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Preoperative Mapping in Unicompartmental Knee Arthroplasty Using Computed Tomography Scans Is Associated with Radiation Exposure and Carries High Cost

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ABSTRACT

Robotic-assisted knee arthroplasty with some systems requires the use of computed tomography (CT) scans. The associated radiation dose has not been studied. The effective dose (ED, mSv) of radiation was calculated for 236 preoperative CT scans used for planning of robotic assisted surgery. The mean ED was 4.8 ± 3.0 mSv. There was a 3-fold difference in ED between institutions. One or more additional CT scans were obtained in 25% of patients, amounting to a cumulative ED per patient up to 103 mSv. Preoperative CT is a disadvantage of some robotic-assisted knee arthroplasty systems due to additional cost and radiation exposure. Newer image-free robotic technologies are an alternative to CT-dependent surgery if accuracy and safety are not compromised.

Robotic assistance enhances the accuracy of bone preparation, implant component alignment, and soft tissue balance in unicompartmental knee arthroplasty (UKA) [1–6]. Such precision relies on patient-specific preoperative and/or intraoperative mapping, which depending on the system utilized, may require a three-dimensional computed topography (CT) scan of the involved knee and ipsilateral hip and ankle. With radiation exposure 100 to 1000 times higher than that associated with conventional radiography, CT examinations may pose a measurable risk to patients [7,8]. The radiation dose produced by a CT scan for preoperative mapping in robotic-assisted UKA has not been reported yet is critical information for the patient and surgeon, particularly since as approximately 15% of UKAs performed in the United States are now being performed with robotic assistance [9]. Further, as the role of customized cutting guides for total knee arthroplasty (TKA) continues to be debated, little discussion has focused on the merits of magnetic resonance imaging (MRI) versus CT-based methods other than potential differences in guide fit on the condylar surfaces [10].

To best represent the overall radiation energy delivered by a given scan protocol, the absorbed dose is factored along the scan length to compute the dose–length product (DLP, mGy cm). The potential biological effects from radiation depend not only on the radiation dose to a body region, but also on the tissue's biological sensitivity [10]. Effective dose (ED), expressed in millisieverts (mSv, 1 mSv = 1 mGy), reflects this difference in biologic sensitivity. ED is calculated from the DLP, which is reported for each CT study, and multiplied by a body region-specific conversion factor (μSv/mGy cm). The ED allows for comparison of biologic effect between different scenarios of ionizing radiation. ED also facilitates communication with patients regarding the potential harm of a radiologic examination. A typical radiation dose of 1 to 10 mSv (in an adult) is produced by a single CT scan (Table 1), which would be additive to the annual level of naturally occurring background radiation in the U.S. of approximately 3.0 mSv [12,13]. There is evidence that doses corresponding to a common CT study result in an increased risk of cancer, likely through radiation-induced carcinogenesis. The risk is cumulative with additional CT scans or other sources of radiation during the course of one's life regardless of time intervals between scans [7]. A singular CT examination (or multiple scans) with an ED of 10 mSv may be associated with an increase in the possibility of fatal cancer of approximately 1 in 2000 compared to the 1 in 5 natural incidence of fatal cancer in the U.S. population [13].

While the rapid evolution of CT technology has enabled expanded clinical applications, concerns regarding radiation exposure prompt the need for discussion of radiation risk versus medical benefit, and physicians and patients must be informed of radiation doses when using CT technology. Currently two robotic technologies are approved for use in UKA by the United States Food and Drug Administration (U.S. FDA) — one, an image-free system that does not require preoperative CT scan or MRI (Navio, Blue Belt Technologies, Plymouth, MN); the other that requires a preoperative CT scan for mapping and planning (RIO, Mako Stryker, Fort Lauderdale, FL). Both systems have been utilized by the senior author with equivalent accuracy [2,6]. The purpose of this study is to quantify the mean effective dose of radiation associated with the CT scan required prior to robotic-assisted knee arthroplasty and to assess the risk to the patient.

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Table 1
Mean Effective Doses for Common Adult Exposures to Ionizing Radiation.

Radiation Source	Mean Effective Dose (mSv) [Range in Literature]
Head or Facial CT	2 [0.9–4.0]
Chest CT	7 [4.0–18.0]
Chest CT for PE	15 [13–40]
Abdomen CT	8 [3.5–25]
Pelvis CT	6 [3.3–10]
Abdomen CT	8 [3.5–25]
Lumbar Spine CT	9 [1.5–12]
Cervical Spine CT	5
Knee CT	1
Hand XR	0.1
Chest XR	0.1–0.2
Knee XR	0.001
U.S. Background	3.0 [1–10]

Methods

Preoperative CT scans were reviewed for 211 adult patients (236 knees) who underwent UKA from 2011 through 2013 performed by a single surgeon (JHL) at two institutions (Hospital #1 [N = 76] and Hospital #2 [N = 160]) with robotic-assisted bone preparation using the Robotic Arm Interactive Orthopedic System (RIO; MAKO Stryker, Fort Lauderdale, FL). Preoperative planning for all patients undergoing robotic-assisted UKA with this system requires a CT scan of the knee and ipsilateral hip and ankle in advance of the procedure. Additional routine perioperative studies include multiple radiographs of the knee: 4 preoperative, 2 postoperative, 3 at the six-week visit, and 3 at the one-year visit. The patients averaged 62.1 years of age at the time of surgery with 117 left-sided and 119 right-sided procedures, 25 of which were bilateral. Fifty-two percent of scans were in female patients.

