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Computed tomography for preoperative planning in minimal-invasive total hip arthroplasty: Radiation exposure and cost analysis

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ABSTRACT

Computed tomography (CT) was used for preoperative planning of minimal-invasive total hip arthroplasty (THA). 92 patients (50 males, 42 females, mean age 59.5 years) with a mean body-mass-index (BMI) of 26.5 kg/m^2 underwent 64-slice CT to depict the pelvis, the knee and the ankle in three independent acquisitions using combined *x*-, *y*-, and *z*-axis tube current modulation. Arthroplasty planning was performed using 3D-Hip Plan® (Symbios, Switzerland) and patient radiation dose exposure was determined. The effects of BMI, gender, and contralateral THA on the effective dose were evaluated by an analysis-of-variance. A process-cost-analysis from the hospital perspective was done. All CT examinations were of sufficient image quality for 3D-THA planning. A mean effective dose of 4.0 mSv (SD 0.9 mSv) modeled by the BMI ($p < 0.0001$) was calculated. The presence of a contralateral THA (9/92 patients; $p = 0.15$) and the difference between males and females were not significant ($p = 0.08$). Personnel involved were the radiologist (4 min), the surgeon (16 min), the radiographer (12 min), and administrative personnel (4 min). A CT operation time of 11 min and direct per-patient costs of 52.80 € were recorded. Preoperative CT for THA was associated with a slight and justifiable increase of radiation exposure in comparison to conventional radiographs and low per-patient costs.

1. Introduction

Total hip arthroplasty (THA) is a very frequently performed surgery in patients with hip arthrosis. The number of patients receiving a hip replacement in Europe in 2006 was more than 650,000. The incidence of primary THA and revision was 2.2 per 1000 inhabitants in some countries of Central Europe compared to 1.4 in the USA [1]. The percentage of intra- and postoperative complications could be decreased in the last decade due to less invasive surgery techniques (e.g. mini-incision anterior, anterolateral, posterolateral, or two-incision approach), the introduction of sophisticated stem and cup systems, and more accurate preoperative planning and/or intraoperative navigation. Nevertheless, the percentage of perioperative complications including femoral or trochanter fractures, nerve palsies, dislocations, infections, or false routes remain in a range between 0.9 and 10% [2–4].

A promising recent development in THA was the replacement of conventional X-ray radiographs with depiction of the pelvis by a spiral computed tomography (CT) [5,6]. The advantages of a standardized CT for preoperative planning include the avoidance of imprecise magnification factors and inaccurate acquisition position by conventional radiographs, availability of an additional axial plane and the replacement of projections by thin slices. The CT data were referred to a workstation equipped with a dedicated planning software (3D-Hip Plan®, SYMBIOS S.A:, Yverdon-les-Bains, Switzerland) allowing an exact depiction of the hip in three planes (Figs. 1 and 2). After determination of the pelvic axis and the anatomical rotation centers, first the acetabular cup and secondly the stem were pre-operatively planned. Both the size and the

