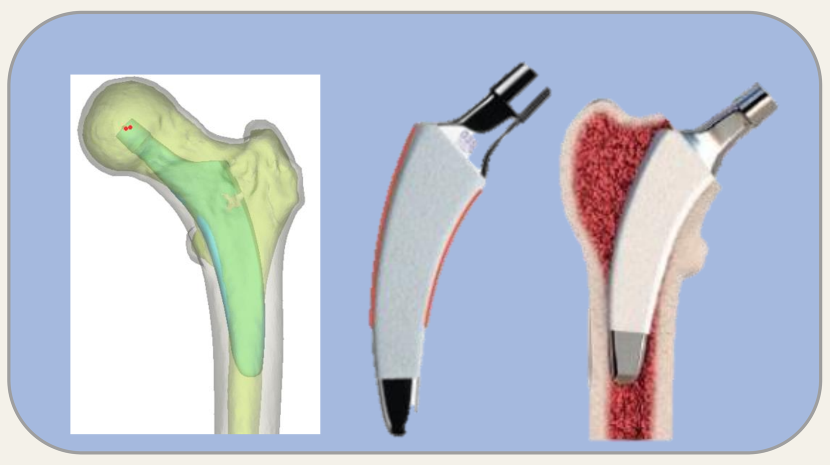

Figure 1 Optimys short stem

The clinical application of this specific design could be enlarged when a cemented version would be available which could be placed in patients with less good bone quality. Two strategies to cement a femoral hip implant are being used (Figure 2):

- Cementing a stem that is equal in size as the largest broach that fits the femoral canal ("Line-to-Line"). This results in a thin but significant cement mantle that corresponds mainly to the cement pressurized in the cancellous bone.
- Cementing a stem that is smaller ("undersized") than the largest broach. This results in a thicker cement mantle composed of a pure cement layer and a layer of cement pressurized into the cancellous bone [2].

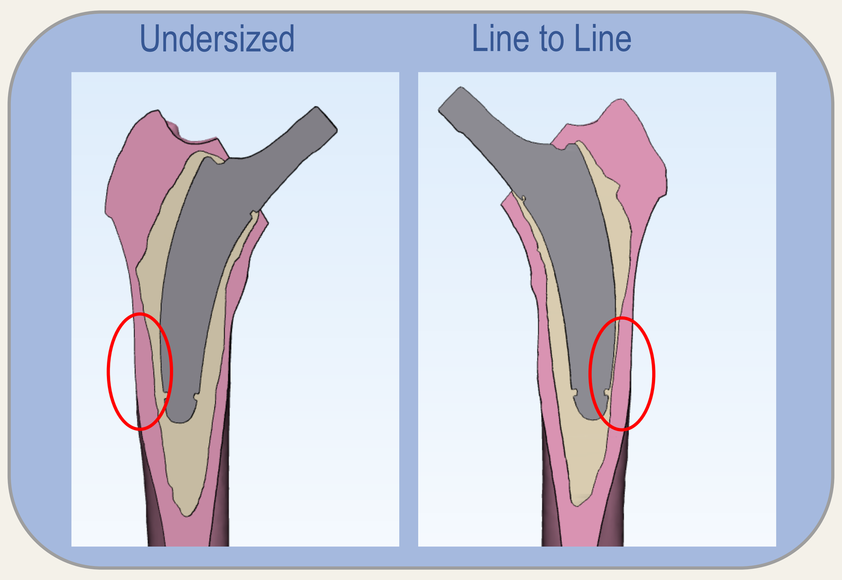

Figure 2 Schematic of the two cementing techniques

Aim of the study

The aim of this study was to evaluate the feasibility of a cemented optimys stem under physiological loading [3] and to evaluate potential mechanical differences between the two cementing strategies, known as "Line-to-Line" and "Undersized" technique.

Methods

Specimen preparation and medical imaging (step 1)

Eight (four pairs) human fresh frozen cadaveric femoral bones were obtained from the Anatomy lab Brussels University Hospital (UZ Brussels). Two bones of each pair were implanted with the calcar-guided short stem (Optmys, Mathys Ltd, Bettlach, Switzerland) using the two cementing techniques (Figure 3). Information on the specimens and implantation process is shown in Table 1. CT-scans of all 8 specimens were performed (Figure 4).