The CT protocol uses helical scanning technology and is specific to the RIO robotic system, providing uniform set-up and radiologic parameters [7]. Both institutions use BrightSpeed Series CT system by GE Healthcare (Fairfield, CT). Contiguous axial slices (pitch = 1) are obtained through regions of the hip, knee, and ankle. The scan is continuous within each region, using either one series or a topogram with three groups. The parameters of the scan include a tube voltage of 120–140 kVp and a tube current of 200–400 mA. The hip region includes 2–5 mm interval spacing through the femoral head. The knee region includes 0.5–1 mm interval spacing with no gap or overlay, including the tibial tuberosity and patellofemoral region. The ankle region includes 2–5 mm interval spacing through the medial and lateral malleoli.

The dose report associated with the preoperative CT scan was queried for each patient to obtain the DLP for each body region scanned and the total DLP for the study, which are recorded during all scans. The ED was calculated from the DLP using the appropriate body region-specific conversion factor for extremity CT (hip = 7.31, knee = 0.44, ankle = 0.23, μSv/mGy cm) [14]. The ED values for each body region were summed to calculate the total ED for the study. The total number of additional CT scans and radiographs performed within the hospital system was counted for each patient as a measure of the volume of studies delivering ionizing radiation to the average knee arthroplasty patient in this cohort over time. Based on the type of additional CT examinations performed, an estimated cumulative ED attributed to CT examinations was calculated using the ED values in Table 1. While CT effective doses are highly dependent on patient size and scanner technology and parameters, reasonable dose estimates were chosen based on the range of published estimates.

Results

The mean DLP associated with the preoperative CT for robotic-assisted knee arthroplasty was 1545 ± 722.9 mGy cm. The mean ED was 4.8 ± 3.0 mSv, which is a dose equivalent to 48 chest radiographs (Table 2). A comparison of the two institutions performing the preoperative CT revealed a 3-fold difference in ED. At hospital #1, the mean DLP was 1106.2 ± 284 mGy cm, and the mean ED was 3.0 ± 0.8 mSv. At hospital #2, the mean DLP was 2470.2 ± 433.5 mGy cm, and the mean ED was 8.5 ± 2.2 mSv (Fig. 1).

The average arthroplasty patient in this cohort had additional sources of radiation exposure over time. Conservatively, counting only studies performed within the hospital system in which they were treated, all patients underwent multiple radiographs, with a mean of 15.4 ± 10.2 radiographs (range 12–98) per patient. Again, using a conservative estimate of only CT scans performed within the hospital systems in which they were treated, one or more additional CT scans (range 0–12) were obtained in 53 patients (25.1%), including head, facial, chest, abdomen, pelvis, spine, knee, and contralateral preoperative arthroplasty CT examinations. Twenty-five (11.8%) patients underwent bilateral arthroplasty with preoperative CT scans at an average interval of 3.8 months (range 0–14 months) with a mean DLP of 3077.9 ± 1285.8 mGy cm and a mean ED of 9.2 ± 5.1 mSv. The mean number of additional CT scans per patient was 0.6 ± 1.3. This does not include potential CT scans that may have been performed at other hospitals or facilities. The distribution of additional CT examinations is depicted in Table 3 with an estimated cumulative ED per patient (mSv), based on previous literature as listed in Table 1. For purposes of estimation, the mean ED associated with preoperative CT for knee arthroplasty was rounded to 5.0 mSv and 9.0 mSv, for unilateral or bilateral studies, respectively. The estimated cumulative ED from CT examinations per patient ranged from 6 to 103 mSv.

Discussion

More than 85 million CT scans are obtained annually in the United States, as compared with 3 million in 1980 [15]. Such growth prompts concern for patients and the population regarding radiation exposure and consequent cancer risks. On the basis of risk estimate and data on CT use, as many as 2% of all cancers in the U.S. may be attributable to the radiation from CT examinations [7,16–18]. While the cancer risks are often suggested to be low, the National Council on Radiation Protection and Measurement has indicated that the average annual background radiation exposure in the U.S. has almost doubled over the previous quarter century, with almost all of the incremental increase derived from medical imaging, particularly CT examinations [19]. While the rapid evolution of CT technology has allowed for expanded clinical applications, such as its use in knee arthroplasty, physicians and patients must consider radiation risk versus medical benefit and should be informed of radiation doses and their potential consequences.

Increasingly, CT scans are being used for preoperative mapping in computer navigation, robotic assistance, or customization of cutting guides in TKA and UKA [1,2,20–23]. Preoperative CT for knee arthroplasty requires special consideration given the non-diagnostic nature of the study, particularly with the availability of alternatives, such as conventional techniques, MRI-based methods for cutting guide customization, or image-free robotic technologies [5,6,24]. Despite widespread use, surgeons and patients have limited knowledge of the associated radiation exposure related to the CT scan for preoperative planning in knee arthroplasty.

Table 2
Mean Radiation Exposure Associated with Preoperative CT for Knee Arthroplasty.

CT Body Region	Mean DLP (mGy cm)	Mean ED (mSv)
Hip	603.2	4.4
Knee	598.7	0.26
Ankle	345.6	0.79
Total	1545.4 ± 722.9	4.8 ± 3.0