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In vivo dosimetry of total body irradiation patients: A 10 year retrospective analysis

S. Carminati [a,b], S. Trivellato [b], C. Ingraito [a,b], G. Montanari [b], S. Morzenti [b], N. Paruccini [b], D. Panizza [b], R. Villa [b], V. Tremolada [b], C. Julita [c], S. Arcangeli [c,d,*], E. De Ponti [b]

[a] Medical Physics Specialization School, University of Milan, Milan, Italy
[b] Medical Physics Department, Fondazione IRCCS San Gerardo dei Tintori, Monza, Italy
[c] Radiation Oncology Department, Fondazione IRCCS San Gerardo dei Tintori, Monza, Italy
[d] School of Medicine and Surgery, University of Milano Bicocca, Milano, Italy

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ABSTRACT

Myeloablative Total Body Irradiation (TBI) used in our Institution, as part of the conditioning scheme for haematopoietic stem cell transplantation, is an extended-distance supine technique that has been implemented using a 15 MV LINAC beam, lead lung compensators, PMMA, and water bolus to improve homogeneity. This study reviews in-vivo dosimetry (IVD) over 10 years of treatments, assessing the technique's robustness, accuracy, and efficiency.

A 2-lateral opposite fields plan was calculated from planning CT with validated Oncentra TPS (Elekta AB, Sweden). Monitor units (MUs), lung compensators shape and thickness were calculated to deliver the prescription dose (12 Gy in 6 bi-daily fractions or 9.9 Gy in 3 daily fractions) to the patient's abdomen midline at the umbilical level, maintaining lung dose within ±5 % range of prescription. Data from 103 patients, of which more than 87 % were pediatric, were retrieved and analyzed for a total of 537 treatment fractions. The impact of IVD omission was evaluated, supposing doing it only once or in the first two fractions, if necessary.

Median ΔMU from planned was −1.2 %. Median percentage dose deviation from prescription in 6 anatomical regions was below 2 %. IVD omission could have resulted in an increase of 7 patients registering at least one anatomical region outside the ±5 % dose range at the end of treatment.

It is possible to confirm the implemented technique's robustness and accuracy in delivering the prescribed dose under IVD monitoring. Nevertheless, this technique and associated IVD are time-consuming and IVD omission could be assessed with limited drawbacks.

1. Introduction

Conditioning regimen prior to allogenic/haploidentical hematopoietic stem cell transplantation (HSCT) includes the use of Total Body Irradiation (TBI) complementary to chemotherapy. The incidence of leukemia continues to rise, comprising more than a quarter of all malignancies diagnosed in children nowadays [1]. TBI has been shown to achieve better outcomes when associated with chemotherapy compared to conditioning regimens excluding TBI [2–4].

Most patients undergoing HCST suffer from acute high-risk or relapsed leukaemia in remission after multimodal chemotherapy and, among these diseases, the majority are acute lymphoblastic leukaemia, with a pediatric prevalence. HSCT can effectively induce immunologic anti-leukemic control in patients with leukemia through the graft-versus-leukemia (GvL) effect, but treatment-related mortality (TRM), morbidity, and late effects remain serious problems. The short-term outcome of patients who received allogeneic HSCT has improved due to the use of donors more closely matched by human leukocyte antigen (HLA) typing, resulting in less severe graft-versus-host disease (GvHD) and better supportive care. However, patients remain at risk for lifelong complications.

TBI has been the most commonly used myeloablative and immunoablative procedure prior to HSCT, the use of fractionated TBI reduces acute side effects such as nausea, vomiting, and mucositis and late effects such as cataracts, lung and liver adverse events. In particular, lung shielding is also widely used to prevent severe non-infectious/interstitial

* Corresponding author at: School of Medicine and Surgery, University of Milano Bicocca, Milano, Italy.
E-mail address: stefano.arcangeli@unimib.it (S. Arcangeli).

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pneumonitis. However, the greatest burdens for patients treated with TBI are the risks of secondary malignancies, growth retardation (especially if irradiated before the age of 10), and infertility (most common after irradiation during or after puberty) [5–10].

Typically, large fields at an extended source-to-surface distance (eSSD) are used to simultaneously irradiate the entire body of the patient, prescribing the clinical dose at the patient midline, often at the umbilical level. The eSSD allows the usage of a lower dose rate correlated with reduced pulmonary, renal, and hepatic toxicities [9]. Fields can be delivered in anterior-posterior or lateral-lateral configurations with the patient standing, sitting, or lying. To ensure dose homogeneity throughout the patient's volume, boluses and lung compensators are frequently used [11].

