Prospective 5-year study with 96 short curved Fitmore™ hip stems shows a high incidence of cortical hypertrophy with no clinical relevance

Caroline Thalmann 1,2†, Patricia Kempter 1,2†, Karl Stoffel 1,2,3, Thea Ziswiler 1,2 and Arno Frigg 1,2,4*

Abstract

Background: An increased occurrence of cortical hypertrophy (CH) was observed 1–2 years after implanting short curved Fitmore hip stems. There are no published data about either the clinical relevance or the progression of CH over the long term.

Methods: Ninety-six primary total hip arthroplasties were performed between 2008 and 2010 using the Fitmore hip stem. Clinical and radiological parameters were recorded preoperatively and at 1, 2, 3, and 5 year follow-up.

Results: CH appeared mainly on antero-posterior radiographs in Gruen Zones 2, 3, 5, and 6. After 1 year, the diameter was 10 ± 2 mm and remained constant thereafter. The CH rate after 1 year was 69% and after 5 years 71%. Subsidence after 1 year was 1.6 ± 1.55 mm and 1.93 ± 1.72 mm after 5 years. Cortical thinning was 46% after 1 year and 56% after 5 years, mainly in Gruen Zones 7 and 8. In the first year radiolucenties were found in 51% in all Gruen Zones, and in 20% after 5 years. Patient, implant, and surgical factors did not correlate with radiological outcomes except that larger stems had more CH. After 5 years, the Harris Hip Score had improved from 59 to 94 and the Oxford Hip Score from 22 to 41. Radiographic parameters, notably CH, were not associated with clinical outcomes except that cortical thinning correlated with lower outcome scores.

Conclusions: CH correlated neither with clinical outcome nor with patient, surgical or implant factors, except for a positive correlation with stem size. The Fitmore hip stems settled within the first year to a stable fixation and then remained almost unchanged. However, cortical thinning is common in Gruen Zone 7 and 8 meaning that there is stress-shielding.

Keywords: Cortical hypertrophy, Long term, Short stem, Fitmore, Clinical relevance

Background

Cortical hypertrophy (CH) is one of several observed bone remodeling mechanisms after total hip arthroplasty (THA). It is a thickening of cortical bone in an adaptive response to altered external mechanical loads, which can cause internal stress and proximal cortical thinning in the femur [1, 2]. Initially, CH was observed around uncemented stems [2]. The intensified appearance around uncemented stems is explained by stress-shielding, a reactive proximal bone atrophy combined with distal bone hypertrophy caused by aberrant loading through distal site [3, 4]. The increased remodeling appears to be due to greater bending stiffness, which depends on stem material and cross-sectional size and shape [5, 6]. By improving the stem design, the incidence of CH in conventional long straight stems could be reduced [7–9].

To reduce proximal stress-shielding and to facilitate minimally invasive approaches, short curved stems with proximal fixation were developed [10, 11]. These stems are easier to implant through small incisions than...
conventional long straight stems [7, 10, 11]. Short stems are thought to facilitate future revision due to decreased proximal bone hypotrophy, although this is not supported by evidence [10]. To preserve more bone stock, the new short stems must bear load more proximally. To achieve this, major changes in femoral stem design were necessary that carried the risk of possible upcoming adverse effects like distal CH [12, 13].

Follow-up data after 1–2 years are available for the new short curved Fitmore hip stem [10, 16], Biomechanical tests showed the new stem to have a lower stress-shielding leading to increased physiological cortical strain, lower micromotion, and reduced migration compared to the conventional stem [14, 15]. However, 1–3 years after implantation, radiographs revealed CH around the distal part of the Fitmore hip stem (Gruen Zones 3 and 5) in 29–63% [10, 16, 17].

The significance of CH remained unclear. In the retrospective short term (1–3 years), no clinical difference was found between patients with or without CH [10, 16]. The results may have started a competition between the new short stems and the conventional straight stems that have provided good results for three decades [18, 19]. This study aims to evaluate for the first time prospectively in a cohort with a follow-up of 5 years the clinical relevance of CH after implantation of the short curved Fitmore hip stem and to assess the effect of patient, surgical, and implant factors on the occurrence of CH.

Methods

This prospective study was approved by the local Ethical Review Board and all patients have provided written informed consent. The study was carried out in accordance with the declaration of Helsinki and the applicable laws.

