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The Use of Computerized Tomography Scans in Elective Knee and Hip Arthroplasty—What Do They Tell Us and at What Risk?

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ABSTRACT

The average background radiation exposure in the United States has nearly doubled over the previous quarter century, with almost all the increase derived from medical imaging. Nearly 2% of all cancers in the United States may be attributable to radiation from computerized tomography (CT) scans. Given the nondiagnostic nature of CT scans that are used in elective knee and hip arthroplasty today, special consideration should be given to the inherent risk of radiation exposure with routine use of this technology. Methods to decrease radiation exposure including modulating the settings of the CT machine and using alternative non-CT-based systems can decrease patient exposure to radiation from CT scans. The rapid evolution of CT technology in arthroplasty has allowed for expanded clinical applications, the benefits of which remain controversial.

Introduction

The use of computerized tomography (CT) scans has increased rapidly since its introduction in the 1970s. Its ability to provide 3-dimensional information is considered by some to be the single most important advance in diagnostic radiology [1]. Within the field of orthopedic surgery, CT scans may be utilized for diagnostic evaluation, preoperative planning, intraoperative assessment, and postoperative evaluations. Compared with other commonly used imaging modalities, including plain radiographs and magnetic resonance imaging (MRI), CT scans expose patients to the greatest amount of radiation [2]. This radiation comes with a set of risks. It is important for orthopedic surgeons to understand not only how CT scans are frequently used in musculoskeletal care of adults but also the potential harm that its radiation can cause and the potential alternative options.

First, we must understand how radiation is quantified. There are 3 primary measures to consider: the absorbed dose, the effective dose (ED), and the CT dose index (CTDI) [1]. The absorbed dose represents the energy absorbed per unit of mass, measured in milligrays (mGy). The ED represents nonhomogenous dose distributions, that is, the body region-specific dose sensitivities, and is designed to be proportional to a generic estimate of the overall harm to the patient caused by the radiation exposure [1]. The ED, typically measured in millisieverts (mSv), allows for direct comparison among different imaging modalities and is the key metric used in quantifying radiation exposure [2]. The ED is a rough estimate that can vary by a factor of 10 or more depending on the type of CT examination, variations in patient size, the CT system's operating technique protocols between institutions, and the limitations of dose measurement and calculation methods [3]. CTDI is useful for quality control but is not directly related to the organ dose or risk [4].

Risks from radiation exposure

Energy from radiation can knock electrons out of their orbits, leading to the creation of ions, such as hydroxyl radicals, which can interact with DNA and cause double-stranded breaks or base damage [1]. Additionally, radiation can ionize DNA directly. While most radiation-induced damage to a cell is rapidly repaired, mis-repair has the potential to lead to point mutations, chromosomal translocations, and gene fusions, each of which has the potential to induce cancer [1].

Much of our knowledge regarding the relationship between radiation exposure and cancer comes from studies looking at the

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effect of the atomic bombs dropped on Japan in 1945 [5]. This large cohort provides a heterogenous population in terms of age range and medical comorbidities with long-term follow-up. Overall, there was an increased risk of cancer in the group subjected to low-dose radiation, ranging from 5 to 150 mSv, with over 50% of the exposed individuals receiving less than 50 mSv of radiation [1,6].

In a multinational retrospective review of workers in the nuclear industry who were exposed to 5 to 150 mSv, there was an excess relative risk [7] of 0.97 per Sv for all cancers other than leukemia. In radiation doses of 100 mSv, the relative risk of developing solid cancers and leukemia excluding chronic lymphocytic leukemia was 1.10 and 1.19, respectively [8]. The Radiation Effects Research Foundation determined the relative risk of developing a solid cancer after 1 Sv of cumulative radiation exposure to be 1.6 [9,10]. This equates to a person receiving 1 Sv of cumulative radiation exposure having a 60% increase in their risk of developing solid cancer at any age [10].