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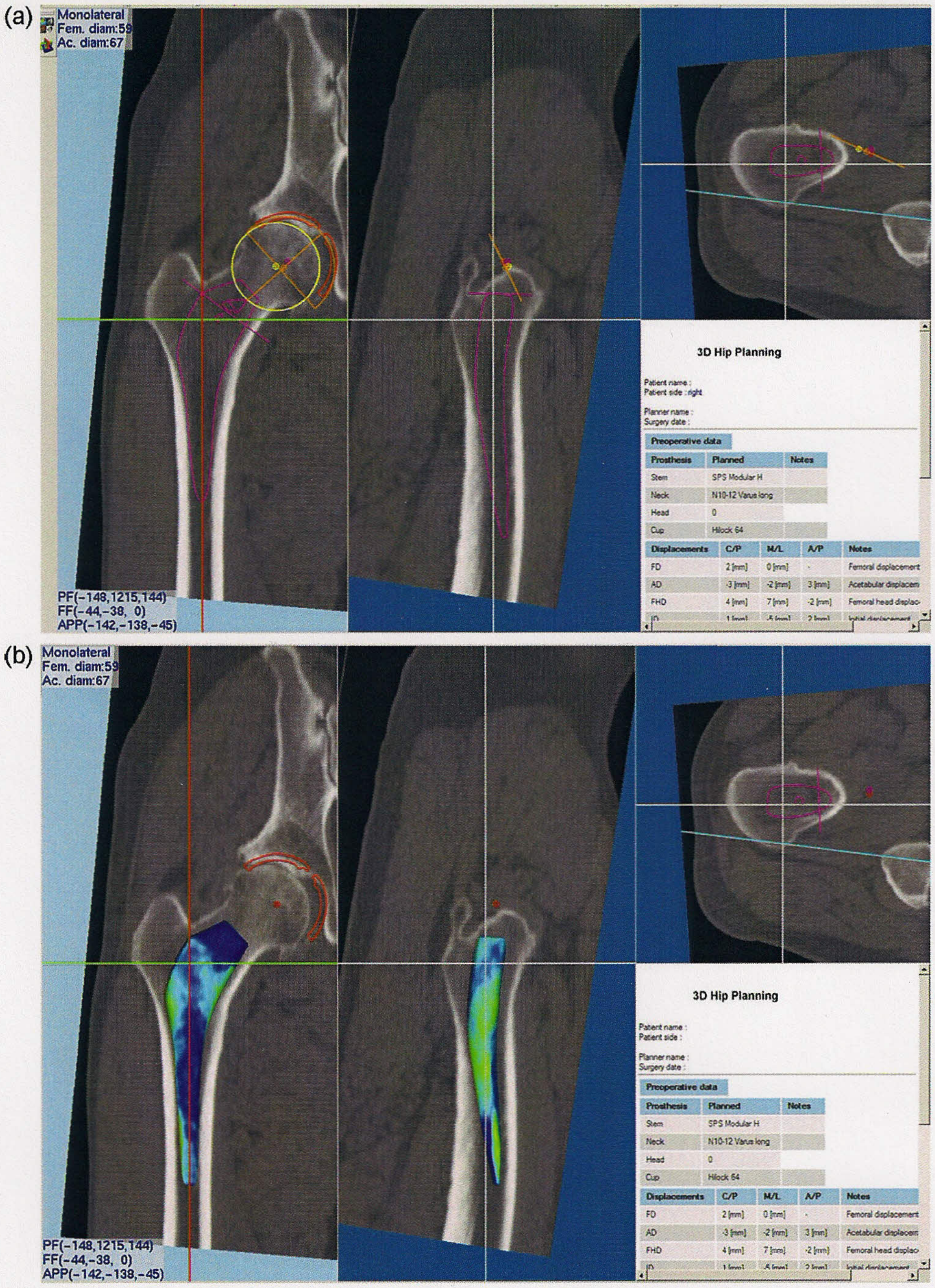

Fig. 1. a. Planning of a total arthroplasty of the right hip in a 65-year-old male: The software surface offers a simultaneous real-time view of the coronal, sagittal and axial plane. The left (coronal) view depicts the anatomical acetabulum rotation center (orange), the cup planning (red), the anatomical femoral neck rotation center (yellow), the planned surgical resection line (line magenta) and the planning of the stem (magenta). The planned geometric rotation center of the femoral head (magenta crosshairs) fits very accurately with the anatomical rotation centers of the femoral head yellow crosshairs) and the acetabulum (orange crosshairs). The planning recommends implantation of a Hilcock cup and an SPS modular stem with the largest size available (H). The stem had to be combined with a long varus neck. b. Prediction of the quality of the contact surface between the implanted stem and the femoral bone. The green color indicates a high quality of the contact surface (smooth contact of the implant with thick cortical bone) whereas the blue color indicates regions with a moderate or low quality of the contact surface (contact of the implant with cancellous bone).

positioning of the implants were planned individually in this 3D real-time representation.

Correct component positioning has been achieved using the CT for the pre-operative planning procedure [6]. However, CT does induce a higher patient radiation exposure compared to conventional radiography and may increase costs for the pre-operative setting. The aim of our retrospective evaluation was to determine the radiation exposure and examination costs of CT in the patients referred to our institution.

2. Materials and Methods

2.1. Patients

In the period of December 2005–December 2008, 92 patients were referred to our department for a preoperative planning CT and were examined with a standardized protocol according to standard care. The local institutional review board approved the retrospective evaluation of the radiation exposure and the cost analysis for

