Lateral Scatter Effects on Dose Due to a Metal Prosthesis

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Three-dimensional treatment planning is an important part of the radiation therapy process, and there are numerous 3-D systems on the market today. Two of the more common planning systems are Pinnacle (Philips Medical Systems, Andover, Mass) and Eclipse (Varian Medical Systems, Palo Alto, Calif). Sophisticated software drives these 3-D systems[1] and makes it possible to treat patients effectively by providing safe, accurate and easy-to-use tools to plan, evaluate and optimize radiation therapy.[2]

For the past decade, most treatment planning systems using computed tomography (CT) images have provided detailed information about the density and geometry of internal structures. However, for cases in which metallic implants such as prosthetic hip joints are present, distortions that appear on CT scans as streaking starbursts challenge the treatment planning system's ability to interpret the density of objects. This leads to inaccurate dose predictions that could cause treatment complications.[3]

This situation raises several important questions: Are there dose distribution differences between treatment fields that include a metallic prosthesis and fields that do not? Is this difference significant enough that it should be accounted for in treatment planning? Can it lead to overdosing or underdosing a treatment area?

Previous research has tested the effects of treatment through a metallic prosthesis. A study by Keall and Siebers[4] demonstrated significant underdosing of tissue behind an irradiated prosthetic device. This underdosing can be attributed to the absorption of dose by the prosthesis and the scatter of particles laterally off the prosthesis to other tissues and even outside the treatment port. In the treatment of soft tissue sarcomas of the extremities, "it is imperative to spare at least a 1-cm strip of soft tissue in the circumference of the extremity to avoid subsequent edema."[5] Because human bone and metallic prostheses have different densities and attenuation properties, it is assumed that prostheses contribute more scatter than bone.[6] However, how much more scatter is unknown.

This study assessed lateral scatter radiation off a metallic prosthesis. The goal was to determine whether the lateral scatter is significant enough to contribute to dose outside the field, thus compromising the margins and, in particular, the margin left for lymphatic drainage.

We hypothesized that the variance is significant and that the lateral dose contributed from prosthesis scatter is distributed outside the field edge. The results of this study may indicate a need to update current treatment planning systems so that dose calculations differentiate between a metallic prosthesis and bone within a treatment field. It may be appropriate to increase lateral margins for limbs with prosthetic implants to account for increased lateral scatter.

Methods

We performed a simple experiment to compare the results of irradiating 2 water phantoms. The first phantom (the control) contained human bone and was placed 4 cm below the water's surface. Thermoluminescent dosimeters (TLDs) were positioned at the depth of the bone's midplane and at lateral distances of 0.5 cm, 1 cm and 1.5 cm. The second phantom (the experimental variable), which contained a prosthesis made of cobalt chrome, was placed 4 cm below the water's surface, with TLDs located at the depth of the prosthesis' midplane. As with the control phantom, the TLDs were placed laterally at distances 0.5 cm, 1.0 cm and 1.5 cm from the prosthesis.

The 2 phantoms were each irradiated using a 5 x 10-cm field with a 4-MV beam energy using 100 monitor unit (MU). The bone and prosthesis were positioned so that the field edge was 1 cm from the edge of the bone or prosthesis. Three trials were

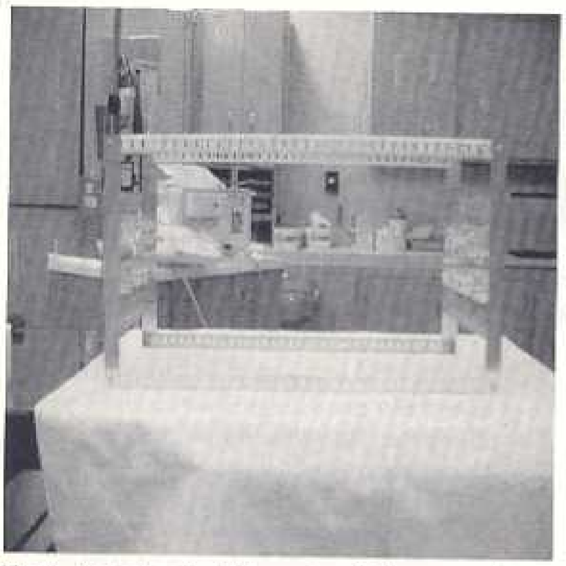

Fig. 1. Central and midplane view of the water tank.