In vivo dosimetry (IVD) with diodes, thermoluminescence detectors (TLD) or metal oxide field effect transistors (MOSFET), allows monitoring variations from the expected planned dose [12]. This verification includes the aspects deriving from beam delivery and, indirectly, patient positioning and compensation setup. Available dosimeters have been shown to have good accuracy with limited uncertainty [13–15]. Diodes calibration should be performed in TBI treatment conditions, due to response dependence on beam spectrum and dose rate. Furthermore, diodes allow real-time intra-fraction feedback on dose delivery [16,17]. Dose deviations from prescription are considered acceptable in a ±10 % range, following AAPM-TG29 indications [12].

In this context of increasing TBI requests, this study aimed to review dose deviations in IVD data collected over 10 years of TBI treatments at our Institution to assess the robustness, accuracy, and efficiency of the present technique. The secondary objective was the evaluation of IVD omission after the first fraction and the adjustments made based on the IVD. The evaluation presented here included lung compensation changes during TBI treatments, registered dose deviations, and MUs adjustments.

2. Materials and methods

2.1. Patient cohort and dose prescriptions

A mono-institutional consecutive cohort of 103 patients treated between 2012 and 2023 was retrospectively retrieved and analyzed for a total of 537 treatment fractions. The registered median age at treatment time was 10 years [2-55], with 87.2 % of pediatric patients (≤18 years). In the adult and pediatric patients' subsets, the registered median ages were 45 [19-55] and 10 [2-18] years, respectively. Ratio between male and female patients is about 2:1 and the most represented diagnosis is acute lymphoblastic leukemia. Only myeloablative TBI treatments were considered, including two different treatment schedules: 12 Gy in 6 bi-daily fractions (Group A) and 9.9 Gy in 3 daily fractions (Group B), prescribed to the patient's abdomen midline at umbilical level. The time slot allocated for TBI CT-acquisition phase is 30 min and 2 h for treatment.

2.2. Patient setup, treatment planning and delivery

In the currently used eSSD LINAC-based technique, patients lay down in a supine position on a dedicated therapy bed at an isocenter-midline distance of 365–390 cm. Patient adherence to the spoiler and

Fig. 1. Example of a patient setup with bent knees. Patient is positioned supine, and alignment is checked (top left figure). Water bags and PMMA slabs are added (top right figure). LINAC is positioned at 90° with collimators rotated at 45°, and cardboard and lead compensators are inserted (bottom left figure). The bottom right figure shows the final setup with the patient ready for treatment.

distances from midline were checked throughout the entire body (head, sternum, umbilicus, groin, legs, feet). Patient alignment was also controlled by means of lasers and tattooed markers made during the CT simulation phase. The maximum useful field size at these distances, along the diagonal of a 45° rotated collimator field, was 155 cm. Patients exceeding this limit were positioned with bent legs supported by a cushion. To increase dose homogeneity throughout the body, water bags were placed around the patient, and additional bolus or PMMA slabs were often added in the neck region. An example of patient positioning is reported in Fig. 1.

Since 2012, CT 3D-planning has been performed with Oncentra TPS (Elekta AB, Stockholm, Sweden) validated for extended distance calculations. The treatment plan was generated on the CT scan (120 kVp, 5 mm-thick slices) including two lateral 15MV LINAC fields with dose rate ranging between 5 and 15 cGy/min. The shape and thickness of lead lung compensators were calculated aiming to homogenize the lung doses into 95 %–105 % range of the prescription dose. Presence of these compensators is taken into account in the planning system and from there the necessary lead thickness is obtained.

The total number of monitor units (MU) was estimated to deliver the prescription dose at the patient midline. Dose calculations were performed by means of a Collapsed Cone algorithm using a 3 mm grid. TPS beam model was optimized for eSSD and validated through measures of PDD, off-axis profiles and dosimetric verifications with Alderson Rando anthropomorphic phantom. PMMA and water bags were simulated by manually inserting an external volume (bolus) with a fixed water equivalent electronic density to achieve uniform thickness across different patient areas.

Lead compensators were affixed to a cropped cardboard inserted into the LINAC's block tray. The resulting body-shaped light field, with the shadow of lung compensator, was used to confirm or adjust the patient positioning, as depicted in Fig. 1. In Fig. 2 provides a detailed representation of the cardboard with the lead compensator.

