



Avascular necrosis of the femoral head: three-dimensional measurement of drilling precision reveals high accuracy and no difference between fluoroscopically controlled core decompression and cancellous bone grafting

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Abstract

Introduction Avascular osteonecrosis of the femoral head (AVN) is a widespread disease affecting mostly young and active people, often exacerbating in progressive stages, ending in joint replacement. The most common joint preserving operative therapy for early stages is core decompression (CD), optional with cancellous bone grafting (CBG). For success it is vital that the necrotic area is hit and the sclerotic rim is broken by drilling into the defect zone to relieve intraosseous pressure. The aim of this study was to investigate if both techniques are precise enough to hit the center of the necrosis and if there is a difference in precision between drilling with small pins (CD) and the trephine (CBG).

Patients and methods 10 patients underwent CD, 12 patients CBG with conventional C-arm imaging. Postoperatively 3D MRI reconstructions of the necrotic area and the drilling channels were compared. The deviation of the drilling channel from the center of the necrotic area was measured. PROMs (HHS, HOOS, EQ-5D, SF-36) were evaluated to compare the clinical success of these procedures.

Results Neither with CD nor with CBG the defect zone was missed. The drilling precision of both procedures did not differ significantly: distance to center 3.58 mm for CD (range 0.0–14.06, SD 4.2) versus 3.91 mm for CBG (range 0.0–15.27, SD 4.7). PROMs showed no significant difference.

Conclusion Concerning the most important difference between the two procedures—the surgical higher demanding technique of CBG—we suggest applying the less invasive technique of CD alone.

Keywords Hip joint · Femoral head necrosis · Bone graft · Core decompression · Bone drilling · Precision

Introduction

Avascular osteonecrosis of the femoral head (AVN) is a progressive disease. Disturbed blood flow within the bone leads to increased intraosseous pressure, reduced intraosseous circulation, impaired nourishment of osseous structures and thereby to aseptic necrosis of the bone [1, 2]. Untreated it ends in secondary arthritis and very often in total hip

replacement (THR). In Germany the prevalence is 5000 to 7000 new cases per year, in the USA about 10,000 to 20,000 [3, 4]. Diagnosis of AVN accounts for 5 to 12 percent of THRs and is an important factor in health care systems worldwide [1, 4].

Several risk factors for reduced blood flow like traumatic conditions, steroid medication, alcohol and nicotine abuse and metabolic diseases are known [1, 5, 6]. Steroid similar to alcohol induced osteonecrosis shows an increase of fat cells and marrow fat and thus a reduction of osteogenetic cells [5]. In addition, the increased intraosseous fat content leads to elevated intraosseous pressure and thus to venous stasis, diminished blood circulation and finally ischemic necrosis [7, 8]. Nicotine abuse causes vasoconstriction and thus decreased osteogenesis, bone volume and vascular

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reactivity [6, 9]. There also seem to be various genetic disorders, connected with avascular necrosis in general and AVN in particular such as sickle cell anemia or other coagulation abnormalities, like Factor V Leiden mutation, thrombophilia or hypofibrinolysis [10].

The ARCO classification of osteonecrosis is the most common one in clinical routine. In addition to the extent of the lesion, which is described in stages I to III, there can be indicated a localization for stages II and III: A: medial, B: central and C: lateral. Grade C has the worst prognosis of these three [11, 12].

Core decompression (CD) currently is the most common operative joint preserving therapy [13–16]. The location of the necrotic area is detected with C-arm imaging. A guide pin is drilled from the proximal lateral femur, about 4 cm below the trochanteric ridge, into the lesion. In the same manner multiple drillings with small k-wires are performed in a fan-shaped way. The sclerotic lamella of the necrotic area is broken up by drilling into the defect zone, leading to a relief of intraosseous pressure, which explains the significant pain reduction after the operation [13, 17, 18]. Nevertheless, literature describes a wide range of success rates, settled between 63.5 and 84%, but only in early stages of the disease [6, 7, 13, 16, 18, 19]. Combined methods, like bone grafts and mesenchymal stem cell transplantation might perform better than CD alone, nonetheless current studies show inconsistent results [20–22]. By autologous cancellous bone grafting (CBG) a core reamer (trephine) is drilled over the guide pin and creates a 10 mm bone channel. After that the necrotic bone can be removed and replaced by healthy cancellous bone [13, 18]. This method is much more elaborate than the multiple drilling with k-wires alone. Nonetheless there is no common consent about their effectiveness yet. So, it is of great importance especially for younger patients to get facts about the comparability of different treatments.