While radiation is all around us, it typically is in such a low amount that the cumulative exposure is not thought to be a problem. For context, the average background dose due to natural radiation exposure is 3 mSv/y, a round-trip flight from New York to London is 0.1 mSv [6], and a conventional chest radiograph 0.08 mSv [2]. The U.S. Nuclear Regulation Commission has published 2 sets of recommended dose limitations. The first is termed "occupational dose" and refers to any dose received by an individual in the course of employment. The second, "public dose," refers to any radiation received by a member of the public from exposure to radiation or to radioactive material by a licensee or under control of a licensee [11]. For each license, occupational dose limits are set at 50 mSv/y for the whole body, and dose limits for the public are set at 1 mSv/y [12]. Ultimately, in an article published in the Proceedings of the National Academy of Sciences of the United States of America, Brenner et al. concluded that there is good evidence that acute exposures of 10-50 mSv carry an increased risk of cancer and reasonable evidence that there is some increased risk at doses above 5 mSv [6]. For protracted exposures, greater than 100 mSv has good evidence for increased risk of cancer, and greater than 50 mSv has reasonable evidence [6]. Brenner points out that the 5 mSv cutoff is largely set by the epidemiology of the studies and does not necessarily mean that radiation below this level has no risk.

The International Commission on Radiological Protection recommends limiting radiation exposure to an ED of 20 mSv/y, averaged over 5 years [5]. An additional caveat states that in any given year, the ED should not exceed 50 mSv [13]. The International Commission on Radiological Protection has also published specific equivalent doses of radiation that should not be exceeded in any one particular year for specific body parts—for example, 150 mSv for the lens of the eye, 500 mSv for the skin, and 500 mSv for the hands and feet [13]. The American College of Radiology position statement recognizes that low doses of CT radiation may cause harm [14], and the U.S. Food and Drug Administration has stated that an effective CT radiation dose of 10 mSv may be associated with the possibility of fatal cancer in approximately 1 in 2000 patients compared with the natural incidence of fatal cancer in the United States ($\approx$1 chance in 5) [15]. In fact, the U.S. FDA has warned that steps should be taken to mitigate exposure to avoidable radiation [16]. A National Cancer Institute study estimates that CT scans performed in the United States in 2007 may cause 29,000 excess cancer cases and 14,500 excess deaths over the lifetime of those exposed [17].

Implications for orthopedic computer tomography scans

In their *New England Journal of Medicine* review of CT imaging, Brenner and Hall concluded that there is enough evidence from epidemiologic studies that the radiation delivered during a common CT study results in an increased risk of cancer, when it includes 2 or 3 scans and a cumulative organ dose of 30 to 90 mSv [1]. This is not inconsequential given the evidence that radiation doses corresponding to a common CT study result in an increased risk of cancer, likely through radiation-induced carcinogenesis. While single scans may pose risk that can be rationalized, the radiation burden is cumulative with additional CT scans or other sources of radiation during the course of one's life irrespective of time intervals between scans [1]. 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 with the 1 in 5 natural incidence of fatal cancer in the U.S. population [18]. In a study by Ponzio and Lonner, depending on which of the 2 institutions performed preoperative CT imaging for robot-assisted knee arthroplasty, the resultant mean CT-associated ED were 3.0 $\pm$ 0.8 mSv and 8.5 $\pm$ 2.2 mSv [3]. Furthermore, in that study, compounding matters, the average arthroplasty patient had additional sources of radiation exposure over time, including 25% who had additional unrelated CT scans [3]. In that study, 12% of patients underwent bilateral arthroplasty with preoperative CT scans at an average interval of 3.8 months with a mean ED of 9.2 $\pm$ 5.1 mSv. The mean number of additional unrelated CT scans per patient was 0.6 $\pm$ 1.3, not including potential CT scans that may have been performed at other hospitals or facilities. 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 and bilateral studies, respectively. The estimated cumulative ED from CT examinations per patient thus ranged from 6 to 103 mSv [3].

It is important to understand the radiosensitivity of different tissues, as imaging of various parts of the body delivers different doses of radiation. Biswas et al. quantified the ED of radiation associated with CT scans of musculoskeletal structures (Table 1) [2]. Overall, the ED decreases as more distal structures are imaged. CT scans of the torso, spine, and proximal extremities deliver a dose of radiation associated with measurable risk, but CT scans of the distal extremities may expose a patient to less radiation than a posteroanterior chest radiograph [2].

The purpose of this article is to review the use of CT scans in elective knee and hip arthroplasty in 2 of the phases of musculoskeletal care—preoperative and postoperative—with a focus on the amount of radiation delivered to patients in each instance.

Preoperative imaging and planning

Preoperative CT images are generally ordered to better characterize the underlying bony anatomy in unusual cases, for planning for computer navigation or robotic surgery, or for the development of patient-specific cutting guides or implants.