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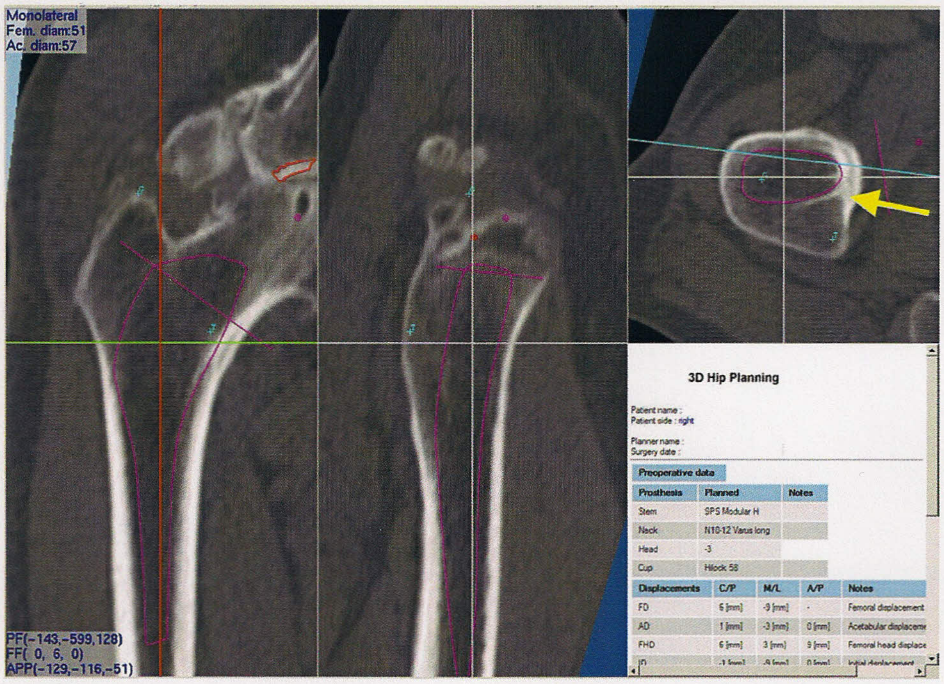

Fig. 2. Planning of a total arthroplasty of the right hip in a 60-year-old male: the planned surgical resection line (line magenta) and the planning of the stem (magenta) are depicted. Note the depiction of cortical spur in the medial femur which has to be integrated in the planning to prevent an unintentional intra-operative displacement of the stem (arrow).

the CT procedure. In all patients, minimal invasive THA was planned on the basis of a preoperative CT.

50 males (mean age 60.9 years, range: 39–84) and 42 females (mean age 58.5 years. range: 30–75) were included in the evaluation, no difference in age was found ($p = 0.2550$). The mean patient weight was 79.8 kg (weight range, 45–120 kg), the mean patient size was 1.73 m (size range, 1.55–1.98 m) and the mean body-mass-index (BMI) was 26.5 kg/m^2 (BMI range, 18.0–37.3 kg/m^2). The BMI for males (27.6; SD 3.8) was higher than for females (25.2, SD 4.2; $p = 0.0050$). 52/92 (56.5%) of patients had an overweight defined by a BMI > 25, more frequently in males than in females ($p = 0.0454$). 9/92 patients (9.8%) had an implanted total hip endoprosthesis in the contralateral side at the time of performance of the CT, equally frequent in both genders ($p = 0.5300$). The THA was planned on the right site in 46/92 patients, on the left site in 40/92 patients, and bilaterally in 6/92 patients.

88/92 patients had a THA surgery with Smith–Petersen anterior approach in an interval between 1 day and 6 months after the CT (mean 53 days). The cups implanted were manufactured from titanium alloy (Ti6Al4 V) covered with porous titanium and hydroxyapatite (HILOCK Line or APRIL Line, Symbios S.A.) with sizes between 48 and 62 mm. Modular stems (SPS Modular Mk II, Symbios S.A.), standard stems (SPS standard, Symbios S.A.) or straight shafts (Arcad HA stem, Symbios S.A.) made of titanium alloy (Ti6Al4 V) with sizes between B and H were implanted in 81/88 patients. Customized stems manufactured on the basis of the study CT data were implanted in 7/88 patients (7.9%). 87/88 stems were implanted cement less and no femur fracture or dislocation was reported in a follow-up interval of 3–39 months (mean 18 months).

2.2. CT examination

All examinations were performed in supine position using a multislice CT (SOMATOM Sensation 64, Siemens Healthcare, Erlangen, Germany). The acquisition parameters are given in Table 1. From the survey CT scan, three separate spiral acquisitions depicting the pelvis, the knee and the ankle were planned. The scan times were 12.7 s for the pelvis, 6.8 s for the knee and 6.4 s for the ankle. For all the three acquisitions, an automatic mode combining online tube current modulation along the x- and y-axes and survey scan-based attenuation data along the patients z-axis were used to take into account the individual patient anatomy (CARE Dose4D™, Siemens Healthcare).

The examination parameters were especially adjusted to be used by the hip surgery planning software (3D-Hip Plan®, Version0.74, Symbios S.A.). The program was able to determine patient anatomic parameters including the acetabulum inclination, the acetabulum anteversion and antetorsion, the femoral anteversion according to the anterior pelvic axis (defined by the anterior superior iliac spines and the pubic tubercles as references), the femoral axis, the leg length, and the bone density and to propose prosthetic positions (Figs. 1 and 2). Furthermore, the cup and the stem implantation were simulated and optimized.

The pelvis was imaged from 10 mm proximal of the iliac crest to the middle femur shaft over a scan length of 410 mm. The knee was imaged over a scan length of 206 mm with a centering on the joint space to depict the bicondylar line and to determine the femur

Table 1
Acquisition parameters of computed tomography.