In the current study we aimed to investigate 1. If both techniques are precise enough to hit the center of the necrosis and 2. If there is a difference in precision between drilling with small pins (CD) or the trephine (CBG). This was evaluated by three-dimensional reconstruction and measurement of the necrosis and the drill hole. PROMs (HHS, HOOS, EQ-5D, SF-36) were evaluated to compare the clinical success of these procedures.

Patients and methods

The study was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

All patients treated for AVN at a Department of Orthopaedic Surgery of a University Hospital between 2007 and 2013, were included. From 289 AVN cases 145 received

THR, because of advanced ARCO stages (ARCO III–IV). 110 affected hips were treated with joint preserving operative therapies like CD and autologous CBG or conservative therapy like Ilomedin infusions. 62 femoral heads aggravated despite therapy and received THR. The other 48 patients consolidated. This group was in our focus to differentiate the most suitable head preserving treatment options and represents the main patient collective, observed in this survey. They were contacted in writing and by phone call. 15 persons did not answer. Two patients did not want to come to the hospital for examination because their hip was good so far. Eight patients denied participation without a statement. Three denied due to current problems with his treated hip, and one patient had passed away. A total of 29 patients had to be excluded. In general, 19 patients with 22 treated hips were left for this study and split up according to their therapy: core decompression versus core decompression in combination with autologous cancellous bone grafting. Bilateral AVN was prevalent in three men, leading to 22 hips available for the study.

ARCO stage I was found twice, stage II 17 times and stage III three times. No systematic disease, like sickle cell anemia, Gaucher's disease, Caisson disease or autoimmune diseases were reported in this group. Five patients reported subjective alcohol abuse, and five patients reported subjective nicotine abuse. Eight patients had a history of corticosteroid intake. The mean disease free survival was 4.93 years (59.1 months), with a range from 26.3 to 92.9 months.

15 (79%) male and four female (21%) patients were divided into two groups. Group A (10 cases with 7 males and 3 females) only contained patients with single CD. Group B (12 cases with 11 males and one woman) represented patients with additional CBG after CD. The mean age in the CD group was 43.1 years (range 28–54, SD 9.3), in the CBG group 40.0 years (range 22–54, SD 10.1). The mean BMI in the CD group was 26.7 kg/m² (range 21.2–33.5, DS 3.9), in the CBG group 27.4 kg/m² (range 24.3–33.8, SD 10.1). There was no discrimination between ARCO stages with 2 stage I patients and 8 stage II patients in the CD group and 9 stage II patients and 3 stage III patients in the CBG group.

Magnetic resonance imaging (MRI) of the pelvis and the hip was retrieved in supine position of all patients, using a Philips Ingenia 1.5 T magnetic resonance imaging system with a digital surface coil. MRI slices were saved in DICOM format with a slice thickness of three millimeters and 20 slices in each weighting. 3D reconstruction, segmentation and measurements were performed with Simpleware Scan IP (Simpleware, Exeter, UK). The method derives from the susceptibility artifacts in MRI technology. This means that during drilling micro metal particles of the drill are abraded. Those particles can be detected postoperatively by MRI. The drill hole and the

necrosis area as the regions of interest (ROI) were marked using the provided manual segmentation tools (Fig. 1). To allow 3D reconstruction the ROI had to be manually segmented in all three dimensions. Both, necrosis area and drill holes were reconstructed in this manner. By applying an ‘extended marching cube algorithm’ 3D reconstruction was ultimately achieved. Then the maximum length of the drill hole and of the necrosis area was measured as a vector in the spatial planes X, Y, Z. The center point of these two vectors was measured. The deviation of the center point of the drill hole to the center point of the necrosis area was defined as a measure for the accuracy of the drill channel in the femoral head to meet the necrosis area. An alignment of both center points would be the optimal result. If the drill hole was performed in a fan-shaped fashion with three or more drillings, the center point of all tips of the drill holes was determined as described above, and the deviation from the center point of the necrosis was measured. Figure 2 shows the measurement of the distance between the center point of the necrosis and the center point of the drill hole.