Table 1 Data on specimens and implantation

Bone	Side	Age	Gender	Weight (Kg)	Final rasp size	Implant size	Cementing concept
1	Left	78	Female	53.50	3	3	Line-to-Line
	Right				3	2	Undersized
2	Left	67	Female	52.70	6	5	Undersized
	Right				6	6	Line-to-Line
3	Left	79	Female	57.80	8	8	Line-to-Line
	Right				8	7	Undersized
4	Left	70	Male	47.30	5	4	Undersized
	Right				5	5	Line-to-Line

Figure 3 Implantation process

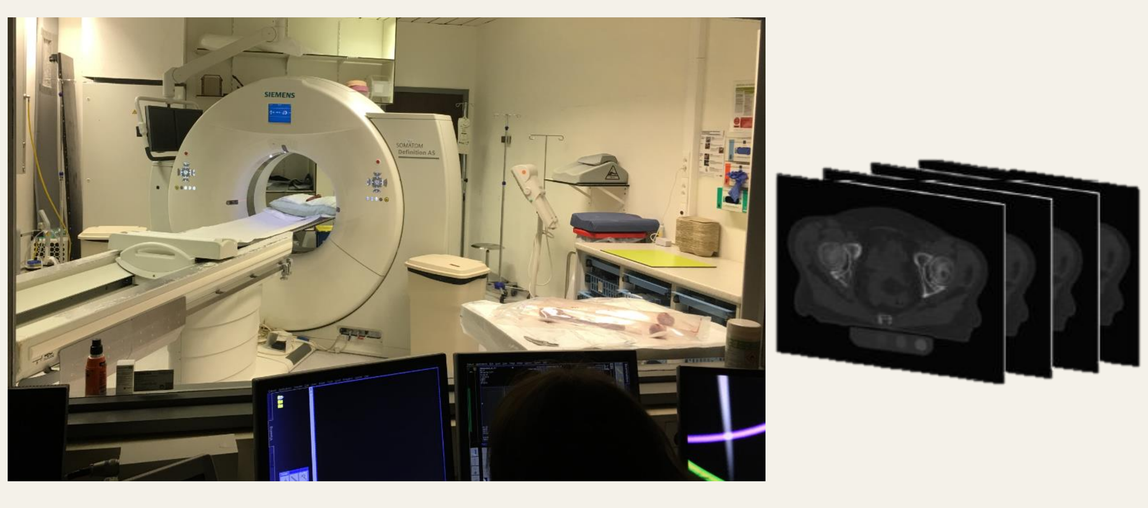

Figure 4 Performing CT-Scans

Implementing mechanical tests (step 2)

Specimen Preparation

Soft tissues were removed from eight fresh-frozen proximal cadaver femora and a random speckle pattern was applied on the anterior aspect of each femur that could be used for tracking displacements of the speckles during mechanical testing (Figure 5).

Figure 5 Specimen preparation

Mechanical Testing

Mechanical loading was applied until macroscopic failure of each specimen. The mechanical tests were force-driven at a speed of 10 N/s. Prior to the test, a preload of 50 N, followed by 20 sinusoidal preconditioning cycles (50-500 N, 1 Hz) were applied to the steel cap (Figure 6). The entire experiment was recorded with two cameras. Digital image correlation (DIC) was applied on the images to reconstruct the full-field displacement response. One specimen (3R) was excluded from the validation due to the sudden failure during the experiment.