From April 2008 to April 2010 a total of 123 of primary THA were performed in 120 consecutive patients using the Fitmore hip stem (Zimmer Biomet, Winterthur, Switzerland, Fig. 1), a cementless, curved, solid short stem. The Fitmore cup was used in 90% and a trabecular metal modular cup was used in 10% in case of decreased bone quality or press-fit of the Fitmore cup (Zimmer Biomet, Winterthur, Switzerland) and a CoCr head. In the time period of this study, two senior surgeons at our institution generally declined minimally invasive surgery and implanted other uncemented hip stems (straight CLS stem, the standard before minimally invasive surgery) using an open approach. All patients started full weight-bearing activities with a 4-point crutch gait immediately after the operation.

Prospective evaluation

Patients were clinically documented at baseline, immediately postoperatively, and followed-up after 1, 2, 3 and 5 years with a physical examination, documentation of thigh pain, EQ-5D, Harris Hip Score (HHS), and Oxford Hip Score. Antero-posterior (AP) and axial radiographs of both hips were taken with internally rotated legs. Standardization was achieved by placing a 25-mm radiopaque gage ball between the thighs of the patient (at baseline) and by using the normalized implant head diameter according to type size (for postoperative radiographs).

Radiological evaluation

All measurements were performed using the MediCAD (Hectec, Germany) operation planning program. Parameters were assessed using the PACS-Web-Viewer program. The following parameters were measured (Table 2) [13, 20–23]: (1) cortical hypertrophy: the extent of CH was evaluated through measuring the maximal distance from the inner to the outer edge of the cortical bone at a right angle to the stem axis; (2) bone condensation: bone condensation describes the reaction of cancellous bone to stem implantation; as in cortical hypertrophy, a radiologically denser area can be observed, usually located below the tip of the stem; (3) cortical thinning; (4) radiolucency; (5) reactive lines; (6) osteolysis; (7) calcar rounding; (8) calcar resorption; (9) subsidence: the difference between the level of the shoulder of the implant and a
parallel line of the trochanteric uppermost tip in AP radiograph between the immediate postoperative and later follow-up radiographs), and (10) varus/valgus position: the angle between the axis of the stem defined as the most distal point of the stem and the midway point between stem shoulder and outer stem neck and the femur. The neutral position was defined as 0 ± 5°, higher positive values as varus and higher negative values as valgus.

**Fig. 1** Radiographs of a 50-year-old female patient with a typical course of a short femoral Fitmore hip stem. a immediately after surgery with radiolucencies at the lesser trochanter, b at 1 year postoperatively showing cortical hypertrophy in Gruen zones 3, 5 and 6, and a decrease in radiolucencies, but also cortical thinning around the lesser trochanter, c at 2 years with equal findings, d after 5 years with cortical hypertrophy, disappearance of radiolucencies, but with cortical thinning at the level of the lesser trochanter

**Statistics**
Patient parameters (age, gender, Dorr Index), implant parameters (stem type, stem size), surgical parameters (leg length difference, offset, varus/valgus), radiological parameters (Table 2), and clinical outcome parameters (Table 3) were analyzed descriptively. Mean and standard deviation are reported. The correlation between radiological and clinical outcomes was analyzed. Patient, implant, and surgical parameters were analyzed for
correlation with radiological and clinical outcome parameters. Binary outcome parameters assessed in AP and axial radiographs were collapsed into one single variable: “yes” in either AP or axial was coded as “yes,” and “no” in both AP and axial was recoded as “no.” Categorical variables were compared with a chi-square test, and continuous variables were compared with Wilcoxon rank sum test (for two groups) or Kruskal-Wallis test (for more than two groups). Kendall’s rank correlation was computed for two ordinal variables. All analyses were performed in the R programming language (version 3.3.3) [24]. The package “tableone” [25] was used for description of baseline and clinical characteristics. No correction for multiple tests was performed in this explorative study.

From the large amount of radiological data collected during 5 years of follow-up, we report only on CH, cortical thinning, and radiolucency because they are the most important parameters and because cortical thinning represents to some extent calcar rounding and osteolysis.

### Results

#### Radiographic results

The radiographic results are summarized in Table 2. CH occurred mainly on the AP radiographs in Gruen Zones 2, 3, 5, and 6 (Table 3, Fig. 1). After 1 year, the maximal diameter of CH on the medial cortex was 10.4 ± 2 mm and on the lateral cortex 9.9 ± 2 mm, which both remained constant over the course of 5 years. The rate of CH after 1 year was 69%, increasing slightly to 71% over 5 years (Table 3).