Robotic surgery and computer-assisted orthopedic surgery

One of the largest increases in CT scan use has been in the evolution of computer-assisted orthopedic surgery (CAOS), particularly with robotics. One statewide analysis reported a 500% increase in the utilization of robotic assistance in all knee replacements performed between 2009 and 2013, jumping from 0.2% in 2009 to 1.2% in 2013 [20]. A recent survey of the membership of the American Association of Hip and Knee Surgeons taken between November 2019 and January 2020 found that 33% are using robot assistance for total knee arthroplasty (TKA) many of which incorporate preoperative CT scanning [21].

Proponents of CAOS and robotics cite increased accuracy of component alignment and positioning, quantified soft-tissue balance, and reduced leg length inequalities as reasons for the

Table 1

Effective doses of computerized tomographic examinations and the number of equivalent conventional chest radiographs.

Scan	No. of scans	Effective dose[a] (mSv)	No. of conventional chest radiographs needed for equivalent dose[b]
Chest, abdomen, and pelvis			
Chest	20	5.27 ± 1.68	65.88
Abdomen	20	4.95 ± 1.40	61.88
Pelvis	20	4.85 ± 1.74	60.63
Upper extremity			
Shoulder	20	2.06 ± 1.52	25.75
Elbow (arm only)	20	0.14 ± 0.22	1.75
Elbow (body)	20	8.35 ± 5.88	104.38
Wrist and hand	20	0.03 ± 0.03	0.38
Lower extremity			
Hip	20	3.09 ± 1.37	38
Knee	20	0.16 ± 0.12	2.00
Ankle and foot (unilateral)	20	0.07 ± 0.05	0.88
Spine			
Cervical	20	4.36 ± 2.03	54.50
Thoracic	20	17.99 ± 6.12	224.88
Lumbar	20	19.15 ± 5.63	239.38

[a] The values are given as the mean and the standard deviation.
[b] The effective dose of a conventional chest radiograph has been reported to be approximately 0.08 mSv [19].

Reused with permission from Biswas D, et al. Radiation exposure from musculoskeletal computerized tomographic scans. J Bone Joint Surg Am. Aug 2009;91(8):1882-9. https://doi.org/10.2106/jbjs.H.01,199.

technology's use [22,23]. A substantial distinction between the different available CAOS and robotic systems has to do with whether they require CT scans for preoperative planning, landmark determinations, and measurements or whether the surgeries can be performed without preoperative CT scans [24,25].

While ROBODOC (now TSOlution One; THINK Surgical, Fremont, CA), first released in the mid-1990s, and Mako (Stryker Corporation, Mahwah, NJ), first released in the mid-2000s, both require a preoperative CT scan to delineate bony landmarks and assist in the planning algorithms, newer image-free systems are also now broadly used—Omnibotic (Corin, Gloucestershire, UK), Navio/CORI (Smith and Nephew, Memphis, TN), ROSA Knee (Zimmer Biomet, Warsaw, IN), and VELYS (DePuy Synthes, Warsaw, IN)—do not require preoperative CT scans, with comparable outcomes in terms of component positioning [19,26–30] (Tables 2 and 3).

Patient-specific instrumentation

The goal of patient-specific instrumentation (PSI) is similar in many ways to that of CAOS—use detailed patient information to more accurately make bone cuts and position the arthroplasty components. The patient-specific guides are created from preoperative CT or MRI scans that include various combinations of the knee, hip, and ankle (Table 4). Similar to robotic and computer navigation strategies, the intended benefits in knee arthroplasty include reduced instrumentation, avoidance of violating the femoral intramedullary canal, and improved component alignment and thus stress distribution across the implant [30].

A novel strategy and extension of PSI has been the customization of implants to better fit the surfaces of the knee, rather than relying on off-the-shelf implants, which are designed based on average bone sizes and shapes [33,34]. In the case of knee arthroplasty, building these custom implants typically relies on CT or MRI scans of the hip and ankle in addition to the knee [35].

Radiation associated with preoperative imaging

The radiation associated with a preoperative pelvis CT scan is an added risk and has been calculated to deliver 3 times the radiation of a standard plain hip radiograph series [36]. Huppertz et al. determined that the mean ED of a CT for preoperative total hip arthroplasty planning (including CT pelvis [12.7 seconds], CT knee [6.8 seconds], and CT ankle [6.4 seconds]) was 4.0 mSv (SD 0.9 mSv) [37] compared with the ED of an anteroposterior pelvis radiograph which has been reported to be between 0.7 and 1.0 mSv [37]. Furthermore, the presence of a contralateral hip endoprosthesis may lead to a small but insignificant increase in the ED. The 4.0-mSv ED is on the lower end to what other groups have found, with the average dose for a pelvic CT scan alone reported to range from 4.0 mSv to 20.0 mSv [38–40]. Ponzio and Lonner found that the ED delivered by preoperative CT scans for unicompartmental knee arthroplasty (UKA) ranged from 3.0 mSv to 8.5 mSv with the only variable being the hospital location at which the scan was performed [3]. Similarly, Huppertz el al. found that the ED for preoperative total hip arthroplasty planning ranged from 1.2 to 7.8 mSv [41].