At last, patients answered several scores, including the HHS, Hip Disability and Osteoarthritis Outcome Score (HOOS), EuroQol 5D (EQ-5D) and Short Form 36 Questionnaire (SF-36).

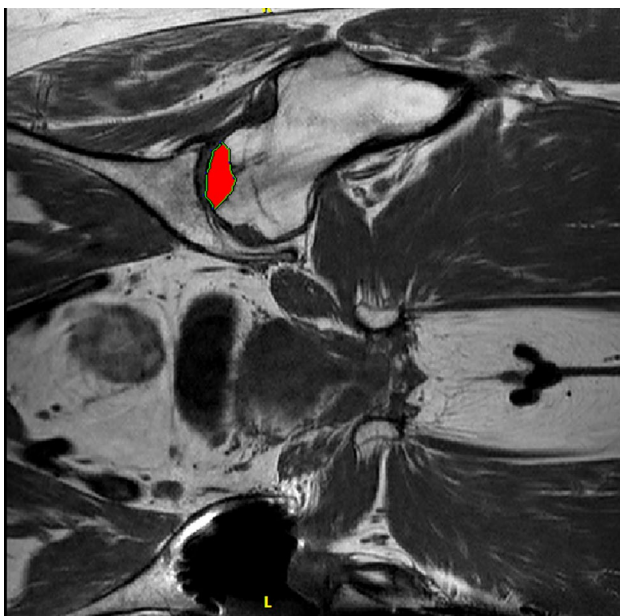


Fig. 1 Segmentation of the necrotic area, colored in red and marked as ROI with the manual segmentation tool. This marking of the defect zone was repeated in every slice of the MRI with visible necrotic areas. The same was done with the drill channel. A short part of the drill channel can be seen underneath the necrosis. In this case CD with a small pin had been performed

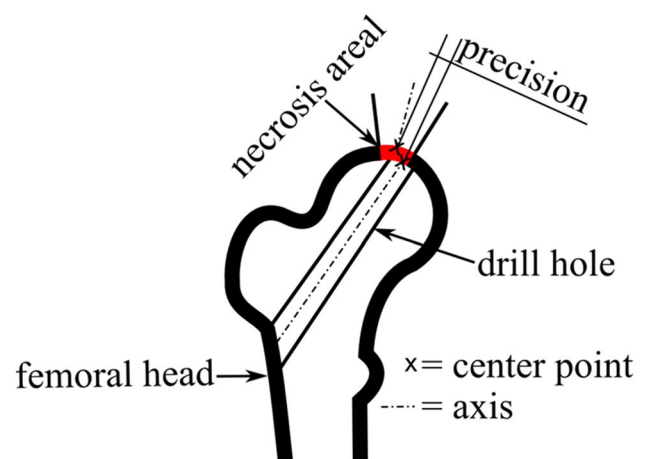


Fig. 2 Schematic drawing of the definition of precision

Statistics

Statistical analysis for comparison of the two groups was carried out using the *t*-test for drilling precision and PROMs. When normality testing failed and *t*-test could not be used, the Mann–Whitney Rank Sum Test was applied. All analyses were performed using SigmaPlot 11.0 (Systat Software Inc., Chicago, IL, USA). Statistical comparisons were made at a 0.05 level of significance.

Results

The position of the drill channel or the cancellous graft within the necrotic volume can be checked on MR images, but the spatial position is only identifiable in three-dimensional reconstruction. In Fig. 3, we see examples of the three-dimensional reconstruction of the necrosis zone, the drill holes and CBG.

The extension of the necrosis was 7.79 ml (range 1.74–23.7, SD 7.7) for the CD group and 21.1 ml (range 6.0–46.2, SD 12.4) for the CBG group. The deviation of the center point of the drill hole to the center point of the necrosis area was 3.58 mm (range 0.0–14.06, SD 4.2) in the CD group and 3.91 mm (range 0.0–15.27, SD 4.7) in the CBG group.

Evaluation showed that in both groups the necrotic area had been reached by the drilling in all cases. It did not matter how large the necrotic bone area had been. The drilling pin (CD) or the reamer (CBG) had at least reached into the defect zone.

A difference in precision between drilling with the small pin for single CD or the 10 mm trephine for CBG was not apparent. Statistical analysis showed no significant difference ($p = 0.459$) (Fig. 4, Table 1).