Slice collimation	64 × 0.6 mm
Slice width	0.6 mm
Spatial resolution	0.4 mm
Rotation time	0.5 s
Pitch	0.9
kV	120
Reference mAs	100
Effective mAs	Individual; Care Dose 4D
Reconstruction slice width	2 mm
Reconstructed FoV	200 and 400 mm for the pelvis, 200 mm for the knee and the ankle
Kernel	B31f and B60f

FoV, field-of-view; kV, Kilovolts; mAs, milliampere second

Table 2
Processes, activities and time of pre-operative planning CT for minimal-invasive THA.

Process	Activity	Person	Time estimate (min), evaluated by expert interviews and averaged	Facility/Room
Registration	Sending of demand of hip planning CT, fixing of examination date (by phone)	Administrative personnel	2	Orthopedic department
		Administrative personnel	1	Radiology department
Welcome	Patient arrives in the Radiology department (CT unit), is welcomed and instructed and receives the informed consent	Administrative personnel	1	Radiology department
	Explanation of the examination, signing of consent form	Radiologist	1	Radiology department
CT examination	Receiving, explanation of the course of the exam, explanation for disrobing	Radiographer	1	Radiology department
	Posititioning of the patient in the CT	Radiographer	2	CT room
	Performance of the CT scan	Radiographer	2	CT room
	End of the examination, patient leaves the CT examination room, repositioning of the scanner	Radiographer	2	CT room
CT post-processing	Reconstruction of the images, print of data on CD, provide the CD to the patient	Radiographer	5	Room for operation of the CT
	Data check	Radiologist	3	Radiology department
	Loading of the CT data to the 3D-Hip Plan® software	Surgeon	2	Orthopedic department
	3D planning	Surgeon	12	Orthopedic department
	Printing of the report, storage of the data, forwarding of result	Surgeon	2	Orthopedic department
	Radiologist 4	Surgeon 16	Radiographer 12	Administrative personnel 4

CD, compact disk; CT, computed tomography; THA, total hip arthroplasty

rotation. The ankle was measured over a scan length of 193 mm with a centering on joint space of the subtalar joint to determine the tibial rotation (the angle between the transverse axes of the proximal and distal tibial articular surfaces, the degree of twisting of the tibia around its own longitudinal axis).

2.3. Calculation of patient radiation exposure

Dedicated software (CT-Expo V1.6 2007, Medical University Hannover, Germany) was used for calculation of effective doses [7]. The program takes into account the patient gender, scanner type and the overranging effects of multislice CT. For the calculation the dose-length products (DLP) of the pelvis, the knee and the ankle of each patient computed by the scanner were used.

The effective dose takes into account the distribution of dose amongst the radiosensitive organs into the body by summing the individual organ doses, having weighted each one according to the relative sensitivity of the organ to radiation induced somatic or genetic effects.

2.4. Statistical evaluation

Results were displayed as frequencies or means with either standard deviations (SD) and/or ranges where appropriate. Continuous variables were tested by a two-sided t-test, whereas frequency data were tested by a two-sided χ^2-test. The effects of the factors BMI, presence of a contralateral hip endoprosthesis, age, sex, sex–BMI interaction, and site of CT on the effective dose were evaluated by an analysis-of-variance (ANOVA). A p-value below 0.05 was considered statistically significant. Calculations were performed using SAS 9.2 (SAS Institute Inc., Cary, NC, USA).

2.5. CT data quality assessment

An orthopedic surgeon experienced in hip surgery and in the use of 3D-hip surgery planning software (S.R., 10 years of experience in THA) evaluated the CT datasets according to a 2-point-score (image quality sufficient or insufficient for confident THA planning using the 3D planning software).

2.6. Process cost analysis

The processes and activities of pre-operative CT were documented (Table 2) and the binding of human resources was collected by four expert interviews (2 radiologists, 2 orthopedic surgeons) in their role as process drivers (time estimates were averaged) and validated by means of measurement of real times in eight patients. A calculation of total direct costs from a hospital perspective was

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performed by addition of fixed and variable costs. The costs of labor were determined from personnel reimbursement data. The fixed direct costs were assessed from hospital accounting records and from vendor pricing. The costs for consumables of preoperative CT (i.e. CD for data transfer, paper, and cleaning agents) were very low and were ignored in the calculation.

The fixed direct costs, i.e. acquisition of the CT scanner were determined. The operating costs including the maintenance of the systems were calculated. The acquisition costs were calculated over a period of 8 years. The capital costs of the investment were calculated with an interest rate of 10% per year and a maturity of 8 years. The calculation was done with an estimate of 250 operating days and eight hours of daily work for the hardware. The fixed direct costs for acquisition of the planning software installed on a commercially available standard computer were ignored.