Given that acute exposure over 10 mSv is associated with an increased risk of cancer [6], routine use of these preoperative CT scans should be carefully weighed, especially in patients undergoing elective surgery. As imaging is moved from the pelvis to distal extremities, the radiation dose delivered to the body decreases. The ED for a CT of the knee is estimated to be 0.16 mSv, and ED for a foot and ankle to be 0.07 mSv [2]. In the upper extremity, a CT shoulder exposes the patient on average to 2.06 mSv [2].

Costs associated with preoperative CT planning

In a review of CT scans performed for primary robot-assisted TKA, Abdelfadeel et al. found that the mean total payment for a preoperative scan was $446, but there was wide variation based on location, negotiated contracts, and other geographical variations [42]. Another cost that should not be overlooked is the potential unnecessary costs accrued to investigate incidental, and typically unimportant, findings found on CT scans [42]. Furthermore, the cost of radiation-induced illness is not well considered at this time.

Table 2

Current FDA-approved robotic arthroplasty platforms.

Robotic system	Corporation	Arthroplasty	Preoperative planning
TSolution One (Robodoc)	Think Surgical, Fremont/CA/USA	TKA, THA (femur)	CT scan
OMNIBotics	Corin, Gloucestershire/UK	TKA	None
MAKO	Stryker Corporation, Mahwah/NJ/USA	UKA, PFA, TKA, THA	CT scan
Navio/CORI	Smith and Nephew, Memphis/TN/USA	UKA, PFA, TKA	None
ROSA Knee	Zimmer Biomet, Warsaw/IN/USA	UKA, TKA, THA	None or x-ray
Velys	DePuy Synthes, Warsaw/IN/USA	TKA	x-rays

THA, total hip arthroplasty; TKA, total knee arthroplasty; UKA, unicompartmental knee arthoplasty; PFA, patellofemoral arthroplasty.

Table 3
Final implant alignment compared with planned implant alignment for robotic devices reported in relative error in degrees (standard deviation in parenthesis).

Study	Robot	Parameters relative to plan			
		Femur		Tibia	
		Coronal	Sagittal	Coronal	Sagittal
Parratte et al [19]	ROSA	0.03 (0.51)	−0.95(0.88)	−0.06 (0.69)	0.2 (0.84)
Casper et al [28]	Navio	−0.1 (0.9)	−2 (2.2)	−0.2 (0.9)	−0.2 (1.3)
Li et al [31]	MAKO	0.57 (NR)	NR	0.48 (NR)	0.54 (NR)
Cosendey et al [32]	TSolution One	−0.03 (0.19)	0.14 (0.69)	−0.50 (0.36)	0.25 (0.48)

NR, not reported.

Other uses of CT including postoperative period

Postoperative CT scans generally are ordered when patients continue to experience pain or decreased function after TJA to evaluate for subtle loosening, osteolysis, patellar maltracking, or component malposition. There is not a standard role for CT scans after elective orthopedic surgery although there is academic interest in determining component position when comparing different techniques or surgical technologies. Given the above risks, patients undergoing postoperative CT scans as part of a research study should be fully advised regarding the possible risks associated with radiation exposure.

The as low as reasonably achievable principle

In light of these radiation exposure risks, CT examination protocols and techniques should be optimized and standardized across sites to limit the radiation associated with individual scans. This would include reducing multiple series within each examination, implementing dose-reduction strategies, and encouraging participation in accreditation programs [43]. A study by Ponzio and Lonner highlights the wide range of CT examinations that a typical arthroplasty patient undergoes for a variety of medical concerns over time, including potential imaging for preoperative arthroplasty planning, with cumulative radiation exposure of up to 103 mSv (the equivalent of 1030 chest radiographs) [3]. In worse case scenarios, albeit relatively uncommon, if a caregiver and patient are committed to using technologies that require preoperative CT imaging, radiation exposure may be inadvertently compounded if upon review of the scan the quality is deemed inadequate for mapping, planning, or instrument fabrication, due to motion artifact or breach in standard scanning protocols. These numbers will continue to increase as increasingly more patients are undergoing technology-based surgery, including with robotics, that require CT imaging preoperatively.