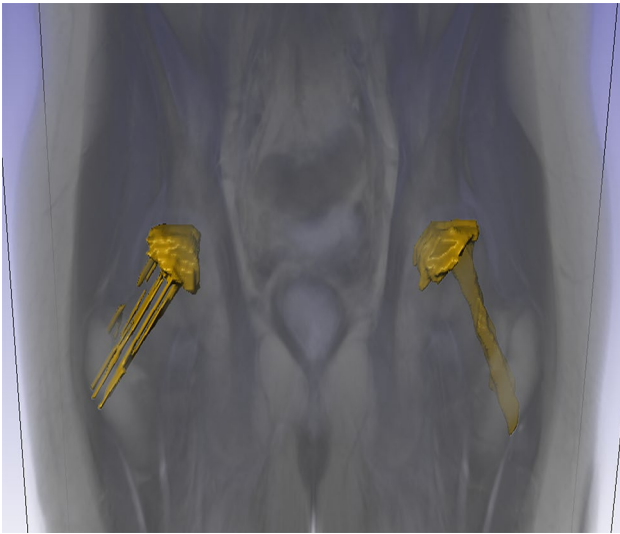


Fig. 3 Three-dimensional MRI excerpt of a patient with bilateral AVN. On the left the necrotic area has been drilled with a reamer and CBG. On the right the necrosis has been drilled with several small pins. The necrosis area and the drill holes were reconstructed as described above. Obviously in both cases the necrotic area was hit by the drilling

In the hip specific scores HHS and HOOS the CBG group showed slightly better results, however they were not statistically significant. The CD group achieved better results in SF-36, again without any significance. For the PROMs altogether, the comparison revealed no statistically significant difference in any of the scores (Table 2).

Discussion

Although core decompression has been performed for about three decades, its effect on the progression of osteonecrosis is still not clear. There are some hints that combined methods like bone grafts and mesenchymal stem cell implantation might bring better results than core decompression alone, other studies show comparable results [7, 13, 16, 19, 22, 23]. General consensus is that for the success of CD or CBG the necrotic area has to be hit by the drilling instrument [18]. Only when the sclerotic rim around the necrosis is broken, intraosseous pressure can be relieved [24, 25]. We compared these two most common joint preserving procedures to clarify 1. if the necrosis was hit by the drilling in every treated