The variable direct costs were determined on the basis of collective labor agreements in force for physicians and technicians (rounded in 100 €). All personnel directly involved in the cases were tracked, and the involvement times were recorded to the nearest minute.

The acquisition costs for the SOMATOM Sensation 64 scanner were calculated with 670,000 € (including installation costs of 30,000 €) and 766,205 € for the capital costs. In relation to the 8-year-period and the daily uptime, acquisition costs of 1.43 € per min of CT examination were calculated (1,366,205 €/8 years/250 working days/8 h/60 min). The maintenance costs for the CT scanner were calculated with a full service contract including guaranty from the second operating year on at an annual price of 80,000 €. These fixed costs per minute averaged out at 0.58 € per minute [(80,000 × 7 years)/8 years/250 working days/8 h/60 min]. The operating costs of the CT scanner were reduced on the power consumption, estimated to 60 KWh in the operating mode and 8 KWh in the stand-by mode. Assuming a daily uptime of 8 h and use of the stand-by mode for rest of time (since CT was integrated in the workflow of emergency patients), a power consumption of 174,080 KW was calculated [(60 kW × 8 h × 250 days) + (8 kW × 16 h × 250 days) + (8 kW × 24 h × 115 days)] and resulted in operating costs of 0.33 € per minute (174,080 KW/365 days/24 h/60 min; assuming a price of 0.20 €/KW). Costs for the CT facility of 0.10 € per minute were calculated (surface area for installation = 50m^2 and rental costs of 20 €/m^2; 20 € × 50m^2 × 12 months/250 working days/8 h/60 min). Total direct fixed costs for CT scanning were, therefore, 2.44 € per minute.

In an alternative hypothetic calculation, daily uptime of 2 h and no use of the stand-by mode (since the hospital was assumed to be not integrated in the treatment of emergency patients reflecting a smaller hospital with a focus on elective orthopedic surgery) were calculated. For this scenario, acquisition costs of 5.69 € per minute of CT examination (1,366,205 €/8 years/250 working days/2 h/60 min), maintenance costs of 2.32 € per minute [(80,000 × 7 years)/8 years/250 working days/2 h/60 min], and operating costs of 0.05 € per minute (30,000 kW/365 days/24 h/60 min) were calculated. The total direct fixed costs including the rental costs for the CT facility for this CT scanner were, therefore, 8.16 € per minute.

Four different qualifications of personnel were found to be involved in the processes of pre-operative CT: the radiologist, the surgeon, the radiographer and non-medical administrative personnel. The variable direct personnel costs of board approved radiologist or surgeon was estimated with a pretax salary of 5300 € per month. The costs of the radiographer and the non-medical administrative personnel was estimated respectively with pretax monthly salaries of 2500 € and 2200 €. The associated employer outlay was calculated with 50% of the pretax salary. The variable direct personnel costs were, therefore, 0.94 €/minute for physicians [(monthly salary × 12 months)/(251 working days–20 days malady–29 leave days)/8.4 h/60 min], 0.46 € for radiographers and 0.41 € for non-medical administrative personnel [(monthly salary × 12 months)/(251 working days–20 days malady–29 leave days)/8 h/60 min].