Cortical thinning was 46% after 1 year, increasing to 56% after 5 years. In the AP view, cortical thinning predominantly occurred in Gruen Zone 7 with 43%, but it was also detectable in Gruen Zones 1, 2, 6 (Table 4, Fig. 1). Cortical thinning increased over 5 years in all Gruen Zones (e.g., to 51% in Gruen Zone 7). In the axial view, cortical thinning occurred mainly in Gruen Zone 8 with 38%, but also in Gruen Zones 9 and 12–14, increasing in all zones over 5 years (e.g., to 51% in Gruen Zone 8).

Radiolucencies occurred in the first year in 51% on the AP and axial radiographs in all Gruen Zones except Zone 2, diminishing to 20% over 5 years (Table 5, Fig. 1).

Subsidence affected 77% after 1 year and this rate remained constant thereafter. Subsidence was 1.6 ± 1.55 mm after 1 year and increased gradually to 1.93 ± 1.72 mm after 5 years (Table 3). Bone condensation (98%), cortical thinning (76%), osteolysis (75%), and calcar rounding (85%) were frequent (Table 2).

### Table 1 Patient, implant, and surgical data

| Parameter                        | Value          |
|----------------------------------|----------------|
| N                                | 96             |
| Operated side (R/L)              | 54%/46%        |
| Mean age at time of operation (SD)| 62.32 ± 9.97  |
| Gender (M/F)                     | 60.4%/39.6%    |
| Dorr Index (A/B/C)               | 82.3%/17.7%/0% |
| Fitmore hip stem family (A/B/B extended/C) | 9.4%/47.9%/40.6%/2.1% |
| Leg axis [°] (Varus/Valgus)      | 94.1%/5.9%     |
| Median stem size (range)         | 7 (5–8)        |
| Mean preoperative leg-length difference [cm] (SD) | − 2.75 ± 5.08 |
| Mean postoperative leg-length difference [cm] (SD) | − 0.8 ± 6.18 |
| Mean difference between preoperative and postoperative leg-length difference [cm] (SD) | 4.13 (± 3.57) |
| Mean preoperative offset [mm] (SD) | 38.24 (± 7.73) |
| Mean postoperative offset [mm] (SD) | 40.4 (± 7.43) |
| Mean difference between preoperative and postoperative offset [mm] (SD) | 2.16 (± 7.17) |
| Varus/valgus position after surgery | 36.5%/0%/63.5% neutral |

### Table 2 Radiological parameters after 5 years

| Radiographical parameter | Value          |
|--------------------------|----------------|
| CH                       | 71%            |
| Bone condensation        | 98%            |
| Cortical thinning        | 76%            |
| Radiolucency             | 22%            |
| Reactive lines           | 17%            |
| Osteolysis               | 75%            |
| Calcar rounding          | 85%            |
| Calcar resorption        | 3%             |
| Mean subsidence [mm] (SD) | − 1.93 (± 1.72) |
### Table 3: CH and Subsidence: appearance in Gruen Zones over course of 5 years

|                         | 1 year | 2 year | 3 year | 5 year |
|-------------------------|--------|--------|--------|--------|
| **Cortical hypertrophy**|        |        |        |        |
| AP: Y/N                 | 68.8%  | 68.8%  | 69.8%  | 70.8%  |
| AP Gruen zone 1         | –      | –      | –      | –      |
| AP Gruen zone 2         | 42%    | 40%    | 42%    | 40%    |
| AP Gruen zone 3         | 58%    | 57%    | 57%    | 59%    |
| AP Gruen zone 4         | –      | –      | –      | –      |
| AP Gruen zone 5         | 43%    | 44%    | 45%    | 46%    |
| AP Gruen zone 6         | 16%    | 18%    | 18%    | 18%    |
| AP Gruen zone 7         | –      | –      | –      | –      |
| Mean medial distance [mm] (SD) | 10.42 (± 2.08) | 10.53 (± 2.09) | 10.48 (± 2.19) | 10.38 (± 2.14) |
| Mean lateral distance [mm] (SD) | 9.89 (± 2.05) | 9.92 (± 2.09) | 9.75 (± 2.01) | 9.72 (± 2.04) |
| **Axial: Y/N**           |        |        |        |        |
| Axial Gruen zone 8      | 2%     | 2%     | 2%     | 2%     |
| Axial Gruen zone 9      | 6%     | 5%     | 5%     | 5%     |
| Axial Gruen zone 10     | 2%     | 3%     | 3%     | 3%     |
| Axial Gruen zone 11     | –      | –      | –      | –      |
| Axial Gruen zone 12     | 5%     | 6%     | 5%     | 6%     |
| Axial Gruen zone 13     | 3%     | 2%     | 3%     | 3%     |
| Axial Gruen zone 14     | –      | –      | –      | –      |
| Mean ventral distance [mm] (SD) | 9.09 (± 2.51) | 9.9 (± 2.69) | 9.4 (± 2.37) | 9.55 (± 2.58) |
| Mean dorsal distance [mm] (SD) | 9.45 (± 3.53) | 9.3 (± 3.5) | 3.5 (± 3.24) | 9.55 (± 3.42) |
| **Subsidence**          |        |        |        |        |
| [mm] (SD)               | –1.62 (± 1.55) | –1.78 (± 1.6) | –1.8 (± 1.67) | –1.93 (± 1.72) |