When reviewing how CT scans are used in orthopedic surgery, there are 2 general ways to decrease the radiation exposure; (1)

decrease the number of scans and (2) operate under the "as low as reasonably achievable" principle [44]. Rather than directly trying to decrease the radiation dose, which may limit the quality of information provided, the goal should be to optimize radiation such that the image quality maintains a diagnostic standard with the lowest amount of radiation possible delivered to the patient [45].

The use of low-dose CT reconstruction algorithms has been shown to lower the median CTDI without negatively impacting the diagnostic value [46]. This method may be highly appropriate for preoperative planning for elective joint arthroplasty. The dose of radiation for a given CT scan is also affected by the scan itself. As technology continues to improve, different types of CT scans will be available and deliver a lower dose of radiation. For example, a study by Dubreuil et al. compared image quality and radiation dose between cone-beam CT and multislice CT [47]. They found that cone-beam CT delivered significantly less radiation to the patient (average CTDI 2.8 mGy vs 13.1 mGy) than multislice CT while providing high-enough-quality images for fracture classification [47]. Much like how CT scans have historically been used in addition to radiographs when more detail is needed or unseen injury is suspected, low-dose CT scans will likely be the first line of evaluation and multislice CTs which deliver a higher dose of radiation only ordered if additional information is needed.

The settings of the CT machine itself can be changed to lower the dose of radiation delivered to the patient. Many variables including the number of scans, the pitch, the tube current, tube voltage, scanning time, the size of the patient, the axial scan range, shielding, and the specific design of the scanner being used impact the radiation dose received by the patient [1,45,48]. The tradeoff in aiming for low doses of radiation is an increase in background noise which decreases the quality of the image [49]. Because these settings are variable, there is variability between hospitals in the radiation dose to which patients are exposed for the same type of scan. In a review of radiation doses associated with common CT scans, Smith-Bindman et al. concluded that the radiation doses experienced by patients were higher and more variable than those generally quoted [43]. Specifically, the average dose for a CT

Table 4
PSI systems in hip and knee arthroplasty.

PSI system	Corporation	Arthroplasty	Preoperative planning
ConforMIS	Conformis, Billerica/MA/USA	TKA, THA, UKA, BiKA	CT
MyKnee system	Medacta-International, Castel San Pietro/Ticino/CH	TKA	MRI or CT
PSI Knee	Zimmer Biomet, Warsaw/IN/USA	TKA	MRI or CT
TruMatch system	DePuy Orthopedics, Warsaw/IN/USA	TKA	CT
Visionaire system	Smith and Nephew, Memphis/TN/USA	TKA	MRI and full-length AP radiograph
Signature system	Zimmer Biomet, Warsaw/IN/USA	TKA, THA (acetabular only)	MRI or CT
Hip Plan	Symbios, Yverdon-les-Bains/Vaud/CH	THA (acetabular only)	CT
aMace	Materialise, Leuven/Belgium	THA (acetabular only)	CT
MyHip	Medacta-International, Castel San Pietro/Ticino/CH	THA (acetabular and femoral)	CT or MRI
OPS	Corin, Gloucestershire/UK	THA (acetabular and femoral)	CT

AP, anteroposterior; THA, total hip arthroplasty; TKA, total knee arthroplasty; BiKA, bilateral knee arthroplasty; UKA, unicompartmental knee arthoplasty.

abdomen-pelvis without contrast ranged from 2.9 mSv to 43 mSv, which is well above the quoted threshold of 10 mSv leading to increased risk for cancer [43]. In that study, there was a 13-fold (range, 6- to 22-fold) variation between the highest and lowest dose scans for a variety of comparable CT studies across 4 institutions. As noted above, CT scans performed for preoperative robotic arthroplasty mapping and planning had a 2.5- to 3-fold difference in radiation exposure depending on where the scans were done [3]. As CT scans have improved in quality, there is an increased risk of unnecessary radiation exposure to patients. A helical scan relies on scanning parameters with extra rotations outside of the planned length for image reconstruction. While an x-ray tech can carefully select scanning parameters to minimize this excess exposure, it is an area where patients are exposed to increasing radiation [50,51]. Reducing the tube voltage of the machine is another way that patients are not exposed to unnecessary radiation [37].