2.3. In-vivo dosimetry

IVD was performed using silicon diodes (semiconductor probes p-type Si, PTW Dosimetry, Freiburg, Germany) or TLDs (LiF TLD-100 chips Harshaw, Thermo Fisher Scientific, United States) to monitor dose delivery in different body positions. During each fraction, measurements at the beam entrance and exits were combined to estimate the midline dose, employing a method similar to those described by Ribas and Noel [16,18].

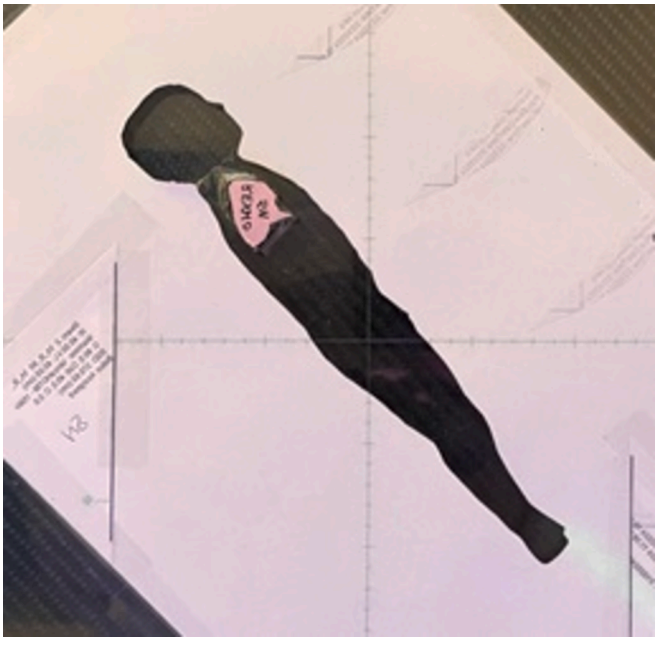

Fig. 2. Cardboard with the patient cropped profile and the lead lung compensator positioned.

Bolus is necessary to ensure that the depth of the PDD in the measurement points is found beyond the buil-up. Water bags are important to uniform the irregularity in patient's profile, tending toward to a flat entry surface condition.

Specifically, for diodes dosimetry, entry and exit dose measurements are combined to derive an effective attenuation coefficient value, from which the midline dose is calculated. Corrections for the depth of the measuring point are applied, considering the varying patient thickness at each anatomical location.

For TLDs, midline dose estimation follows a similar protocol, averaging three or more individual TLD readouts per anatomical position and adding the entry and exit dose for each l location. Corrections for patient thickness differences are applied at each anatomical site.

The six anatomical locations selected for dosimetry were groin (G), oral cavity (C), neck (N), apical lung (AL), basal lung (BL) and hip (H).

When TLD are used, a single diode is placed at the patient's groin to provide an online check of dose delivery. Annealing of TLDs is performed, and calibration using the same treatment parameters is conducted before each TBI treatment. Three or more TLDs are placed at a single anatomical location; their readings are corrected by individual sensitivity factors, and an average dose value is obtained from their readouts. Prior to the readout procedures, the TLDs are pre-heated for 15 min at 100 °C. The TLD reading protocol includes a pre-heating phase using a TLD Heater for 2.5 s, followed by a heating phase at 300 °C for 12 s. TLDs are then automatically read using a TLD Reader RE 2000A (Mirion Technologies, Atlanta, United States).

Diodes are calibrated within 1 % tolerance and checked monthly under the same TBI conditions: using a 15MV and a 6MV LINAC beam with a fixed number of MUs and the same treatment dose rate.

The uncertainty associated with the midline dose estimate obtained with the aforementioned IVD methods was considered not to exceed 2 % [19–22].

During each treatment, IVD was used to adjust the patient setup, suggesting the use of a different compensator combination or to correct the delivered MUs with respect to the TPS estimates.

2.4. Data analysis

IVD data collection included registered doses at each anatomical location and midline estimates for each treatment fraction, TPS-estimated MUs and delivered MUs, as well as changes in lung or PMMA compensators during treatment.

2.5. Setup/MU adjustments impact

Adjustments during treatment can be made in various ways with multiple aims: PMMA and lung lead compensators could be modified to correct midline doses in specific anatomical districts, such as C, N and lungs. Alternatively, MUs could be modified to achieve a homogeneous dose increase or decrease in each district. IVD may provide guidance on which method and the correction magnitude to apply in each specific case. To quantify the effect on overall treatment dose delivery of these interventions, patients were subdivided in homogenous groups based on the type of adjustment.