### Table 4: Cortical Thinning: appearance in Gruen Zones over the course of 5 years

|                         | 1 year | 2 year | 3 year | 5 year |
|-------------------------|--------|--------|--------|--------|
| **Cortical thinning**   |        |        |        |        |
| AP: Y/N                 | 46%    | 52%    | 55%    | 56%    |
| AP Gruen zone 1         | 2%     | 5%     | 7%     | 7%     |
| AP Gruen zone 2         | 3%     | 5%     | 9%     | 11%    |
| AP Gruen zone 3         | –      | –      | –      | –      |
| AP Gruen zone 4         | –      | –      | –      | –      |
| AP Gruen zone 5         | –      | –      | –      | –      |
| AP Gruen zone 6         | 9%     | 14%    | 16%    | 17%    |
| AP Gruen zone 7         | 43%    | 48%    | 51%    | 51%    |
| Axial: Y/N              | 46%    | 59%    | 63%    | 70%    |
| Axial Gruen zone 8      | 14%    | 45%    | 43%    | 51%    |
| Axial Gruen zone 9      | 14%    | 24%    | 24%    | 27%    |
| Axial Gruen zone 10     | –      | –      | 5%     | 4%     |
| Axial Gruen zone 11     | –      | –      | –      | –      |
| Axial Gruen zone 12     | 4%     | 8%     | 8%     | 13%    |
| Axial Gruen zone 13     | 10%    | 18%    | 22%    | 23%    |
| Axial Gruen zone 14     | 2%     | 5%     | 5%     | 7%     |

### Table 5: Radiolucencies: appearance in Gruen Zones over the course of 5 years

|                         | 1 year | 2 year | 3 year | 5 year |
|-------------------------|--------|--------|--------|--------|
| **Radiolucencies**      |        |        |        |        |
| AP: Y/N                 | 51%    | 38%    | 28%    | 20%    |
| AP Gruen zone 1         | 41%    | 31%    | 26%    | 19%    |
| AP Gruen zone 2         | –      | 2%     | 2%     | –      |
| AP Gruen zone 3         | 13%    | 7%     | 2%     | –      |
| AP Gruen zone 4         | 17%    | 9%     | 4%     | –      |
| AP Gruen zone 5         | 16%    | 8%     | 3%     | –      |
| AP Gruen zone 6         | 10%    | 3%     | 3%     | 2%     |
| AP Gruen zone 7         | 13%    | 7%     | 55%    | 2%     |
| Axial: Y/N              | 35%    | 21%    | 17%    | 9%     |
| Axial Gruen zone 8      | 26%    | 16%    | 14%    | 9%     |
| Axial Gruen zone 9      | 4%     | 5%     | 3%     | 2%     |
| Axial Gruen zone 10     | 11%    | 8%     | 6%     | –      |
| Axial Gruen zone 11     | 9%     | 6%     | 5%     | –      |
| Axial Gruen zone 12     | 11%    | 8%     | 5%     | –      |
| Axial Gruen zone 13     | 5%     | 6%     | 4%     | 3%     |
| Axial Gruen zone 14     | 13%    | 7%     | 6%     | 6%     |
Clinical results
After 5 years, the Harris Hip Score improved from 59.2 ± 15.6 to 93.8 ± 10.25 and the Oxford Hip Score improved from 22.2 ± 8.5 to 41.02 ± 9.07. Patient satisfaction was 99% (Table 6). There were no implant failures and survival was 99%: 1 of 102 Fitmore stems showed an aseptic loosening after 18 months that was treated by removing the implant and replacing it with a straight uncemented CLS stem. Complications included 1 hip dislocation (after mobilization on the first postoperative day; treated with closed reposition; it resolved thereafter), 1 postoperative hematoma (on the 11th postoperative day; it resolved with conservative therapy), and 1 wound infection (deep infection after 7 days, treated with open debridement, irrigation, and antibiotics; it resolved completely with the implant in place). Most patients experienced no (84%) or only slight (13%) thigh pain. Similarly, most patients experienced no (72%) or at most moderate pain (27%) on the EQ5D-severity scale.