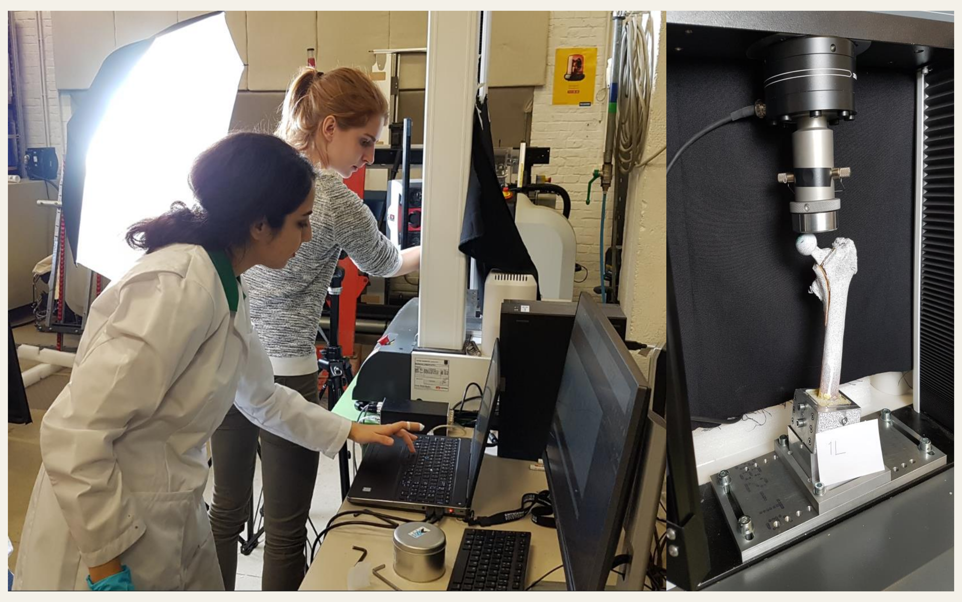

Figure 6 Mechanical testing

Performing CT-scan-based Finite Element Analysis (step 3)

Finite element (FE) analyses were performed to evaluate the mechanical behavior of the implanted femora under physiological loading. An overview of the all steps for FE analysis is shown in Figure 7. The models were validated relative to experimental mechanical tests.

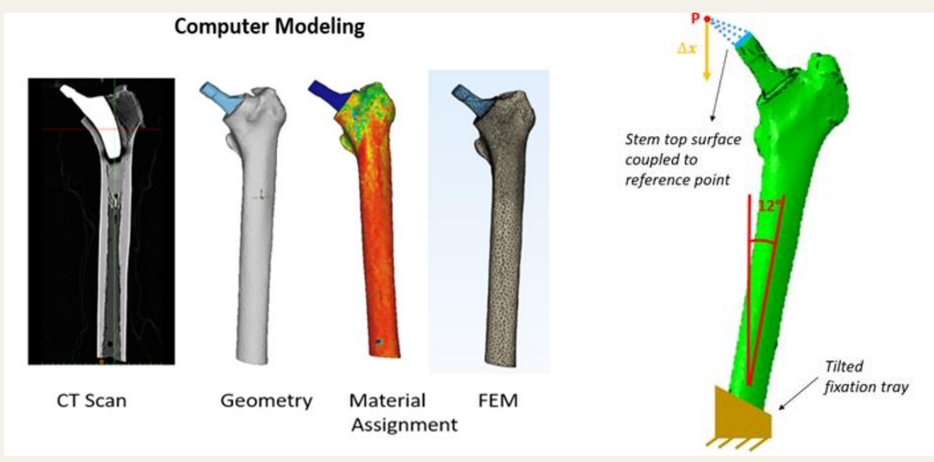

Figure 7 Finite Element Analysis

Results and Discussion

The mechanical behavior of the undersized and line-to-line stems was very similar; only small non-significant differences in stiffness (SD=4.7%, Max=7.4%, Min:1.5%) and strength (SD=6.9%, Max=12.5%, Min:1.6%) were noticed between the femora from each pair. The deformation behavior was very similar for all implanted femora. The mechanical data as obtained from the FE models replicated the experimental tests well. The validated FE models showed that bone, cement and implant can withstand daily loading conditions encountered during level walking. Volume of the bone cement and bone cement thickness are shown in Table 2 and Table 3 respectively. A visualization of the cement around the stem is shown in Figure 8.

Table 2 Volume of the bone cement for all specimens

Bone	Cementing concept	Cement volume (mm^3 ×10^3)	Bone	Cementing concept	Cement volume (mm^3 ×10^3)
1L	Line-to-Line	15.83	1R	Undersized	17.94
2R	Line-to-Line	21.46	2L	Undersized	22.67
3L	Line-to-Line	36.73	3R	Undersized	38.75
4R	Line-to-Line	24.35	4L	Undersized	24.55
Mean	**Line-to-Line**	**24.60±8.83**	**Mean**	**Undersized**	**25.98±8.96**

Table 3 Bone cement thickness for all specimens

Bone	Cementing concept	Average cement thickness (mm)	Bone	Cementing concept	Average cement thickness (mm)
1L	Line-to-Line	5.97	1R	Undersized	5.69
2R	Line-to-Line	5.64	2L	Undersized	5.41
3L	Line-to-Line	9.24	3R	Undersized	10.28
4R	Line-to-Line	8.84	4L	Undersized	9.25
Mean	**Line-to-Line**	**7.42**	**Mean**	**Undersized**	**7.66**