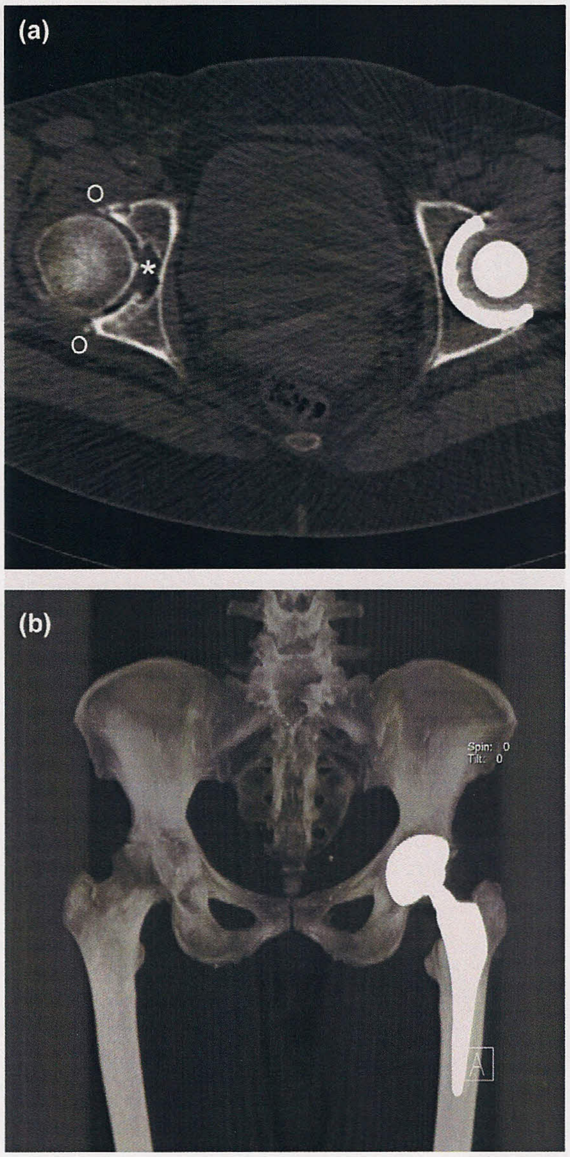

Fig. 3. a. Axial slice trough the hip joint in a 58-year-old female with a contralateral total hip arthroplasty (THA). Severe osteoarthritis with subchondral sclerosis, large subchondral cyst of the actatabular joint surface (*), narrowing of the joint space, and osteophytes (O). Despite the limitation in image quality caused by the radial metallic artifacts, the accurate planning of THA is not disturbed. b. Reconstruction of the entire pelvic volume in a thick maximum-intensity-projection (MIP) with a slice thickness of 250 mm. The image confirms the high quality of the dataset in the presence of a contralateral THA.

3. Results

All CT data were of sufficient image quality to be post-processed with the dedicated 3D-hip planning tool, no scan repetition was necessary. In particular, in patients with presence of the contralateral THA, all data were rated to be of sufficient image quality for 3D-THA planning (Fig. 3). The scan time for all the patients was 25.9 s plus 0.5–5 s for the table movements.

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Table 3
Organ doses values H_T calculated on the basis of conversion factors for standardized patients for the mean radiation exposure for males and females.

		Males				Females			
Scan region	Organ	H_T (mSv)	DLP (mGy cm)	$CTDI_{vol}$ (mGy)	eff. dose (mSv)	H_T (mSv)	DLP (mGy cm)	$CTDI_{vol}$ (mGy)	eff. dose (mSv)
Pelvis	Testes	9.7	254	5.8	4.1	–	234	5.3	3.8
	Bladder	8.6				8.4			
	Uterus	–				8.1			
	Lower colon	7.6				7.5			
	Ovaries	–				7.4			
	Upper colon	7.5				7.5			
	Small intestine	7.2				7.3			
	Bone	5.4				5.3			
	Bone marrow	3.3				3.2			
	Skin	3.2				3.3			
	Kidney	2.0				3.3			
	Stomach	1.5				2.2			
	Liver	1.1				1.7			
	Spleen	0.7				1.1			
	Pancreas	0.7				0.9			
	Adrenals	0.3				0.5			
	Lung	0.1				0.1			
Knee	Bone	0.8	47	2.0	0.0	0.8	48	2.0	0.0
	Skin	0.5				0.5			
Ankle	Bone	0.2	26	1.2	0.0	0.2	26	1.2	0.0
	Skin	0.2				0.2			

CTDIvol, volume computed tomography dose index; DLP, dose-length-product; Eff. Dose, effective dose; H_T, Organ doses value

3.1. Radiation dose

A mean total DLP of 315.7 mGy cm (SD 60.0) was computed. A mean DLP of 244.4 mGy cm (SD, 54.4) was computed for the pelvic region (253.2 mGy cm for males, and 234.1 mGy cm for females), 47.4 mGy cm for the knee (46.7 mGy cm for males, 48.3 mGy cm for females) and 25.8 mGy cm for the ankle (26.0 mGy cm for males, and 25.7 mGy cm for females). A mean effective dose of 4.0 mSv (SD 0.9 mSv; range: 2.5–6.3 mSv) was calculated. The mean effective dose for males was 4.1 mSv (SD 0.8 mSv) and was not found to be different from females (3.8 mSv, SD 0.9 mSv, $p = 0.0812$). The organ doses values for the mean radiation exposure for males and females were calculated on the basis of conversion factors for standardized patients (Table 3). The effective dose revealed to be modeled by the BMI ($p < 0.0001$, Fig. 4): it was proven with high statistical significance that patients with increasing BMI are exposed to increasing radiation doses. The presence of a contralateral hip endoprosthesis revealed a small but insignificant increase in the effective dose ($p = 0.1466$). Also the factors age, sex, and sex-BMI interaction were found to be insignificant ($p > 0.25$ each).