Effect of patient, implant, or surgical factors on radiological outcome
Patient parameters did not correlate with radiological outcomes, except for cortical thinning which was more frequent in females (87%) than in males (69%, \( P = 0.045 \)). Implant parameters did not correlate with radiological outcomes, except that CH was more frequent in stem sizes 9–12 (94.1%) than in stem sizes 5–8 (66.2%) or sizes 1–4 (64.3%; \( P = 0.05 \)).

Surgical parameters did not correlate with radiological outcomes. Subsidence was significantly larger when CH (median − 2 mm, IQR − 3 to − 1; \( P = 0.013 \)) was present than when it was absent (median − 1 mm; IQR − 2 to 0).

Effect of radiological parameters on clinical outcome
Radiographic parameters did not correlate with clinical outcome or pain, except for cortical thinning which showed a lower EQ5D-score (median 1, IQR 0.8–1 versus 1, 1–1; \( P = 0.014 \)), a lower Harris Hip Score (median 96, IQR 21–100 versus 100, IQR 97–100; \( P = 0.01 \)) and a lower Oxford hip score (median 45, IQR 37–48 versus 48, IQR 42–48; \( P = 0.033 \)), compared to patients without cortical thinning. However, these differences had no clinical significance or consequences. There was no difference in the clinical scores or pain subscores in patients with or without CH (EQ5D \( P = 0.988 \), Harris Hip Score \( P = 0.975 \), Oxford Severity of Pain \( P = 0.172 \)).

Discussion
This is the first prospective study analyzing clinical and radiographical parameters of a cohort of 96 Fitmore hip stems over 5 years to evaluate the rate and clinical relevance of CH and factors affecting CH. Follow-up data beyond 3 years have not been published so far [10, 16].

CH in short femoral stems
We found 71% of CH after 5 years. The literature reports 29–63% after 1–3 years for the Fitmore hip stem [10, 16]. No 5-year data are available. In contrast to the Optimys stem, another short curved femoral stem, only 4.4% of CH were found after 2 years [26]. This difference can be explained by the large proximal taper of the Optimys stem, which leads to higher primary rotation stability and increased proximal stress loading. Also, the polished tip of the Optimys stem prevents bone ingrowth and load transfer and, as a calcar guided stem, usually has no bone contact. In contrast, the Fitmore stem has a 3-point fixation allowing for bone contact at the tip, thereby causing CH.

CH in straight stems
In straight stems, CH has been found to occur in 2–10% [3, 27–30], which is much lower than in this study with the Fitmore hip stem. One reason may be that conventional straight stems better follow the bending of the bone whereas the shorter Fitmore stem acts more rigidly [15]. Another reason may be that the Fitmore hip stem primarily has three points of bone contact (calcar proximally Gruen Zone 7, lateral endostal surface Gruen Zone 2 and 3, medial tip Gruen Zone 5). After settling down with some subsidence, it has a 2-point bone contact distally with increased load transfer, whereas straight stems have a larger total bone contact surface. Therefore, the Fitmore stems have a different distribution of

| Table 6  | Descriptive statistics of clinical parameters |
|----------|---------------------------------------------|
| Clinical parameter | 98.8%/1.2% | 84.2%/12.6%/2.1%/1.1% | 71.6%/27.3%/1%/1.1% | 0.9 (± 0.16) | 93.8 (± 10.25) | 41.02 (9.07) | 56.7%/14.4%/14.4%/5.6%/8.9% |

Patient satisfaction (Y/N)
Thigh pain (none/slight/moderate/severe)
EQ5D-severity of pain (none/moderate/excessive)
Mean EQ5D score (SD)
Mean Harris Hip Score (SD)
Oxford Hip Score
Oxford-severity of pain (none/very mild/mild/moderate/severe)
CH than straight stems which also show CH in Gruen Zone 6 in addition to 2, 3 and 5 [3, 30, 31].

**Progression of CH over 5 years**
This study is the first to report on the Fitmore hip stem’s settling over time. We found that CH and subsidence remained constant over the course of 5 years and that the Fitmore hip stem subsides within the first year and changes minimally thereafter. This is in line with other stem types, where an initial remodeling is observed in the first 6–12 months with almost no further changes after 3–4 years [23, 31].

**Clinical relevance**
We found that CH affects neither the clinical outcome nor thigh pain, which is in line with other findings [27, 29, 31–33].