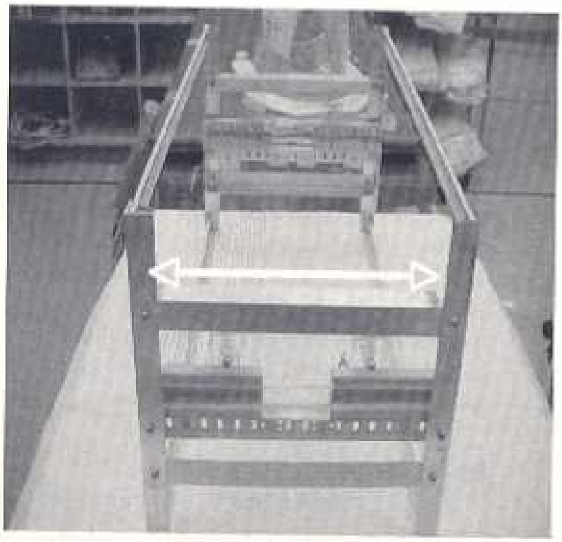

Fig. 2. Lateral view of the water tank.

conducted for both phantoms at each of the 3 distances. The doses recorded by the TLDs in each trial were averaged to yield a mean dose for each phantom at each point. This data was then analyzed to determine what effect lateral scatter from the prosthesis had on dose distribution to the surrounding tissue.

Procedure

The initial step in the experiment was to develop a water phantom that allowed for proper positioning of the bone or prosthesis and the TLDs at the 3 distances used for data collection. The challenge was to find a method to position the TLDs with regard to a 3-D coordinate system: lateral distance from the bone or prosthesis (x-coordinate), position relative to the central axis of the beam (y-coordinate) and position relative to the midplane of the bone or prosthesis (z-coordinate). To meet these requirements, we constructed a metal frame that fit inside a 10-gallon aquarium. The frame was assembled out of angled iron and metal shelving frames as shown in Figures 1 and 2. The framework had to be large enough to accommodate the distance between the TLDs and the test material and not contaminate the experiment.

Attached to the frame was an adjustable system designed to allow up to 17 strands of fishing line to be strung across the length of the frame. The lines were parallel and were spaced 0.5 cm apart. The fishing lines allowed the TLDs to be positioned in the x and y coordinates at desired depth z. (See Figs. 3 and 4.)

The next quandary was to position the bone or prosthesis. To solve this problem, we constructed adjustable shelves from plexiglass, bolts and wing nuts. The shelves were designed so that the bone or prosthesis could be positioned across the length of the tank and be supported by shelves at either end. The shelves' height could be adjusted so that the midline of the bone or prosthesis was parallel to the fishing lines. The shelves remained far enough away from the radiation field to prevent them from contributing to scatter. (See Figs. 5, 6 and 7.) After the components were constructed, the frame and shelves were placed inside the tank. (See Fig. 8.)

To conduct the experiment, a 5 x 10-cm field size was set on the linear accelerator. The bone was placed on the shelves and positioned so that its lateral edge touched the first fishing line. The radiation field was designed so that the projected field edge was lateral to and 1 cm away from the bone. The tank then was filled with water to a level that put the bone's midplane 4 cm deep. The 3 TLDs were located 0.5 cm (point A) from the bone on the second fishing line and at the central axis of the beam (y coordinate). The water phantom was then irradiated with a 4-MV beam using 100 MU. The TLDs were exchanged for 2 more trials at the same point, 0.5 cm inside the treatment field, to validate the data. This process was repeated at 1 cm (the field edge, point B) for 3 trials and 1.5 cm (0.5 cm outside of the field, point C) for 3 trials. The same procedure was used to measure the dose with the prosthetic cobalt limb. Figure 9 illustrates the position of the limb relative to the treatment port and the TLDs at points A, B and C.

Results

The readings from the 3 TLDs were averaged to get the mean dose for each trial. The mean doses of the trials then were averaged to get the mean dose for each distance. Then the doses for the bone and prosthesis were compared for each distance. There was a 20.3% increase in dose at 0.5 cm when the prosthesis was irradiated compared with the bone. Furthermore, there was a 34.8% increase in dose at 1 cm and a 27.5% increase at 1.5 cm when the prosthesis was irradiated compared with the bone. (See Table 1 and Fig 10.)