Patient positioning can also dramatically affect the dose of radiation received by the patient. A traditional CT of the elbow, with the patient's arm positioned at their side, gives an average dose of 8.35 mSv as the intraabdominal cavity and chest are included. When the arm is positioned above the head, the average dose of a CT elbow drops to 0.14 $mSvAs^2$. One in 10 Americans undergoes a CT scan every year; eliminating or limiting the dose of each scan can make a big difference in cumulative radiation exposure [3].

Alternatives to conventional CT imaging

While the risk of radiation-induced cancer is much smaller than the natural risk of cancer for any individual, the small increase in radiation-associated cancer risk for an individual can become a public health concern if large numbers of the population undergo increasing numbers of CT examinations of uncertain benefit. This is particularly important because the threshold for using CT has declined, and CT is increasingly being used among healthy individuals, in whom the risk of potential carcinogenesis from CT could outweigh its diagnostic value [52]. Currently in the United States, if just 20% of the roughly 1 million knee arthroplasty procedures in the United States are being performed with robotic technology that requires preoperative CT scanning, representing approximately 200,000 cases with additional radiation exposures per year, it is not unreasonable to sound an alarm about a potential health concern. In consideration of efforts to decrease radiation exposure, nondiagnostic CT examinations, as used for robot-assisted knee arthroplasty or for customization of cutting guides, are not an ideal application of this technology and may be best substituted by navigation systems or cutting guide customization methods that are not dependent upon CT imaging if accuracy and safety are not compromised. Indeed, published data demonstrate equivalent precision of alignment with CT-based and image-free robot-assisted TKA and UKA systems, as well as safety, raising the question of whether the use of CT is justified in light of its increased cost and risk [53–55].

Besides decreasing radiation exposure, it is important to consider other imaging modalities that can provide similar information to CT scans. Historically, bone models based on MRI are more prone to artifact, and measurements taken from this imaging are less predictable than those from CT scans [56]. Additionally, plain radiographs may replace CT scans for preoperative planning and have been shown to create highly accurate 3-dimensional models both for PSI and robotic assistance [57,58]. Alternatives to CT scans for preoperative planning in robotics/computer navigation, custom guide or implant development may thus be reasonable alternatives when available and practical.

Conclusions

CT scans provide valuable information regarding bony detail, aiding in surgical planning and facilitating advanced technologies. However, with more than 85 million CT scans performed annually in the United States [59], its routine use for preoperative planning in elective orthopedic cases for elective surgery must be considered in the context of its inherent risks in terms of radiation exposure for the patient. Modulating the settings of the CT machine or using alternative non-CT-based systems can decrease patient exposure to radiation from CT scans. The risk estimates on CT use and its role in contributing to cancer are not insignificant. In fact, as many as 2% of all cancers in the United States may be attributable to the radiation from CT scans [60]. The National Council on Radiation Protection and Measurement has indicated that the average annual background radiation exposure in the United States has almost doubled over the previous quarter century, with almost all the incremental increase derived from medical imaging, particularly CT examinations [61]. Therefore, while the rapid evolution of CT technology has allowed for expanded clinical applications—such as its use in developing PSI for joint arthroplasty, computer-assisted surgery, and robotics, physicians and patients must consider the radiation risk vs medical benefit of these scans, particularly when there are alternative methods of assessment [62–65]. Preoperative CT for knee and hip arthroplasty requires special consideration given the nondiagnostic nature of the study, particularly with the availability of alternatives, such as conventional techniques, MRI-based methods for cutting guide customization, portable hand-held accelerometer-based navigation, or image-free robotic technologies [66–70].

Conflicts of interest

Dr. Lonner receives royalties from Zimmer Biomet and Smith and Nephew, is a member of the speakers bureau of/delivers paid presentations at Zimmer Biomet, is a paid consultant for Zimmer Biomet, Smith and Nephew, and Force Therapeutics, owns stock in Force Therapeutics, receives research support as a principal investigator from Zimmer Biomet, Smith and Nephew, and Force Therapeutics, receives royalties and financial or material support from Wolters Kluwer and Springer, and is a board member of the American Association of Hip and Knee Surgeons and Knee Society; Dr. Klein receives royalties from Zimmer Biomet, is a paid consultant for Zimmer Biomet, receives research support as a principal investigator from Zimmer Biomet, receives royalties and financial or material support from Jay Pee Publishers, and is a board member of the AAOS (Hip Committee); all other authors declare no potential conflicts of interest.

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