**Subsidence**
We found a subsidence of 1.6 mm (± 1.6) after 1 year and 1.93 mm (± 1.7) after 5 years. This is in accordance with other studies with short and long stems which reported a subsidence of 1–4 mm [34–36]. In the literature, a subsidence of less than 2–5 mm is accepted as normal [34–36]. Our subsidence of 1–2 mm could be interpreted as micromotion and as a sign of a stable implant [10, 12, 18, 23, 35–38]. Subsidence was significantly higher (≤ 2 mm) in the presence of CH than in its absence (≤ 1 mm). Our findings contrast with Cho et al. [29] who report subsidence to have been lower in hips with CH compared to hips without CH (1.5 versus 3.4 mm). We explain the increased CH in case of subsidence with the primary stability of the Fitmore stem: in case of an optimal press-fit after reaming, the stem has a 3-point fixation (proximal calcar, lateral cortex, medial tip) while if the press-fit was not optimal, the Fitmore stem subsides and locks distally with a 2-point load transfer causing CH.

**Stress-shielding**
Stress-shielding of the proximal femur has been observed in a number of conventional cementless implants used in THA [5, 30, 39, 40]. Short femoral-neck implants were originally invented to reduce interference with the biomechanics of the proximal femur [12, 41]. In theory, the Fitmore stem was designed to have a 3-point fixation to avoid proximal bone loss. However, our study shows that in reality, the Fitmore stem exhibits a distal 2-point fixation with distal load transfer and proximal stress-shielding. This explains our finding of a high rate of cortical thinning in 56% of cases after 5 years, which is in line with the literature on other short stems. With the short Mayo stem, bone mineral density had decreased significantly 2 years after surgery [12, 38, 42]. For Nanos and Mayo short stems, a bone loss of 30–69% in Gruen zones 1 and 7 was also reported [42, 43]. In summary, a substantial loss in the proximal periprosthetic bone cannot be prevented by using short curved stems because forces are distally transmitted [12]. We found lower EQ5D, Harris Hip, and Oxford Hip scores with cortical thinning. Although these differences were statistically significant, the absolute differences were small and clinically not significant after 5 years. Future research is needed to evaluate potential consequence in the long-term.

**Clinical outcome**
Maier et al. reported an HHS of 94, which equals our results [10]. We found 3.3% of moderate to severe thigh pain, which is also in agreement with the results of Maier et al. who reported 4% of thigh or hip pain [10]. Cinotti, using a short femoral stem, found thigh pain in 8% of patients after 2 years, which reduced to 3% after 9 years [34].

**Survival**
Our survival rate of 99% at 5 years and the 100% reported by Maier et al. [10] after 2 years confirm the encouraging results for the Fitmore hip stem. Patel et al. using a short custom stem found 100% survival at 5 years [44]. However, long-term studies with 10–20 years of follow-up are needed to establish whether the short stems can challenge the conventional stems.

**Limitations**
A study with novel THA-implants requires a 10-year follow-up to be conclusive. Our prospective study is still running and 10-year follow-up results will be available in a few years. Second, we have accumulated a large number of radiological parameters (Table 2) of which progression could be reported over 5 years. Because of space constraints, we have focused on the parameters reported in Tables 3, 4, and 5. The strengths of this study are the prospective design since all other publications are retrospective and that it reports with 5 years the longest follow-up [10, 16].

**Conclusions**
This is the first prospective cohort study with 96 Fitmore hip stem THA with a 5-year follow-up. We could show that CH is frequent with Fitmore hip stems but did not correlate with clinical outcome and was not influenced by factors related to patient, implant, or surgical procedure. CH occurred within the first year and then remained constant. This means that the Fitmore hip stem settles within the first year to a stable fixation and then remains almost unchanged, with constant subsidence, and with radiolucencies even disappearing over the years. However, cortical thinning was frequent in Gruen Zones 7 and 8 meaning that there is stress-shielding.
Abbreviations
AP: Antero-posterior; Ch: Cortical hypertrophy; HHS: Harris Hip Score; IQR: Interquartile range; PACS: Picture archiving system; SD: Standard deviation; THA: Total hip arthroplasty

Acknowledgements
Not applicable.

Funding
No funding was received.

Availability of data and materials
The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Authors’ contributions
CT, PK, TZ, and AF contributed to the study design; CT and KS to clinical data collection; PK, TZ, CT, and AF to radiological data collection; AF to statistical analysis; AF and PK to the writing; and CT, PK, TZ, and KS to the editing. All authors have read and approved the final manuscript.