To understand the effects of this increase, it would be most useful to compare total dose with tissue tolerance dose. Soft tissue sarcomas are treated postoperatively with 1.8 to 2.0 Gy fractions to doses of 45 to 50 Gy. Reduced fields are treated to doses of 55 to 65 Gy, with boost fields not to exceed 75 Gy.[7] These doses are safe when no prosthesis is present because skin is relatively radioresistant. Studies have shown the tolerance of skin to be 70 Gy, which is when necrosis begins.[7] However, the increase in dose to lateral tissue caused by scatter from a prosthesis could exceed the tolerance dose for soft tissue.

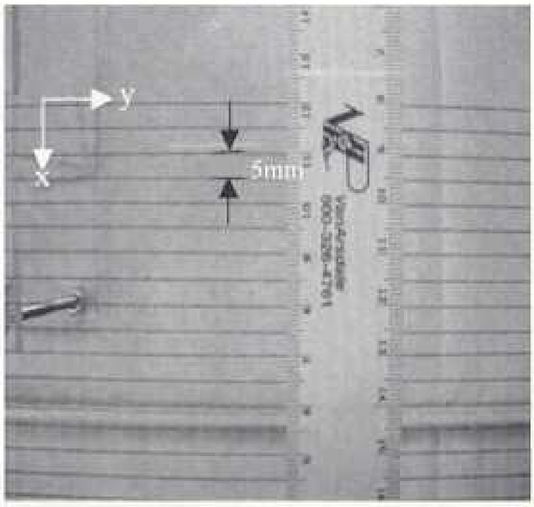

Fig. 3. Support assemblies.

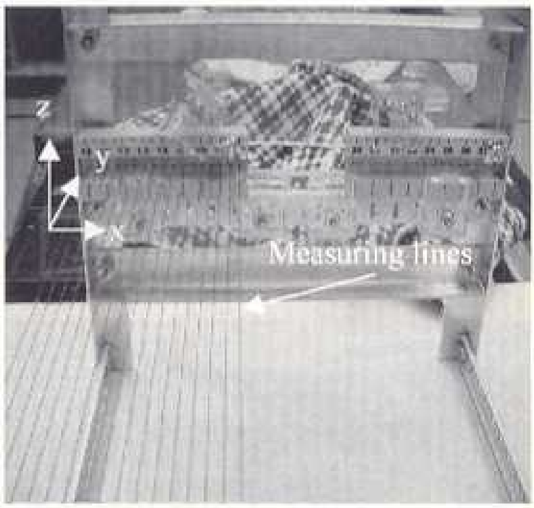

Fig. 4. Support wires, 0.5 cm apart.

Discussion

The data show a significant increase in dose due to lateral radiation scatter from a metal prosthesis compared with human bone. It is important to note that at the distances we measured, the increase in dose is within the radiation field; however, there are normal tissue structures within the radiation field that may be damaged by additional scattered radiation. Regarding the dose outside the radiation field, the scatter produced by the metal prosthesis significantly increased the dose at the 1.5-cm point by 27.5% compared with scatter resulting from human bone. Although this percentage is high, it is also important to consider the overall difference in dose. The increased dose at 1.5 cm can be construed as less detrimental than the contributions at 0.5 cm and 1 cm.

One of the objectives of this experiment was to determine if steps must be taken to spare tissues outside the radiation field from lateral scatter caused by irradiation of a metallic prosthesis. Although this proved to be of minimal concern, the possibility of exceeding tissue tolerance just outside the radiation field is of great interest. Because of the inability of some treatment planning systems to account for the dose distribution created when a metal prosthesis is irradiated, it is possible that the resultant lateral scatter could cause a significant dose increase to normal tissue structures. The treatment team should take this into consideration and make every effort to retain lymphatic drainage when a prosthetic implant is present.