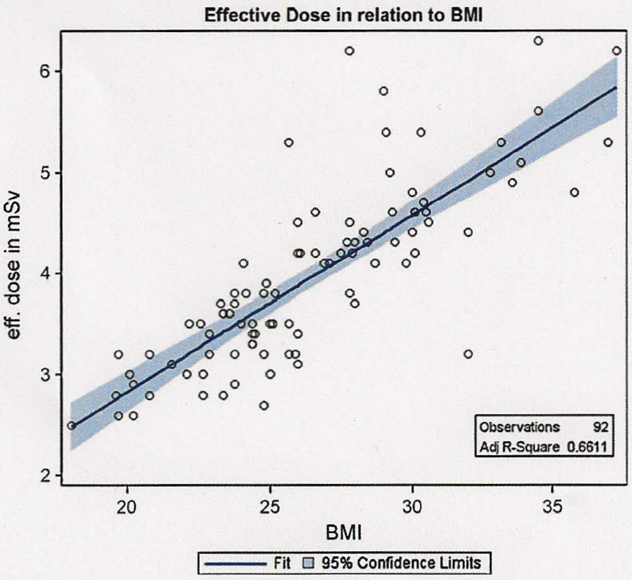

Fig. 4. Scatter diagram that illustrates the modeling of the effective dose by the body-mass-index (BMI).

3.2. Cost analysis

The four process steps registration, patient information, examination and post-processing were identified. The operation time for the CT scanner was 11 min (Table 2). The direct fixed costs for CT scanning were calculated with 26.84 € (2.44 € × 11 min). Personnel involvements of 16 min for the surgeon, 4 min for the radiologist, 12 min for the radiographer and 4 min for the non-medical administrative personnel were determined. The direct variable costs were calculated with 25.96 € [(0.94 € × 20 min) + (0.46 € × 12 min) + (0.41 € × 4 min). The total direct costs of preoperative CT for planning of THA revealed to be 52.80 € per patient.

Referred to our second hypothetic calculation with a CT scanner used exclusively for orthopedic imaging two hours per working day, the total direct costs would be (8.16 € × 11 min; direct variable costs identical with 25.96 €) 115.72 € per patient.

4. Discussion

The analysis of anatomic configuration by CT in patients undergoing THA (with a cementless acetabular component and a cementless modular-neck femoral stem) has proven a high accuracy in 223 patients with a realization of preoperative planning in 86% for the acetabular implant, 94% for the stem, and 93% for the neck-shaft angle [8]. Modularity of the femoral neck helped to restore the femoral offset, the limb length and to renew a physiologic muscular function [9]. The high accuracy in hip reconstruction was based on the anticipation and preoperative solving of difficulties and intraoperative complication by optimizing the selection of implants. A sintering of the stem, caused by a too small stem diameter, or a fracture of the femur, caused by a too large diameter could be avoided [10]. The 3D planning tool was able to discover the regions with thick cancellous bone and high stability. The stem could be adjusted to conserve those areas. It was possible, therefore, to increase the contact surface (interface) between the femoral bone and the graft. In combination, all these effects could potentially result in an accelerated rehabilitation caused by an increased muscular stability of the hip joint.

In another evaluation of 117 patients after surgery with Smith–Petersen anterior approach based on the dedicated planning software, mean surgery duration of 69 min, a mean blood loss of 365 mL and a mean incision length of 79 mm were reported [5]. A good recovery of hip joint mobility documented with the Merle d'Aubigné score [11] and a decrease of postoperative pain documented with the visual-analogue score (VAS) was reported. The preoperative planning was realized in 108/117 patients (92.3%) for the cup and in 101/114 patients (88.6%) for the stem.

In the classical preoperative diagnostic workflow of patients scheduled for THA, conventional radiographs of the pelvis in anterior–posterior projection, in lateral view and optionally a frog-leg lateral view are performed. The effective dose of a single pelvis radiograph was reported to be in the range of 0.7–1.0 mSv [12,13]. By addition of these values, the effective dose in the conventional workflow can be estimated in a range of 1.4–3.0 mSv. In clinical routine, repeating of radiography for overexposure, underexposure, or position fault caused by human error or equipment malfunction is a frequent problem and was reported in 13.6% of the pelvic radiographs [14]. With the introduction of digital radiography the repeat rate may be reduced due to the decreased sensitivity to over- or underexposure [15]. Nevertheless, the meticulous preoperative planning necessary to perform the procedure expediently and precisely, anticipate potential intraoperative complications, and achieve reproducible results will continue to result in a relevant percentage of repeat radiographs [16,17]. In addition, intraoperative fluoroscopy leading to a further increase of effective dose was proposed for certain minimal-invasive surgery techniques, e.g. the two-incision technique [18]. Our evaluation revealed a mean effective dose of 4.0 mSv and is well comparable to other published results of spiral CT in the setting of preoperative planning reporting a range of 2.9–5.1 mSv [16]. The above mentioned study can not be directly compared to our results, as the data were obtained in a phantom, using early spiral CT and datasets adapted for computer aided surgery systems. In fact, our study results are based on the use of an automatic modus combining online tube current modulation along the x- and y-axes and survey scan-based attenuation data along the patients z-axis which has been shown to effectively reduce the patient radiation exposure in CT colonography or cardiac CT angiography by a factor of 1.5–2 without loss of image quality [19–21]. A radiation dose exposure of 11.2 mSv reported recently for preoperative planning using a 16-slice CT without current tube modulation [8] is supporting our assumptions.

