Comparison of Out-Of-Field Doses in pediatric patients from Craniospinal Irradiations using photon, proton and electron spinal fields

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Purpose

Radiation therapy is a significant therapy and has greatly increase the survival rate for pediatric patients specifically with medulloblastoma and Acute Lymphoblastic Leukemia (ALL). The survival rates of these patients drastically increased after the introduction of Craniospinal Irradiation (CSI) technique. However, with this improvement a new challenge has emerged – late secondary complications and malignancies, resulting from the leakage and scatter radiation. Children, because of their smaller bodies, greater radiosensitivity and early age are most vulnerable to such late complications. Moreover 70% of childhood cancer survivors are expected to experience late complications 30 years after diagnosis [1]. Rapid development in the treatment techniques and utilization of new treatment modalities, like heavy charged particles (protons), have shown to greatly improve the dose distribution around the target and minimize the scattered radiation. However passively scattered protons produce neutrons primarily in nuclear interactions within the nozzle and the high-Z aperture. These scattered neutrons can potentially increase the peripheral doses over and beyond what has been normally accepted with more established treatment modalities such as x-ray and electron treatments.

The purpose of current study is to investigate and compare the out-of-field doses to a pediatric patient from three different courses of CSI.

CSI Treatment technique	Spinal field	Cranial Fields
1 Photon CSI	Photons	Photons
2 Electron CSI	Electrons	Photons
3 Proton CSI (passively scattered)	Protons	Protons

Methods and Materials

A pediatric anthropomorphic RANDO® (fig.1) phantom that represents a 5-years old patient was CT scanned for treatment planning. Based on these images the major organs of risk for secondary malignancies as defined by BEIR VII [2] were contoured. These organs include thyroid, lung, heart, breast, stomach, liver, bladder, ovaries, kidneys, colon, sigmoid and bone barrow.

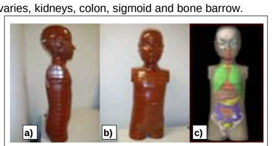

Fig.1 Pediatric RANDO phantom – a),b), and organ contours – c).

After contouring the major organs of risk as well as the treated brain and spinal cord, three different treatment plans were designed following MD Anderson Cancer Center protocols. The plans utilized two lateral opposed cranial fields with collimator angle such that they match the junction with the superior divergence of the superior spinal field. For the electron plan two different spinal fields were designed with two different electron energies because the inferior spine is at greater depth and so higher energy is needed for the 90th % isodose to cover the treatment volume. The proton plan also used two spinal fields because of the limited aperture size. Feathering and junction shifts were not considered because they were not relevant to the scope of the project and would not affect the results. Typical dose for medulloblastoma patients of 36 Gy to the cerebrospinal axis was prescribed at each of the plans.

Plan	Spinal Field(s)	Cranial Fields
Photon (Pinnacle)	6MV photons	6MV photons
Electron (Pinnacle)	12MeV electrons 16 MeV electrons	6MV photons
Proton (Eclipse)	120 MeV protons	160 MeV protons

Table 2. Treatment plans designed for the project

Methods and Materials /continued/

The delineated organs helped defining the points of interest, at which the doses were later measured and calculated. 24 locations of interest were defined throughout all the organs. (fig.2, table.3)

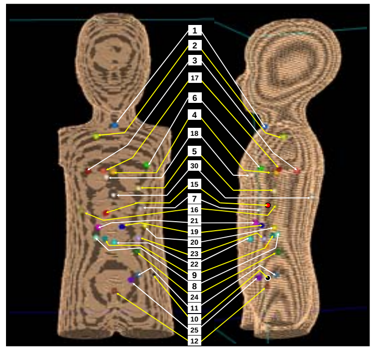

Fig.2 Locations of interest relative to AP and lateral orientation of the phantom

# of POI	Organ Site
1	Thyroid
2	Right Lung (sup OF, lat)
3	Right Lung (central OF)
4	Heart (center, IF)
5	Heart (Left Lateral)
6	Breast Bud
7	Liver (Ant Left)
8	Right Kidney (OF)
9	Right Kidney (IF)
10	Pelvis (bone marrow)
11	Left Ovary
12	Bladder
13	Left Eye
14	Right Lense
15	Liver (Center IF)
16	Liver (Right Lateral)
17	Right Lung (central POST, IF)
18	Right Lung (central ANT, IF)
19	Stomach (central)
20	Stomach (Left Lateral)
21	Stomach (Right Lateral)
22	Transcending Colon (IF)
23	Transcending Colon (OF)
24	Descending Colon
25	Sigmoid
30	Skin (Posterior, IF)

Table 3 Number and location of the Points of interest. Because of the complicated arrangements of the CSI technique, a clarification of the terms In Field (IF) and Out of Field (OF) was necessary. A location is considered to be OF if it lies out of the volume, defined by the geometric divergence of the photon beam. IF means that the respective POI lies inside that volume but it is still outside the target. Out of Field *doses* still corresponds to all point doses that are outside the target.