Fig. 4 Box plot precision

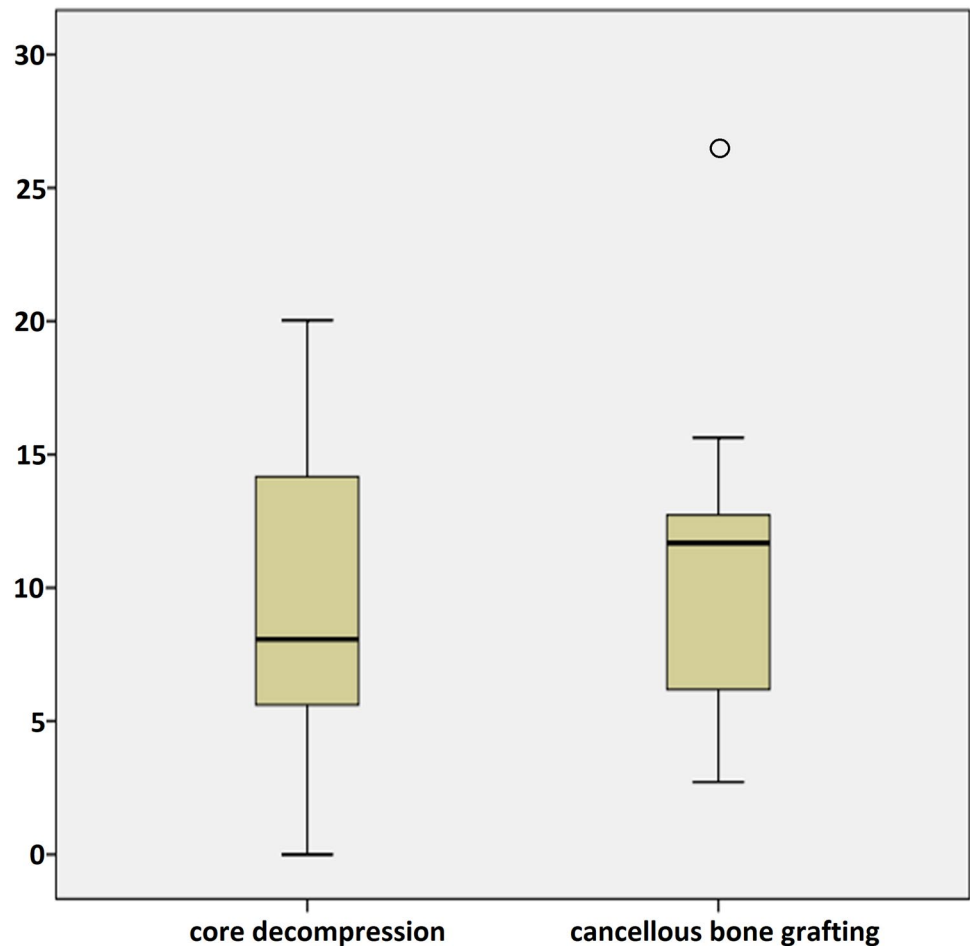


Table 1 Values of precision measuring

	CD	CD+CBG
Mean necrosis in X-axis (mm) min/max, SD	21.5 6.7/40.7; 9.3	32.34 19.7/45.8; 7.5
Mean necrosis in Y-axis (mm) min/max, SD	11.01 6.6/16.0; 3.7	19.15 11.5/35.4; 6.4
Mean necrosis in Z-axis (mm) min/max, SD	26.95 13.1/42.0; 11.1	30.86 17.2/42.2; 7.4
Mean volume of necrosis (ml) min/max, SD	7.79 1.74/23.7; 7.7	21.1 6.0/46.2; 12.4
Deviation distance in X-axis (mm) min/max, SD	4.95 0.0/12.0; 3.4	4.63 0.0/11.2; 3.9
Deviation distance in Y-axis (mm) min/max, SD	1.02 0.0/10.2; 3.1	0.0
Deviation distance in Z-axis (mm) min/max, SD	4.77 0.0/14.1; 4.8	7.13 0.0/15.3; 4.9

CD core decompression, CBG cancellous bone grafting

Table 2 Evaluation of clinical scores

Score	CD	CD+CBG
Harris hip score mean value (range <i>p</i>)	87.7 (58–100, 0.362)	93.2 (58–100, 0.362)
HOOS mean value (range <i>p</i>)	75.6 (37.2–95, 0.470)	81.2 (37.2–100, 0.470)
EQ-5D mean value (range <i>p</i>)	79.1 (50–100, 0.788)	80.9 (60–100, 0.788)
SF-36 physical health mean value (range <i>p</i>)	46.6 (21.2–56.2, 0.599)	42.3 (20.1–57.3, 0.599)
SF-36 mental health mean value (range <i>p</i>)	53.2 (37.8–59.6, 1.000)	49.8 (32.9–61.3, 1.000)

CD core decompression, CBG cancellous bone grafting

subject and 2. if there would be any difference in precision in reaching the necrosis area. Neither with CD nor with CBG the defect zone was missed. The drilling precision of both procedures did not differ significantly. PROMs after average 4.93 years of follow-up showed no significant difference.

The first limitation of our study is the low number of patients, partially lost in follow-up. Due to low patient numbers in comparable studies, it would be desirable to include bigger patient collectives and of course to perform prospective study designs in future.

Second, our patients were only drawn from a patient collective with consolidated hips after therapy. We had no comparison with a group of therapy failure because these patients were converted to THR already. In future we should perform a prospective study and compare drilling precision of a consolidated and a failed group, possibly in the time before conversion to THR. This could answer the question why therapy fails. Is it due to the fact that the necrosis area was not hit precisely enough? Or is CD not efficient enough, and CBG would have been required?

The third limitation of our study may be a possible selection bias. ARCO stages I and II are mostly seen in the CD group, II and III mostly in the CBG group. That could suggest that patients with bigger AVN were treated with CBG. However, since the study tries to find out the hit rate of the lesions, this bias has no consequences for the results.

