The influence of various vascular access ports on MV photon beam uniformity examined on the PMMA phantom

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Abstract. The presence of a high-density material object such as the vascular access port made of titanium, can affect the homogeneity of dose distribution in underlying tissues. This influence depends on numerous factors but in the first place on the composition material of such an object and its geometry. In this work an influence of the various titanium-made vascular ports, placed in the 6 MV photon field, have been analyzed. The vascular ports of various sizes were placed on the top of the polymethyl-methacrylate (PMMA) phantom which is then scanned on a computed tomography (CT) simulator to generate the digitized 3-dimensional images for the purpose of treatment planning. The treatment plans were prepared in matRad treatment planning toolkit. The beam profiles and the percentage depth doses have been analyzed. The observed maximum dose values, for ports A, B, C and D, relatively to the maximum dose value in PMMA phantom alone, were 102.25%, 100.62%, 101.78% and 102.48%, respectively. The titanium edges of the ports reduce the dose below them in amount of 8.52%, 8.64%, 10.01% and 10.04% observed for ports A, B, C and D, respectively, in comparison to the central axis dose value obtained in PMMA phantom for the port-free case. The established changes in PDD curves and beam profiles depend on the vascular access port dimensions, reservoir volumes as well as of the amount of titanium content.

1. Introduction

The vascular port is long-term implantable vascular access system composed of port chamber connected to a catheter with a silicone septum on top. It comes in venous, arterial and spinal version, each with its own indications. Each vascular access port system comprises some, mainly single use, accessories for implantation of port (tunneler, introducer, guide wire, coring needle).

These devices vary in construction materials, shapes and sizes. The portal chamber is made of hypoallergenic biocompatible titanium. This material is non-magnetic. The base plate has holes for securing the system to the fascia with sutures. The catheter is connected to the portal chamber through the portal outlet tube and locked. It is conically tapered at the tip and it has calibration marks that allow its reliable positioning and shortening at the proximal end.

The silicone septum allows direct access of a needle for drug injection or collection of samples into the reservoir. It can be punctured frequently, up to 3000 times, but only with a special SFN (Stanzfreie Nadel) non-coring access needle. The silicone septum is highly resistant to pressure and holds the inserted needle reliably in place. The needles have a unique bevel and angle at the tip. This prevents punch defects of the silicone septum when the needle is inserted. Different lengths and diameters of needles are available, but 20 or 22 Gauge is most common in standard use [1,2].
Various techniques are available for implantation of vascular port system; the choice of technique depends on the surgeon's preference. The vascular access port catheter may be placed in the central venous circulation by surgical cut down or percutaneous puncture of an appropriate vein [3].

The implantation of vascular port system is usually possible under local anesthesia, and sterile handling is absolutely mandatory during implantation.

It is recommended to place catheter into vein with strong blood flow (cephalic vein, subclavian vein, or internal and external jugular veins). Radiological assessment of the correct position of catheter tip should be carried out [4].

Subcutaneous pocket for port chamber placement should be created on anatomical site where it will be supported by a reliable bony structure and not interfere with mobility of patient. The most common place for port chamber placement is anterior thoracic wall in the right or left infraclavicular space. The port chamber should be placed on minimum depth of 0.5 – 1 cm, and easily identifiable upon digital palpation and accessible [5].

The vascular access port is indicated to be implanted into vascular system for long-term use in order to permit repeated access to the vascular system for: long-term treatment with chemotherapy agents and other aggressive medication, patients with poor peripheral veins, antibiotics infusion therapy, parenteral nutrition, blood transfusions and venous blood sampling.

Since vascular access ports are widely used among radiation oncology patients, it is important to investigate how vascular access port, as a foreign material implanted into human body, affects radiation therapy dose distribution.

To achieve a homogenous dose distribution in a treatment volume is the crucial requirement in order to meet the radiation therapy treatment goal. Any inhomogeneity in the treatment area, whether it is anatomical or caused by the presence of a foreign object, can compromise this goal. A complexity of a treatment planning and delivering process can be increased in order to overcome this inhomogeneity problem. The changes in the attenuation and scatter processes, including backscatter, due to material inhomogeneity are the main causes of changes in the dose distribution. The high-density materials such as vascular access ports, especially those made of titanium, can significantly affect the dose distribution for the underlying tissues [6], including a treatment volume. In this work the effects of four titanium-made vascular access ports, different in shape and size, on the 6 MV photon beam's profile and on the characteristics of its percentage depth dose (PDD), observed in the polymethyl-methacrylate (PMMA) phantom, have been described.

