Do We Need to Redefine Electron Beam Treatment Parameters for IORT Applications?

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Purpose:

The large number of conventional electron accelerators on the market far exceeds the small, but growing number of mobile IORT linacs suitable for use in unshielded operating rooms. We discuss the technical aspects of the treatment beams produced by small mobile IORT linacs and question whether the beam parameter characterization for mobile IORT units needs to be redefined to better reflect mobile IORT applications, provide more meaningful information for clinicians, and provide a basis for future technological development in the industry.

Materials and Methods:

Using currently accepted industry standards, we compared the following electron treatment parameters of conventional and IORT linacs:

- ☐ Penetration depth and Surface dose
- ☐ Treatment field size and shape
- ☐ Beam Penumbra and Flatness
- ☐ Treatment on angular surfaces

Results:

The following key electron beam parameters are either not controlled for IORT, or controlled in a way that is not very clear and effective.

Penetration depth and Surface Dose: Conventional units, except when the CTV includes the skin, attempt to provide as much skin-sparing as possible, sometimes even mixing electrons and x-rays to achieve a lower surface dose. In IORT, the CTV ***always*** includes the surface of the tumor bed, so surface doses ≥90% are needed. For lower energy electron beams, this is not achieved. To increase the surface dose, 5 mm or 10 mm of bolus can be added to the distal end of the applicator (Fig 1). However, bolus will also reduce the depth of penetration, so the reduced penetration when using bolus must be taken into account in the dose prescription. The use of chest wall (CW) protectors in IORT treatment in breast cancer generates a component of backscatter into the treatment volume. Currently, this is generally not taken into account in the dose prescription.