Undersized Line to Line

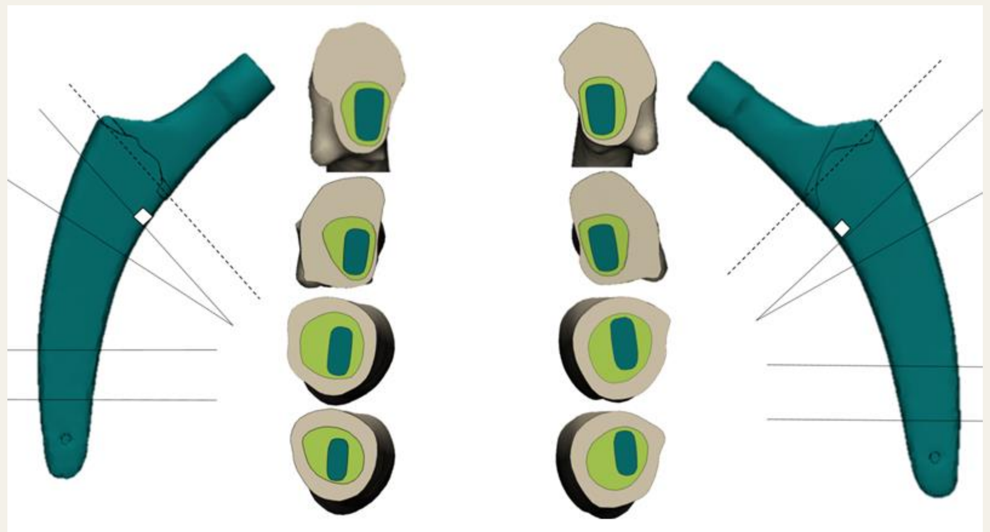

Figure 8 Cement distribution pattern

The stiffness and strength as determined from FE analysis closely matched the experimentally measured stiffness and strength (Fig. 9).

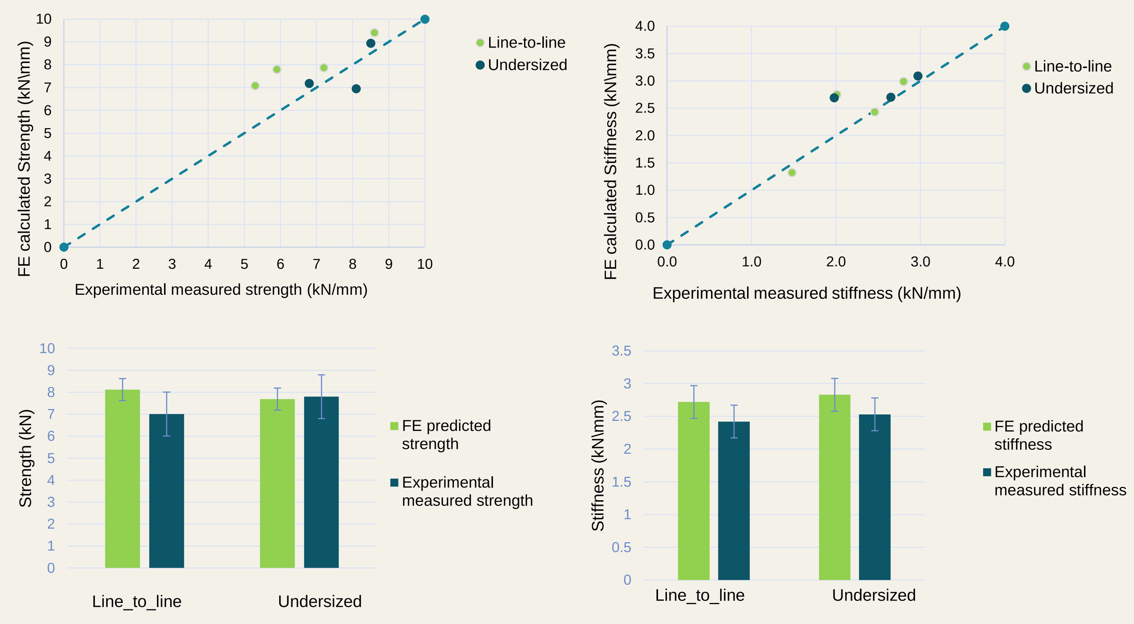

Figure 9 Scatter plots and bar charts of strength and stiffness for FE results against experimental data

An excellent agreement (for all specimens R^2 > 0.97) was found between the displacement as calculated by FE analyses and the experimentally measured displacement (using DIC) evaluated at a force of 5 kN. Ordinary least squares regression analysis between experimental and the FE calculated values was performed for all specimens, and it is shown for one specimen in Figure 10.