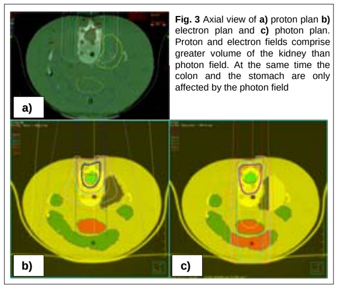

Fig. 3 Axial view of **a)** proton plan **b)** electron plan and **c)** photon plan. Proton and electron fields comprise greater volume of the kidney than photon field. At the same time the colon and the stomach are only affected by the photon field

Both, the electron and photon plans were delivered on a Varian 21-EX linac at MDACC. Double loaded TLD-100 capsules were placed at each point of interest and each of the two conventional plans were delivered three times for better statistics resulting in total of six measurements for a treatment at a given point. The TLDs were read and analyzed at the Radiological Physics Center (RPC) in Houston. Standards were prepared and irradiated in advance, according to the expected dose to each points of interest. For this purpose three main dose ranges were defined – for TLDs that were expected to receive less than 5 Gy, between 5 and 15 Gy an above 15 Gy respectively.

Out-of-field doses from the proton therapy plan were calculated using the MCNPX Monte Carlo simulation code. The treatment plan, treatment unit, and phantom CT data were converted to MCNPX geometry using the MCPRTP procedure described by Newhauser et al [4]. The position of each TLD was represented by a respective point tally. Doses from stray radiation were calculated for each field by simulating the transport of 9x10^9 source protons per field. Rotation of the range modulator wheel was approximated by simulating 18 discrete angles of the RMW, and then summing over all angles. Absorbed dose from neutrons was converted to equivalent dose using an average radiation weighting factor of 9 [5].

Equivalent organ doses for all the three plans were estimated based on the point doses. DVHs were used to derive the integral doses at these partial volumes of the organs, for which it was observed that measured doses were within +/- 4% of agreement with the planned doses. For the photon plan these organ partial volumes were the ones that were inside the photon field albeit yet outside of the target. For the electron and proton plans the partial organ volumes were the ones that lie within the 5% isodose volume. TLDs at the other locations were used to weight the doses for the rest of the organ volumes. For the proton treatment the doses from the kV images at each treatment were also estimated based on combined ICRU-60 and Rzeszotarski's methods [3].

Results and Discussions

Although proton treatment units are rapidly increasing all over the world, still the majority of the cancer centers rely on conventional linear accelerators. From this perspective it is useful to compare the out of field doses from CSI treatments that could be performed on a standard linac only (table.4, fig.4). It was found that for the majority of the investigated locations, the doses from the photon treatment were significantly higher than those due to the electron treatment. Yet at three location the electron CSI plan out of field doses were significantly higher. One of these locations was the skin. The other two were in the anterior lung proximal to the beam axis.

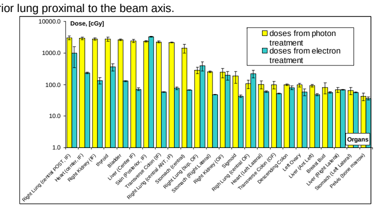

Fig. 4 Measured out of target doses from CSI with electron and photon spinal fields

Organ Site	#	Mean dose, [cGy]		Significance
		photon treatment	electron treatment	
Thyroid	1	2755	361.9	photons
Right Lung (sup OF, lat)	2	287.6	394.9	electrons
Right Lung (central OF)	3	106.6	223.5	electrons
Heart (center, IF)	4	2910	235.6	photons
Heart (Left Lateral)	5	101.5	60.37	photons
Breast Bud	6	81.4	56.56	photons
Liver (Ant Left)	7	93.0	48.39	photons
Right Kidney (OF)	8	244.3	197. 5	photons
Right Kidney (IF)	9	2788.4	135.4	photons
Pelvis (bone marrow)	10	42.3	36.43	photons
Left Ovary	11	97.9	58.19	photons
Bladder	12	2653	128.5	photons
Liver (Center IF)	15	2425	71.50	photons
Liver (Right Lateral)	16	68.8	69.04	no diff
Right Lung (central POST, IF)	17	3024	980.7	photons
Right Lung (central ANT, IF)	18	2150	75.80	photons
Stomach (central)	19	1427	67.58	photons
Stomach (Left Lateral)	20	64.94	56.37	photons
Stomach (Right Lateral)	21	252.7	54.82	photons
Transverse Colon (IF)	22	2246	58.80	photons
Transverse Colon (OF)	23	99.88	51.85	photons
Descending Colon	24	98.91	79.59	photons
Sigmoid	25	184.8	43.37	photons
Skin (Posterior, IF)	30	2352	3305	electrons