2.6. Evaluation of IVD omission

The evaluation of the impact of omitting IVD was performed on dose data from patients in Group A. Patients in Group B were all pediatric, and the 3-fraction schedule was carried out under sedation, requiring additional monitoring throughout treatment. The hypothesis from omitting IVD was based was based on dose data from the first fraction

dosimetry: if the estimated midline dose fell within a 5 % range of the expected dose at each anatomical region, patient setup and MUs would be confirmed until the end of therapy without repeating IVD. In this scenario, the IVD data at each anatomic location from the first fraction would be assumed constant for all subsequent treatment sessions. However, if any of the six anatomical regions showed a dose difference greater than 5 %, necessary setup adjustments and MUs changes would be applied, and IVD would be repeated in the second fraction. In this case, for each anatomic location, the IVD data from the first fraction would be combined with the second fraction's IVD data, which would be repeated from the 2nd to the 6th fraction.

The resulting modified IVD data (IVD_{hyp}) were compared to the actual measured dose data, evaluating absolute percentage dose differences, to determine how many fractions could have been performed without IVD and the impact this would have on IVD results.

2.7. Statistical analysis

The Shapiro-Wilk test was used to determine whether to perform a parametric *t*-test or a non-parametric Wilcoxon-Mann-Whitney (WMW) rank-sum test (significance level $p < 0.05$). All the statistical tests were performed using custom Python algorithms running on Spyder software (version 5.4.1) part of the Anaconda Navigator distribution.

3. Results

3.1. Treatment summary

A summary of collected data is presented in Table 1. Table 2 displays TPS estimates for lung compensator thickness. Lead compensator thickness was modified during treatment in 5 % of total patients.

The total delivered MUs per fraction per patient were recorded and compared with the TPS estimate. The median and range of MUs variation were 0.5 % [−7.0 %, +3.6 %] and −1.9 % [−5.7 %, +2.6 %] for Groups A and B, respectively. Absolute MUs were not reported as they were influenced by beam calibration (MU/cGy), which varied over the years. A frequency plot of MUs percentage variation is presented in Fig. 3.

Table 3 summarized MUs variations. In 17 out of 76 patients in Group A, there was no MU variation or the registered variations resulted in cumulative delivered MU equal to the TPS estimate, resulting in no changes in total MUs. In 35 out of 76 patients, delivered MUs were higher than estimated. In the remaining 24 cases, delivered MUs were lower than estimated. The mean magnitude of these variations was approximately 2 %, with registered maximum variations of about 7 %.

In Group B, cumulative MUs were increased in 24 out of 27 patients, while they decreased or remained equal in 2 and 1 patient(s), respectively. The mean percentage increment and range of MUs for Group B patients were about 4 % [−3 %, 14 %].

3.2. IVD results

The total dosimetric results recorded at the conclusion of treatment for Groups A and B were compiled in Table 4, detailing values for each anatomical location as estimated at the midline. Average dose deviations were calculated for all 103 patients and are presented in boxplots in Fig. 4. Group A showed a percentage dose difference below 2 % in all locations except the neck, where it reached 4.6 %. In contrast, Group B displayed a percentage dose difference outside the ±10 % range in less than 5 % of cases, except for the neck region, where nearly 15 % of total midline doses fell outside the range suggested by AAPM-TG29.

Dose values obtained in first and last treatment fractions were compared, and p-values obtained from WMW signed-rank tests were reported in Table 5: significant dose differences were found in one and four out of six anatomical regions in Groups A and B, respectively.

To track the trend of the cumulative IVD results during treatments, the cumulative absolute dose differences from prescription at different fractions were plotted as median values with uncertainties in Fig. 5.

Table 1
An overview of TBI treatments administered over a span of ten years, including patient demographics and the IVD method employed.

	Group A	Group B
Number of treatments	76	27
Number of total fractions	456	81
Pediatric patients	64	27
Adult patients	12	–
Number of TLD IVD	–	24 (89 %)
Number of diodes IVD	76	3 (11 %)

Abbreviations: *TLD: thermoluminescent dosimeters, IVD: in-vivo dosimetry.*

Table 2
TPS-estimated thickness of lead lung compensators.