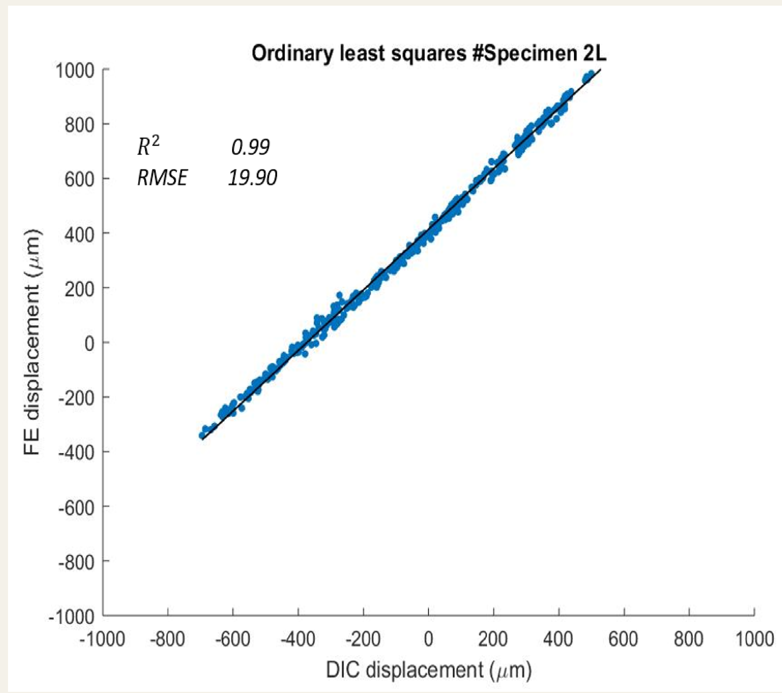

Figure 10 Regression analysis on the displacement data using DIC and FE results

After validating FE models with experimental data, simulations under physiological loading conditions were performed to resemble level walking, showing that failure of the bone and of the cement is very unlikely. The stress distributions in the cement for all specimens are shown in Figure 11.

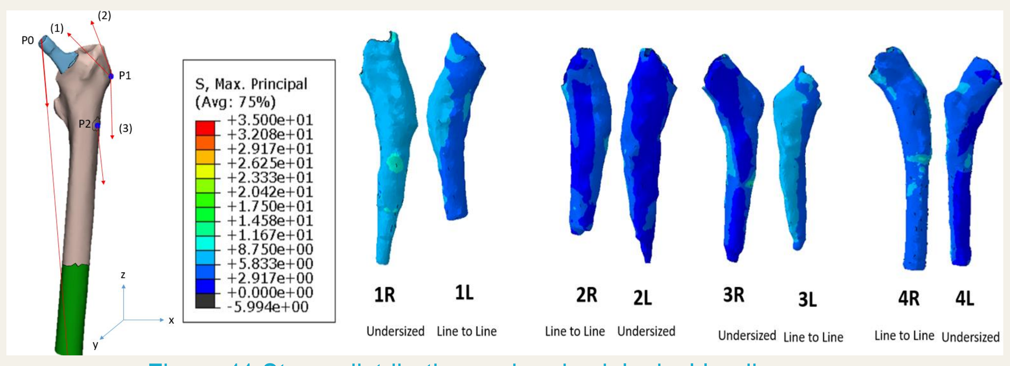

Figure 11 Stress distribution under physiological loading conditions

Conclusion

The small differences in stem size and cement volume had little effect on the mechanical behavior. Therefore, the specific cementing technique did not affect the mechanics of the construct; the behavior of the undersized and line-to-line cementing technique was very similar.

Moreover, it is very unlikely (with a safety factor equal to 3.5) that the bone cement will fail under normal physiological loading.

References

[1] Burchard et al., BMC Musculoskelet Disord, 2017. 18: 343.
[2] Scheerlinck et al., JBJS (Br), 2006. 88: 19-25.
[3] Heller et al., J Biomech, 2005. 38: 1155-63.

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