Our results present that three dimensional MRI segmentation and reconstruction of the necrosis and the drill channel—to date not measured in that manner—showed that in every case the necrosis was hit by the drilling. So, the precondition for a successful intraosseous pressure relieve was

given in every observed hip. Though not 100% of the drillings hit the center of the necrosis. However, our data present good mid term results in follow-up regarding PROMs. Albeit different authors suggest hitting the central part of the necrotic area [24, 26], it seems reasonable that CD can also work when the pin hits a decentral part of the necrotic area. Hence it could be sufficient to break up the sclerotic lesion distal to the necrotic area, so intraosseous pressure can be relieved and blood supply can be restored inside the defect zone [27]. Up to now it was not clear if a decentral hit of the necrotic area is also successful because it had not been analyzed yet.

Furthermore, there was no difference in precision of the drilling between both techniques. They are equally reliable regarding precision. The mean deviation of the K-wire or the trephine from the center point of the necrosis was 3.58 mm in the CD group, respectively, 3.91 mm in the CBG group ($p=0.459$). This deviation results from the addition of all deviations in every of the three spatial axis. The precision lies in between those of different studies with navigated CD and conventional techniques. Beckmann et al. showed that with navigated CD a precision of up to 0.51 mm could be reached in sawbone compared to 1.1 mm with conventional technique [24]. However, this was measured in one plane, not in three planes like in our study. Hernigou et al. reported precision with computer-based navigation of 1.6 mm compared to 5.9 mm in the control group in a collective of patients with osteonecrosis of the knee [21]. Facing our results of reliable conventional drilling into the defect zone the necessity of expensive navigation systems to perform drilling has to be discussed. One aspect in favor would be

a reduction of radiation dose and time for the patients and the surgeons [24]. The most important advantage of navigation may be the reduced number of drilling corrections. The directional changes of the pin lead to multiple drilling, which can weaken the femoral neck. This seems to be especially significant for obese patients because the spatial orientation is more difficult [24]. Nonetheless for pin based navigation there is also the risk of complications, like navigation pin related infection or fractures [16]. However, it is necessary to perform further prospective randomized studies to answer this question definitely.

Our evaluation of some clinical scores—hip specific ones (HHS and HOOS), as well as general health scores (SF-36 and EQ-5D)—showed that CBG patients presented better in the hip specific scores, but not statistically significant. However, it is remarkable due to the long follow-up time of four years. In literature 12 months follow-up results for HHS between 72.25 and 88.42 are reported [28–30]. So, our study provides encouraging figures for good mid term outcome after joint preserving therapy. In contrast to the hip specific scores CD patients had equal or slightly better results in general health scores compared to the CBG group. Compared to SF-36 results in literature (mental health aspect 63.63 to 87.53, physical health aspect 42.77 to 83.13) our results are slightly better [30]. Nonetheless we saw no significant difference in PROMs between the CD and the CBG group.

In view of that outcome and the available literature that does not provide enough evidence respectively shows inconsistent data for long term success of patients treated with CBG [22, 23] and the matter of fact that multiple drilling with small wires (CD) shows less complications like subtrochanteric fractures or hip joint penetration [31, 32] our results may lead to the conclusion that the intra- and post-operative risks of a bigger drill channel, as performed for CBG, could be avoided by using only small K-wire pins or a smaller drill. However, it may be a disadvantage that there could not be taken histological samples and it would not be possible to perform CBG.

Summarizing, we notice that both analyzed interventions are comparable according to the drilling precision. It was shown that neither in CD nor in CBG the defect zone had been missed. PROMs show no differences after follow-up. The most important remaining difference between the two procedures is that CD is less surgically demanding than CBG. In conclusion, our data may contribute to applying the less invasive technique of CD in future alone. Navigation systems may not be necessary for CD and CBG when the operation is performed by experienced surgeons. To clarify the risk factors for a therapy failure it is necessary to perform further prospective studies with longer follow-up to get more information about the course of the disease and to make it possible to decide which therapy concept fits best for every patient individually.

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Declarations

Conflict of interest The Authors declare that there is no conflict of interest. This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Ethical approval This study was conducted after authorisation by the Institutional Ethical Board of the Medical University of Regensburg (No. 14-101-0108). It has been performed in accordance with the ethical standards in the 1964 Declaration of Helsinki and has been carried out in accordance with regulations of the US Health Insurance Portability and Accountability Act (HIPAA). Written informed consent for participation in this investigation was obtained from all patients.

Informed consent Written informed consent for participation in this investigation was obtained from all patients.

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