Using our protocol, the dose is increased by at least 30% compared to conventional radiographs, taking repeat of exposure out of consideration. As the risk of radiation-induced effect is known to be dependent on the patient age, this increase can be justified in the collective because of the mean age of patients scheduled for THA (in our study 59.8 years) and the low rate of intra- and postoperative complication reported after CT-based preoperative planning [5,6].

The direct costs of the preoperative CT revealed to be very low with approximately 53–116 €. In relation to the costs of the surgical procedure, of the hospitalization, and the rehabilitation they appear negligible. According to the German reimbursement system, the diagnosis-related groups (DRGs), the THA is classified in the I03 and is reimbursed between 8.000 and 12.000 € depending on the complexity of the disease and the co-diseases. CT consumes less than 0.4–1.4% of the budget. Preoperative planning CT promises even an economization of resources due to the apparently improved patient outcome, the accelerated rehabilitation and a decrease of surgery time. The costs for the CT examination might be even further decreased if a less sophisticated CT with lower acquisition and maintenance costs would be used. In that case, however, the image quality could potentially be hampered by the increased acquisition time with an increasing risk of patient movement artifacts. Considering the costs of the CT, it has to be underlined that our calculation was based on a sophisticated system used over a whole working day by different physicians. In case the CT would be installed in an orthopedic surgery center with a low general CT throughput, the examination costs would increase as shown for our alternative calculation with a two-hour daily uptime.

In the future, although the radiation exposure of the reported CT protocol is judged justifiable, a further reduction of radiation exposure should be in the focus. A promising approach could be the reduction of tube voltage. It has been shown that examinations with high contrast (bones, sinuses) or small diameters (extremities) can be done without compromising the diagnostic informative value [22–25]. From a physical perspective a reduction by a factor 1–2 seems feasible [23]. Further studies will be necessary to prove that the accuracy in the determination of relevant parameters by the 3D hip-planning tool would be not compromised. Secondly, it has to be evaluated whether the image quality is still sufficient for the eventual usage of the data for the manufacturing of an individualized stem. An additional approach could lie in the use of techniques to decrease the over-radiation effect. The continuous demand for more coverage and the corresponding increase of detector size has unveiled a new challenge for CT manufacturers: over-radiation, both pre- and post-spiral scan, has significantly grown. After selecting a certain scan range, the system needs at least half a rotation in order to be able to reconstruct the first image. At the same time, the entire width of the detector is being irradiated without any clinical need. Especially for short scan ranges, a high amount of clinically unnecessary over-radiation is applied to patients [26]. By implementing an adaptive shield technique, over-radiation could be decreased. Finally, a further post-processing software development could be done in a decreased need for z-coverage of the knee an ankle, also these anatomic region include no relevant radiosensitive tissue in adult patients scheduled for THA. By introducing the novelties reduced tube voltage, decrease of over-radiation and reduced z-coverage into the dedicated scanning protocol for the 3D-hip planning software, a reduction of the patient radiation exposure to a comparable level to the standard preoperative setting with at least two to three conventional radiographs in different projections might be feasible.

Our evaluation has several limitations. First, the dose calculation was done using software based estimation on the basis of the individual DLP values given by the CT scanner. A comparison of the results to phantom measurements was not performed but previous publications in other field of CT have proven the reproducibility of our dose estimation approach [27,28]. Second, our estimation was done by neglecting the radiation effects of the survey scan. In fact the contribution of the survey CT scan to the total radiation dose of a CT examination has been shown to be in the dimension of chest radiographs and was judged negligible [29]. Third, our comparative of CT dose exposure to conventional radiographs was based to results published by other groups. In the future, an intraindividual comparative of CT data to conventional radiography in the setting of a prospectively planned study would increase the accuracy of the results. Last, the times in the process cost analysis was based on interviews, but the approach is scientifically established and avoids external influences not directly related to the process itself.

5. Conclusions

The perspective distortion, magnification errors and orientation uncertainties associated with conventional radiographs make them an insufficiently sensitive tool for preoperative planning. CT has revealed a higher accuracy and, therefore, an improved patient out-

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come and a reduction of revision rate. Our evaluation proved that preoperative planning CT for THA is associated with a justifiable increase of radiation exposure and causes negligible increases of costs for the preoperative diagnostic.

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