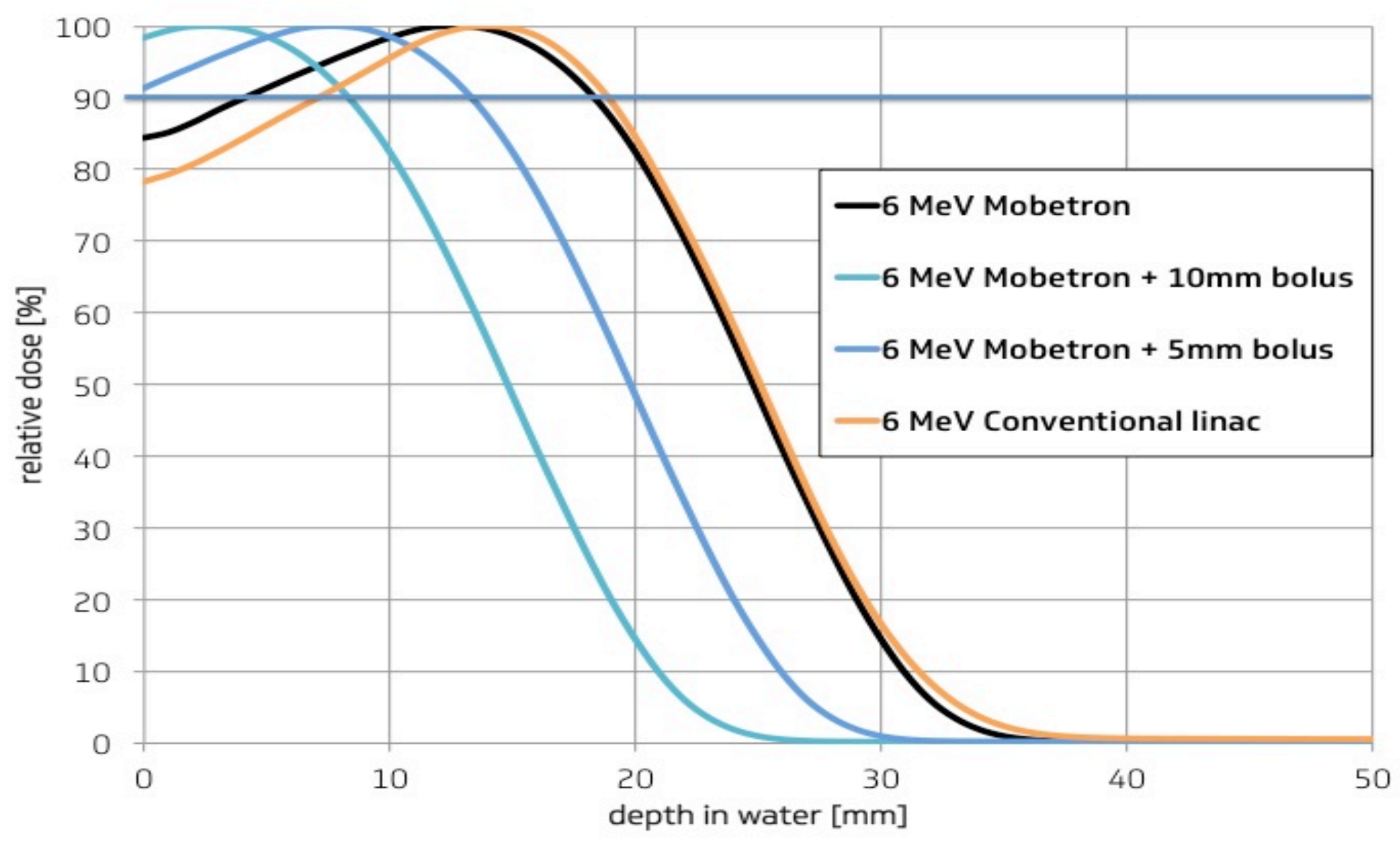

Figure 1. PDDs for Conventional and IORT Linacs. 5 mm and 10 mm boluses used to increase the surface dose.

Field Size Differences: Most Conventional electron linac fields are 10 cm or greater (possibly blocked to a smaller field size), resulting a fairly homogeneous dose distribution in the volume irradiated. The majority of IORT fields are 6 cm or smaller. The methods used to characterize output factors and other dosimetric properties with conventional linacs may not always apply for IORT smaller fields. It is important to use a small volume dosimeter to properly characterize the output factors for small field sizes. It is difficult to compare clinical data if different users have widely varying output factors caused by measurement techniques.
A Task Group could recommend appropriate detector to use for smaller field sizes.

Treatment on angular surfaces: With Conventional linacs, electron penetration follows the patient contour. If the variable contour leads to inadequate homogeneity at the treatment depth, soft bolus can be placed on the patient surface to compensate. In IORT, applicators should be in contact with the tumor bed. Beveled applicators help achieve contact when there are angled anatomic planes (e.g. the pelvis), but beveled applicators also reduce the homogeneity of the radiation and reduce the depth of penetration. A standard measurement protocol is needed for beveled applicators as they are in use in 25%+ of clinical situations. In order to compare clinical results, a uniform method to characterize these applicators is needed.

Table 1. Comparison of the critical beam characteristics for conventional linacs and mobile IORT linacs.

Parameter	Conventional	Mobile
Treatment field size and shape	Field size is usually 10cm + and is constrained by the moveable collimators and cutouts on the distal end of the applicator to form the treatment area. Fields are usually rectangular.	Collimators are not adjustable. Fields are usually circular, but some oblong applicators are available. Size of the field is usually less than 10 cm, often 4-6 cm diameter.
Treatment on angular surfaces	Soft bolus placed on the patient surface can compensate for inhomogeneous distribution caused by sloping surfaces	All IORT applicators have bevel ends of 0º, 15º, 30º and sometimes 45º to match anatomic planes. The larger the bevel, the greater the dose inhomogeneity across the field.
Penetration depth	Quantized with about 1 cm steps (3 MeV equivalent)	Quantized with about 1 cm steps (3 MeV equivalent)
Surface dose	There are attempts to reduce surface dose to spare the skin	Surface dose should be as close to 100% as possible to provide optimal treatment
Flatness	Beam is generally quite flat	Beam is generally less flat. Standard flatness definitions are often non-applicable due to smaller field sizes used in IORT
Penumbra of the beam	Treating at a 5 cm distance. Due to very good flatness inside the treatment area, penumbra of the beam only affects exposure of the healthy tissue outside the treatment field.	Treating in contact with the tissue. Metal applicators provide almost 100% protection of the tissue outside the applicator, and “penumbra” now results in cold spots adjacent to the inside walls of the applicator,

Beam Penumbra and Flatness: Conventional units can use the x-ray collimators to improve the flatness of the electron field. Fields are rectangular, with the majority of use ≥10 cm. Mobile IORT units have a non-adjustable collimator to limit the maximum field size, which is 10-12 cm. Fields are circular. For the most frequently used applicators in IORT (≤6 cm), conventional flatness definitions have little clinical relevance. These smaller IORT fields are rounded with substantial cold spots adjacent to the applicator walls.
For Conventional units, the clinical penumbra is the healthy tissue volume inside the field that receives unwanted radiation. In IORT the clinical penumbra is the volume of tissue inside the applicator that receives inadequate dose. For larger fields, this effect of clinical penumbra is modest, but it can be substantial for smaller field sizes (Fig 2). It is important to select a sufficiently large applicator to avoid underdosing the CTV. A clear understanding of the treatment volume and effective coverage area for the applicator and energy used is needed to quantify the volume of tissue which actually receives the prescription dose. Perhaps the ratio of the treatment volume with delivered dose above the threshold (e.g. 90%) to the nominal treatment volume (Fig 2) would be a useful measure.