Lead compensator thickness (mm)	Nr of patients
1.5	1
2.0	85
2.5	15
3.0	2

3.3. Impact of setup/MU adjustments

The homogeneous groups selected for analysis consisted of patients with MU adjustments, patients with variations in PMMA thickness, patients with both interventions, and patients without any interventions. Changes in lung compensators were excluded from consideration due to their infrequency. The resulting four groups were compared in terms of delivered MUs for each fraction and the total dose delivered at the end of treatment. The results are presented in Table 6, revealing a limited percentage dose variation, below 3 %, in every anatomical region. Statistical differences in the estimated doses for the same anatomical location across different groups were assessed. Non-paired WMW rank-sum tests revealed no significant differences between any combination of groups, thus p-values were not reported.

3.4. IVD omission

Fig. 6 illustrates the accumulated absolute dose difference from prescription. Nineteen out of 76 patients showed no more than a 5 % difference in the midline dose estimate during the first treatment fraction. Propagating the estimated doses at each anatomic location from this fraction to the end of therapy ensured that dosimetry for each anatomical region in every subsequent fraction remained within the 5 % range. Among the remaining 57 patients, propagating the dosimetry at each anatomic location from the second fraction to the last fraction resulted in 7 additional patients with at least one IDV_{hyp} point falling outside the ±5 % range. Notably, one patient exceeded a 10 % difference in the neck location. In the registered IVD data, 20 patients had at least one anatomical location with a dose outside the ±5 % range at the end of treatment, with 5 out of 20 reporting it in the AL or the BL. With the IDV_{hyp} data, 8 patients would exceed the 5 % range in lung dosimetry (Table 7).

As shown in Fig. 6, the hypothesis approach led to a clear improvement in second fraction IVD_{hyp}, but setup modifications at each anatomic locations remained effective point by point, fraction after fraction. The graphic representation of median values shows the asymptotic trend summed with the cumulative effect giving small reversing trend deviations with respect to the cumulative IVD_{hyp} at the second fraction.