Table 1
Mean Dose for Bone and Prosthetic Phantoms

Point/Distance	Dose (Bone) cGy	Dose (Prosthesis) cGy	% Increase
A (0.5 cm)	70.4	84.7	20.3
B (1 cm)	43.9	59.2	34.8
C (1.5 cm)	8.31	10.6	27.5

An experiment testing the same variables but using a more sophisticated water phantom, multiple energies and more precise techniques for measuring dose could improve the accuracy of this study. It would also be interesting to compare the doses achieved in this experiment or a replication of the experiment to doses calculated by different treatment planning systems. Although the methods used in this study may be considered crude, the results should stimulate interest in investigating the topic further. ◆

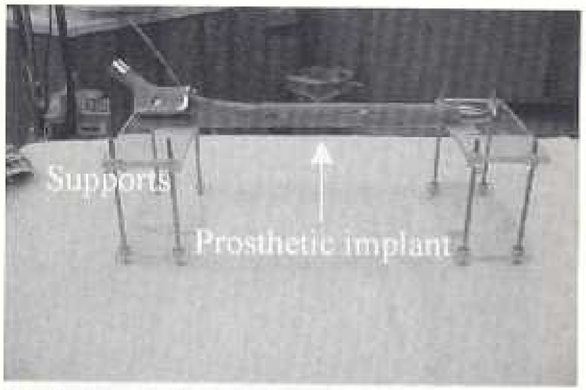

Fig. 5. Supported prosthetic implant.

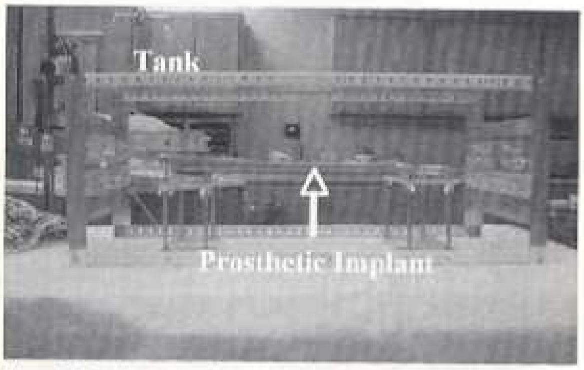

Fig. 6. Prosthetic implant in tank.

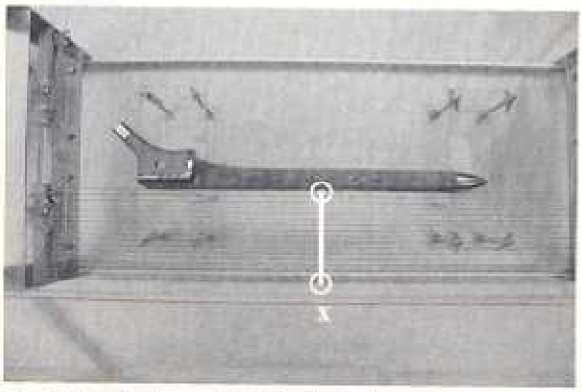

Fig. 7. Prosthetic implant, view from above.

Fig. 8. Prosthetic limb positioned.

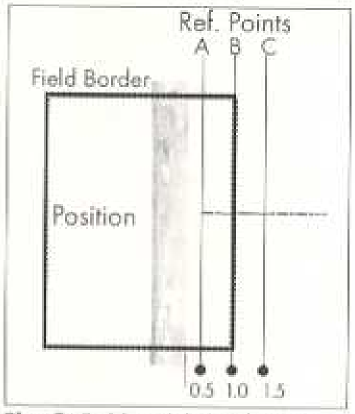

Fig. 9. Field and thermoluminescent dosimeters positions.

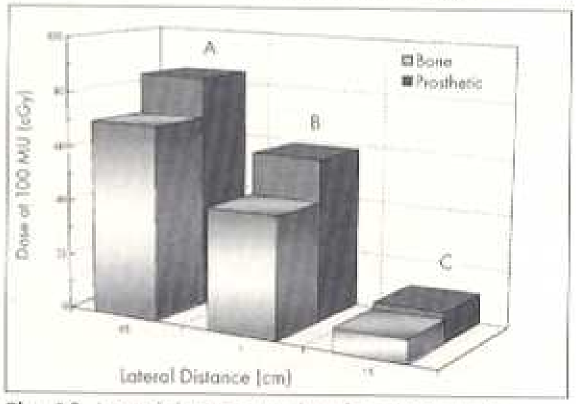

Fig. 10. Lateral distances vs dose for a bone and a prosthetic phantom.

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