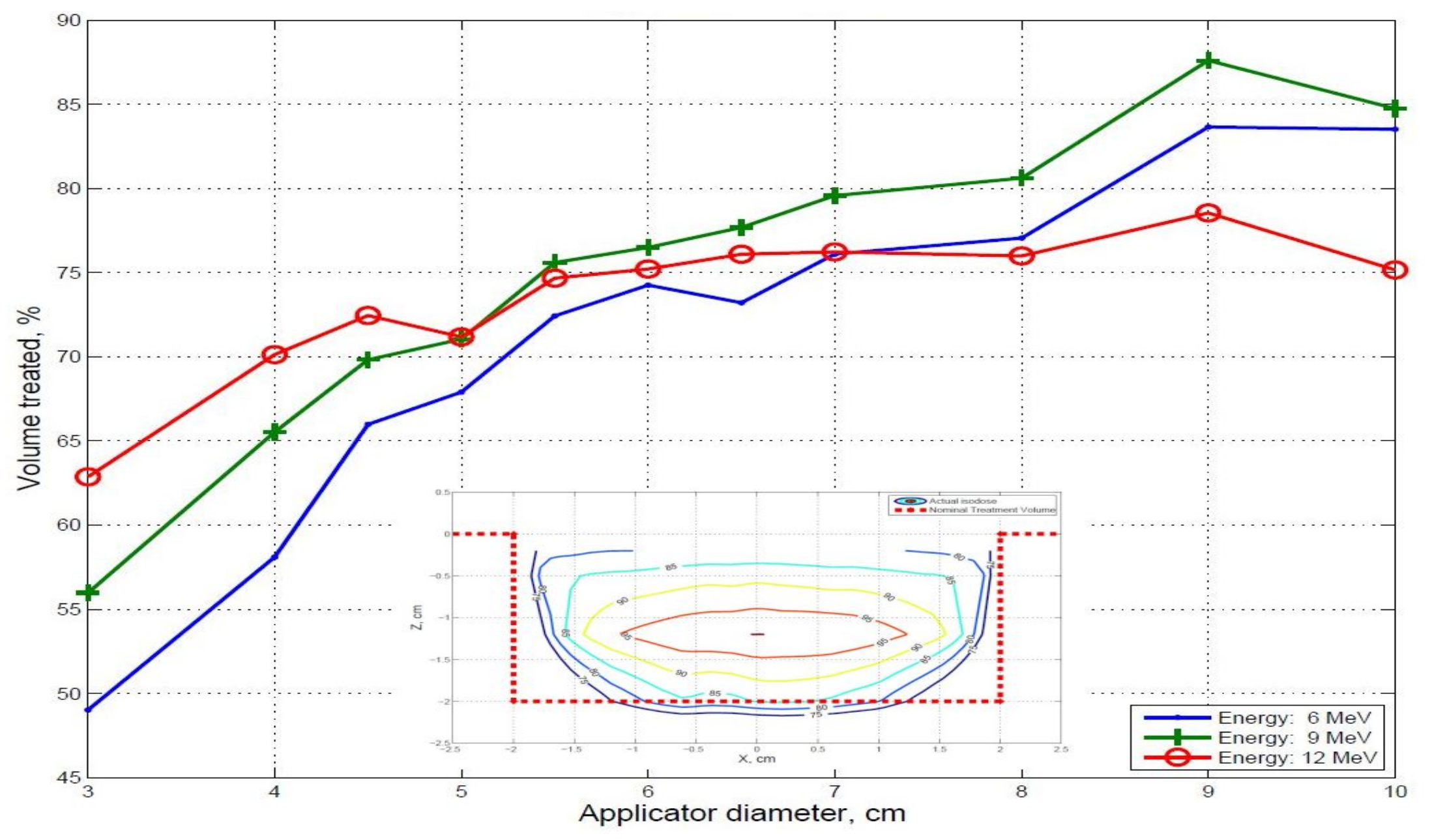

Figure 2. The effect of beam penumbra on volume treated for different beam energies and applicator sizes.

Conclusions:

We presented differences between parameters used and features of conventional and IORT linacs that could benefit from better standardization for IORT users. These parameters have important clinical implications and it is important that the IORT community use a standard approach to better compare clinical results from different IORT centers. When defined and controlled, these parameters will also allow engineering teams to optimize the parameters of the treatment devices and provide improved beam characteristics to improve treatment results.