Ethics approval and consent to participate
This study was approved by the local Ethical Review Board (KEK-NR 132-13)

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

Publisher’s Note
Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Author details
1Orthopedic Department, Kantonsspital Graubünden, Loestrasse 99, 7000 Chur, Switzerland. 2Orthopedic Department, University Hospital Basel, Spitalstrasse 21, 4031 Basel, Switzerland. 3Orthopedic Department, Kantonsspital Liestal-Rheinstrasse 26, 4410 Liestal, Switzerland. 4Private University of the Principality of Liechtenstein, Triesen, Liechtenstein.

Received: 14 November 2018 Accepted: 29 April 2019

References
1. Weinans H, Huijkes R, Van Rietbergen B, Sumner DR, Turner TM, Galante JO. Adaptive bone remodeling around bonded noncemented total hip arthroplasty: a comparison between animal experiments and computer simulation. J Orthop Res. 1993;11:500–13.
2. Teusink MJ, Callaghan KA, Kloeke NF, Goetz DD, Callaghan JJ. Femoral remodeling around Charnley total hip arthroplasty is unpredictable. Clin Orthop Relat Res. 2013;471:3838–46.
3. Schuh A, Ebert A, Holzwarth U, Zeiler G. Cementless Vektor-Titan stem in total hip arthroplasty. Biomed Tech (Berl). 2005;50:30–4.
4. Sumner DR, Turner TM, Urban RM, Galante JO. Experimental studies of bone remodeling in total hip arthroplasty. Clin Orthop Relat Res. 1992;276:83–90.
5. Sychtz CJ, Engh CA. The influence of clinical factors on periprosthetic bone remodeling. Clin Orthop Relat Res. 1996;332:285–92.
6. Glassman AH, Robyn JD, Tanzer M. New femoral design—do they influence stress shielding? Clin Orthop Relat Res. 2006;453:64–74.
7. Decking R, Puhl W, Simon U, Claes LE. Changes in strain distribution of loaded proximal femora caused by different types of cementless femoral stems. Clin Biomech. 2005;21:495–501.
8. Sumner DR. Long-term implant fixation and stress-shielding in total hip replacement. J Biomech. 2015;48:797–800.
9. Tannast M, Ecker TM, Murphy SB. Second-generation uncemented stems: excellent 5–13 year results. Arch Orthop Trauma Surg. 2009;129:1691–700.
10. Maier MW, Streit MR, Immann MM, Krüger M, Nadorf J, Kretzer JP, et al. Cortical hypertrophy with a short, curved uncemented hip stem does not have any clinical impact during early followup. BMC Musculoskelet Disord. 2015;16:1–9.
11. Molli RG, Lombardi AV Jr, Berend KR, Adams JB, Sneller MA. A short tapered stem reduces intraoperative complications in primary total hip arthroplasty. Clin Orthop Relat Res. 2012;470:60–61.
12. Lazarinis S, Mattsson P, Millbrink J, Mallmin H, Hailer NP. A prospective cohort study on the short collum femoris-preserving (CFP) stem using RSA and DXA. Acta Orthop. 2013;84(1):32–9.
13. Issa K, Stroh AD, Mont MA, Bonutti PM. Effect of bone type on clinical and radiographic outcomes of a proximally-coated cementless stem in primary total hip arthroplasties. J Orthop Res. 2014;32:1214–20.
14. Bieger R, Ignatius A, Decking R, Claes L, Reichel H, Dänelsen L. Primary stability and strain distribution of cementless hip stems as a function of implant design. Clin Biomech. 2012;27:158–64.
15. Pepke W, Nadorf J, Ewerbeck V, Streit MR, Kinkel S, Gotterbarm T, et al. Primary stability of the Fitmore stem: biomechanical comparison. Int Orthop. 2014;38:483–7.
16. Guite A. Short stems for total hip arthroplasty. Initial experience with the Fitmore stem. J Bone Joint Surg Br. 2012;94-B(Suppl A):47–51.
17. 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(1):125–30.
18. Sathappan SS, Teicher ML, Capanzi C, Yoon M, Wasserman BR, Jaffe WL. Clinical outcome of total hip arthroplasty using the normalized and proportionalized femoral stem with a minimum 20-year followup. J Arthroplasty. 2007;22(3):356–62.
19. Meding JB, Ritter MA, Keating EM, Berend ME. Twenty-year followup of an uncemented stem in primary THA. Clin Orthop Relat Res. 2015;473:543–8.
20. D’Antonio JA, Capello WN, Manley MT. Remodeling of bone around hydroxyapatite-coated femoral stems. J Bone Joint Surg. 1996;78-A(8):1126–234.
21. Gruen TA, McHeire GM, Amstutz HC. “Modes of failure” of cemented stem-type femoral components: a radiographic analysis of loosening. Clin Orthop. 1979;141:17–27.
22. Engh CA, Massin P, Suthers KE. Roentgenographic assessment of the biologic fixation of porous-surfaced femoral components. Clin Orthop. 1990;257:107–28.
23. Mulliken BD, Naya N, Bourne RB, Rosabeck CH, Bullas R. Early radiographic results comparing cemented and uncemented total hip arthroplasty. J Arthroplasty. 1996;11(1):24–32.
24. R Core Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna. https://www.R-project.org/ (2017, Accessed 1.3.2018).
25. Yoshida K and Bohn J. Tableone: create Table 1 to describe baseline characteristics. R package version 0.7.3. https://CRAN.R-project.org/package=tableone (2015, accessed 1.3.2018).
26. Kutner KP, Pfeil D, Kovačević MP, Rehbein P, Mai S, Siebert W, Pfeil J. Radiographic changes in second- and third-generation Zweymüller stems. J Bone Joint Surg. 2004;86-B:1108–14.
27. Cho YL, Chun YS, Ryu KH, Baek JH, Liang H. Distal femoral CH after hip arthroplasty using a cementless double-tapered femoral stem. J Orthop Surg. 2016;24(3):317–22.
28. Pittro RP, Schramm M, Hohmann D, Schmidt R. Clinical outcome and quantitative evaluation of periprosthetic bone-remodeling of an uncemented femoral component with taper design - a prospective study. Chir Organi Mov. 2001;8687–97.
29. Reigstad A, Rakkum M, Bye K, Brandt M. Femoral remodeling after arthroplasty of the hip. Acta Orthop Scand. 1993;64(4):411–6.
30. Katsimbas M, Katsimbas G, Lee MB, Learmonth ID. Distal femoral cortical hypertrophy: predisposing factors and their effect on clinical outcome. Hip Int. 2006;16(1):18–22.
31. Saito J, Aslam N, Tokunaga K, Schemitsch EH, Waddell JP. Bone remodeling and radiographic outcomes of a proximally-coated cementless stem in primary total hip arthroplasties. J Orthop Relat Res. 2006;451:128–33.
32. Cinotti G, Della Rocca A, Sessa P, Ripani FR, Giannicola G. Thigh pain, subsidence and survival using a short cementless femoral stem with pure metaphyseal fixation at minimum 9-year followup. Orthop Traumatol Surg Res. 2013;99:30–6.
35. Kutzner KP, Freitag T, Donner S, Kovacevic MP, Bieger R. Outcome of extensive varus and valgus stem alignment in short-stem THA: clinical and radiological analysis using EBRA-FCA. Arch Orthop Trauma Surg. 2017;137:431–9.