2. Methodology and materials

The percentage depth dose curve, especially build-up region and depth of maximum dose, as well as beam profile of the 6 MV photon beam are analyzed for the case of absent and presence of various titanium-made vascular access ports in an area of the radiation beam field.

| Port | Material | Base | Septum | Height | Weight | Reservoir |
|------|----------|------|--------|--------|--------|-----------|
| Port A | Titanium | 21 mm | 8 mm | 9.8 mm | 10 g | 0.4 ml |
| Port B | Titanium | 27.5 mm | 10 mm | 11.5 mm | 10.5 g | 0.53 ml |
| Port C | Titanium | 25 mm | 12 mm | 12.7 mm | 12 g | 0.6 ml |
| Port D | Titanium | 28 mm | 12 mm | 12.9 mm | 16 g | 0.9 ml |
The computed tomography (CT) images of the PMMA phantom alone and PMMA phantom with each of four vascular access ports (see table 1) were obtained on the Philips Brilliance 6 CT scanner. The exposure parameters of the chosen CT scanning protocol were as follows: tube voltage of 120 kV, tube current of 220 mA, reconstruction slice thickness of 5 mm, type B filter, type B of convolution kernel, the image size of 512 x 512, helical scan mode. The PMMA phantom’s dimensions were: length of 30 cm, width of 30 cm and thickness of 10 cm. For cases with vascular access port present, the ports were placed in the middle of the top surface of the phantom (figure 2a). For each set of the CT images, the treatment plan was prepared using matRad treatment planning toolkit using a single anterior treatment field [7]. The size of the treatment field was 30 cm x 30 cm and the reference point was located below the port at the depth of 5 cm in PMMA phantom. The other treatment planning parameters were: photon beam energy 6 MV, gantry angle 0°, collimator angle 0°, couch angle 0° and source to surface distance (SSD) value 100 cm (figure 2b).

3. Results and Discussion

On figure 3a, the PDD curve of the 6 MV photon beam in PMMA phantom is shown, in the absence of a vascular access port. The depth at which the radiation dose reaches its maximum value is equal to 1.30 cm. This value is a bit lower than the depth value of a maximum dose observed in a
water phantom for the 6 MV photon beam, which is equal to 1.50 cm. It is because of the fact that the PMMA phantom has a bit higher density than water. On the part (b) of figure 3, the PDD curves, obtained in the presence of various vascular access ports, are shown. For ports A, B, C and D the maximum dose values are 102.25%, 100.62%, 101.78% and 102.48%, respectively, observed relatively to the maximum dose value obtained in PMMA phantom in the case of port absent. The corresponding depths at which the maximum dose values occur are 0.95 cm, 1.70 cm, 1.85 cm and 2.00 cm for port A, B, C and D, respectively, measured from the top surface of the ports. The relatively higher maximum doses are caused by forward electron scatter. The forward electron scatter contributes to the increase of the central axis dose below the depth of the dose maximum. This increase is higher for the ports with higher titanium content. The higher depths of the maximum dose values, for ports B, C and D, can be explained by a fact that those ports possess the empty reservoirs in which the beam attenuation doesn’t occur. The higher volumes of the reservoirs correspond to the higher depths of dose maximums. The port A has the smallest reservoir volume and the beam attenuation is mainly caused by titanium’s body which is the reason that the depth of dose maximum value is the lowest and equal to 0.95 cm. The backward electron scatter produces the peak dose values in build-up regions (figure 3b).

Figure 3. PDD curves.
When considering the dose profiles, in the regions below the titanium outer edge of the ports, a dose reduction is evident due to attenuation (figure 4b). The decrease in dose below these edges, considered relatively to the central axis dose of the normal beam profile obtained in PMMA with no ports in place, have the values of 8.52%, 8.64%, 10.01% and 10.04% observed for ports A, B, C and D, respectively. Observed decrease in doses are in accordance to the results obtained in the other researches [6-8]. On the other side, the off-axis dose values are greater for port-present cases in comparison to the central axis dose value of port-free case. The off-axis dose values are greater for ports with the higher titanium content. The increase in off-axis dose values is due to backscatter contribution.

4. Conclusions
Through this work, the effects of the vascular access ports on the PDD curves as well as on the beam profiles have been analyzed. The observed maximum dose values, for ports A, B, C and D, relatively to the maximum dose value in PMMA phantom, are 102.25%, 100.62%, 101.78% and 102.48%, respectively. The titanium edges of the ports reduce the dose below them in the amount of 8.52%, 8.64%, 10.01% and 10.04% observed for ports A, B, C and D, respectively, in comparison to the central axis dose value obtained in PMMA phantom for port-free case. The established changes in
PDD curves and beam profiles depend on the vascular access port dimensions, reservoir volumes as well as the amount of titanium content.

Since the implantation of the vascular access port is indicated in cases of long-term treatment with chemotherapy agents and patients with poor peripheral veins, vascular access ports are widely used among radiation oncology patients. Therefore, each of these factors should be carefully considered when deciding on a vascular access port placement and particularly in the treatment planning process.

5. References
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