Table.4 mean doses to the investigated locations. Yellow color indicates that doses from photons of that POI are significantly greater. Blue indicates significantly greater doses from electron treatment. No color means that no significant difference was observed for this respective POI.

The comparison of the equivalent doses from all the treatment techniques is illustrated in figure 5 below. It was found that the doses due to the proton therapy were lower than both other irradiation methods. An average radiation weighting factor of 9 was used for simplicity, which contributed to an extra 15% uncertainty to the proton results.

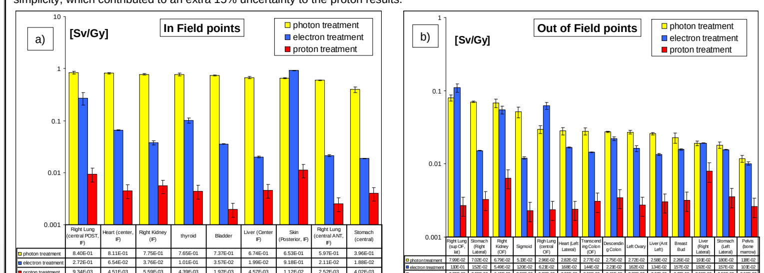

Fig.5 Equivalent point doses normalized to the therapeutic dose at a) (left) IF locations and b) (right) OF locations from the three different CSI treatments with respective 95% Confidence Levels. Yellow indicates doses from photon therapy, blue – doses from electron and red – from proton treatments

Equivalent organ doses were also estimated (figure 6) and the majority of the organs at risk were calculated to receive the highest dose when treated with photons and lowest dose when treated with protons. The dose contribution to most of the organs due to the set-up kV X-ray imaging was found to account for 2% to 9% from the overall equivalent dose from the proton treatment. The dose to the kidney was highest from the proton treatment. A large portion of the kidney was actually inside the 5% proton isodose line (fig. 3), which was not the case for the other two plans. The equivalent organ doses seem to depend primarily on the portion of the organ that is directly irradiated by the treatment field. Hence for charged particles organs that are lateral to the spinal cord are most endangered. While for CSI with photons that do not have limited range, all the organs located on the path of the direct field are directly irradiated. Another important factor as shown earlier is the treatment modality.

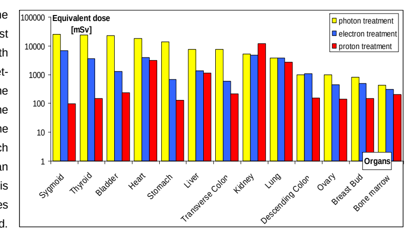

Fig.6 Estimated Equivalent doses to organs at risk from the three investigated CSI techniques. The doses account for interactions from the direct treatment beam as well as stray radiation.

Conclusion and references

Craniospinal irradiation from passively scattered protons suggests lowest out of field doses to pediatric patients. Proton therapy is still an emerging modality for the majority of the cancer centers in the USA. As an alternate to proton therapy, the use of electron spinal fields showed lower peripheral doses than megavoltage X-rays CSI. In addition to minimize potential late complications due to out of field doses one should also consider set-up imaging doses before each fraction and to strictly adhere to the ALARA principle.

References:

1. Oeffinger, K. C. "Chronic Health Conditions in Adults Survivors of Childhood Cancer." N Engl J Med 15(355): 1572-82. (2006).
2. "BEIR VII Health Risks from Exposure to Low Levels of Ionizing Radiation." National Research Council. (2005).
3. "Patient Dosimetry for X Rays used in Medical Imaging." ICRU report 74 vol.5. (2005).
4. Newhauser W et al, "Monte Carlo proton radiation therapy planning calculations" Trans Am Nucl Soc 99 (2008).
5. Newhauser W, et al The risk of developing a second cancer after receiving craniospinal proton irradiation Phys. Med. Biol. 54 (2009).

Support

The investigation was supported by PHS grants CA10953 awarded by the NCI, DHHS