36. Jacobs CA, Christensen CP. Progressive subsidence of a tapered, proximally coated femoral stem in total hip arthroplasty. Int Orthop. 2009;33:917–22.

37. Kinov P, Radl R, Zacherl M, Leithner A, Windhager R. Correlation between thigh pain and radiological findings with a proximally porous-coated stem. Acta Orthop Belg. 2007;73:618–24.

38. Lerch M, Von der Haar-Tran A, Windhagen H, Behrens BA, Wefstaedt P, Stuckenborg-Colisman CM. Bone remodeling around the Metha short stem in total hip arthroplasty: a prospective dual-energy X-ray absorptiometry study. Int Orthop. 2012;36:533–8.

39. Stiehl JB. Long-term periprosthetic remodeling in THA shows structural preservation. Clin Orthop Relat Res. 2009;467:2356–61.

40. Ellison B, Cheney NA, Berend KR, Lombardi AV Jr, Mallory TH. Minimal stress shielding with a Mallory-Head titanium femoral stem with proximal porous coating in total hip arthroplasty. J Orthop Surg Res. 2009;4(2):1–10.

41. Decking R, Rokahr C, Zurstrieg M, Simon U, Decking J. Maintenance of bone mineral density after implantation of a femoral neck hip prosthesis. BMC Musculoskelet Disord. 2008;9(17):1–7.

42. Speirs AD, Heller MO, Taylor WR, Duda GN, Perka C. Influence of changes in stem positioning on femoral loading after THR using a short-stemmed hip implant. Clin Biomech. 2007;22:431–9.

43. Tiao A, Pesut T, Peacock C, Tucci M, Buckhalter RA. Bone sparing surgical options for total hip replacement. Biomed Sci Instrum. 2003;39:284–8.

44. Patel RM, Lo WM, Cayo MA, Dolan MM, Stulberg SD. Stable, dependable fixation of short-stem femoral implants at 5 years. Orthopedics. 2013;36(3):301–7.