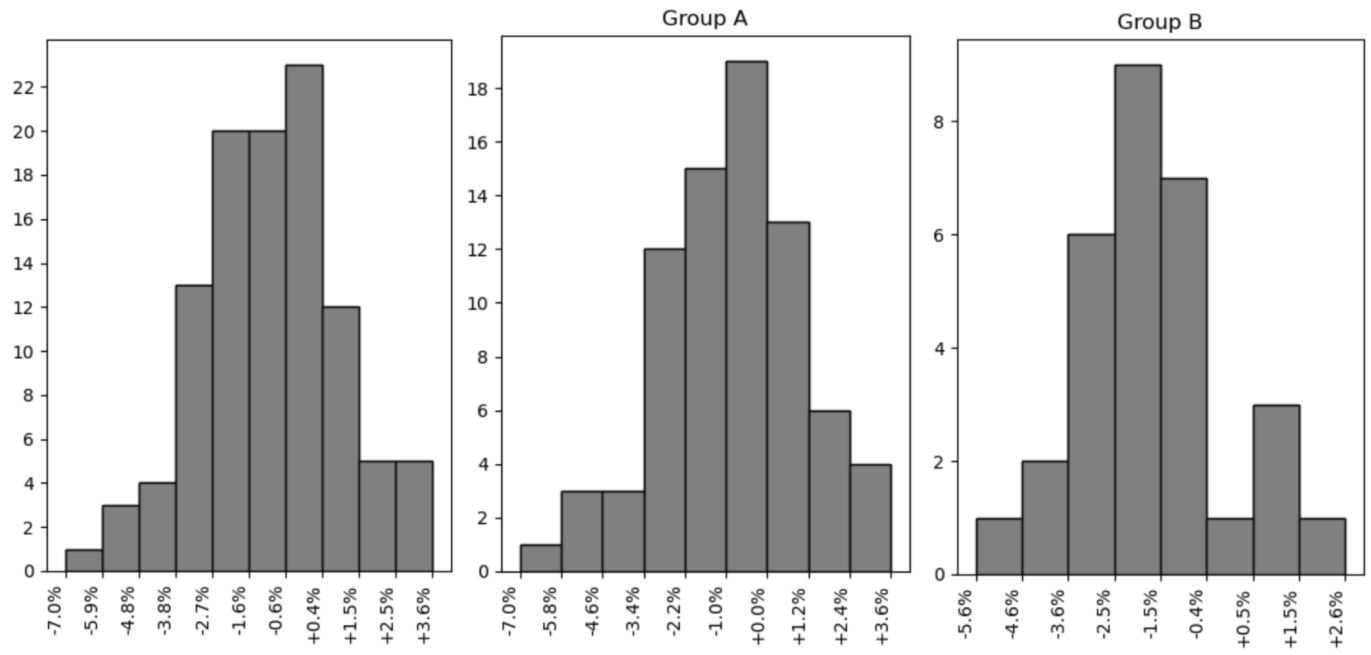

Fig. 3. Frequency plot of MUs' percentage variations between planned and delivered. Left: results from all 103 patients. Middle: results for Group A (6 fractions). Right: results for Group B (3 fractions).

Table 3
Mean patient MUs variations. Variations were expressed as percentage, calculated as difference between delivered and planned divided by the latter.

Group A			Group B		
MU		Mean variation	MU		Mean variation
No changes*	17	–	No changes	1	–
Increase	35	+2.1 %	Increase	24	+3.7 %
Decrease	24	−2.3 %	Decrease	2	−2.6 %

Abbreviations: *MU: monitor units.*
* "no changes" included cases in which MUs were not modified and cases in which subsequent modifications led to a cumulative delivered MU equal to planned cumulative MU at the end of treatment.

4. Discussions

In the context of an increasing number of TBI treatments, this study reviewed IVD data collected over a span of 10 years of clinical activity at our Institution to assess the robustness, accuracy, and efficiency of the current technique and its TPS calculation.

User interventions on lung compensators were recorded in only 5 % of cases, indicating the accuracy in lead thickness determination by TPS calculation from complete CT acquisitions. On the other hand, deviations in delivered MUs from TPS-estimated MUs were more frequent, although the median registered variations were modest. As previously mentioned, MUs adjustments could be associated with patient positioning, a significant source of uncertainty. Patients are meticulously positioned by aligning markers and lasers without image guidance. Implementing a portal imaging system could provide real-time visualization of patient positioning, potentially offering several benefits. For instance, bolus placement currently requires several minutes, during which involuntary movements may occur, leading to undetected misalignments. Moreover, uncertainties may arise from the simulation of bolus material in TPS, which typically utilizes a uniform block of fixed density, while actual compensation with water-filled bags may result in variations in shape, density, and the potential presence of small air gaps.

The registered IVD results were found to be comparable to similar experiences reported in the literature [14,23,24]. At the conclusion of treatment, the majority of measured IVD results fell within the ±10 % range, consistent with the AAPM-TG29 recommendations for e-SSD TBI. The median variations of estimated midline doses at each anatomical region were below 2 % and 4 % for Group A and Group B patients, respectively. The neck and oral cavity were identified as the anatomical regions most prone to dose discrepancies, likely due to their high non-uniformity requiring significant compensation and susceptibility to positioning inaccuracies. Conversely, the smallest gap between prescribed and measured dose was observed at the groin.

Subdividing IVD results by dose schedule, Group A showed a lower frequency of measurements exceeding the ±10 % range, with the majority of IVD performed using diodes. However, both dosimetry methods yielded comparable results, indicating flexibility in choosing dosimetric instrumentation and techniques tailored to the clinical demands. For

Table 4
In-vivo dosimetry results as registered at the end of treatment. Dose values reported are median midline estimates with minimum and maximum values at different anatomic locations and deviation percentage from prescription.

Group A	**G**	**C**	**N**	**AL**	**BL**	**H**
IVD (Gy)	**12.04** [11.24–13.04]	**11.86** [11.17–12.36]	**12.09** [11.66–12.76]	**12.04** [9.92–12.49]	**11.97** [11.28–12.56]	**11.95** [11.48–12.68]
Median deviation (%)	0.29	− 1.16	0.74	0.36	− 0.28	− 0.44
Group B	**G**	**C**	**N**	**AL**	**BL**	**H**
IVD (Gy)	**9.91** [9.24–10.35]	**9.60** [9.29–10.01]	**10.08** [9.33–11.03]	**9.72** [9.05–10.15]	**9.76** [9.10 – 10.18]	**9.63** [9.19–10.13]
Median deviation (%)	0.07	−3.03	1.77	−1.78	−1.46	−2.73

Abbreviations: *IVD: in-vivo dosimetry, G: groin, C: oral cavity, N: neck, AL: apical lung, BL: basal lung, H: hips.*

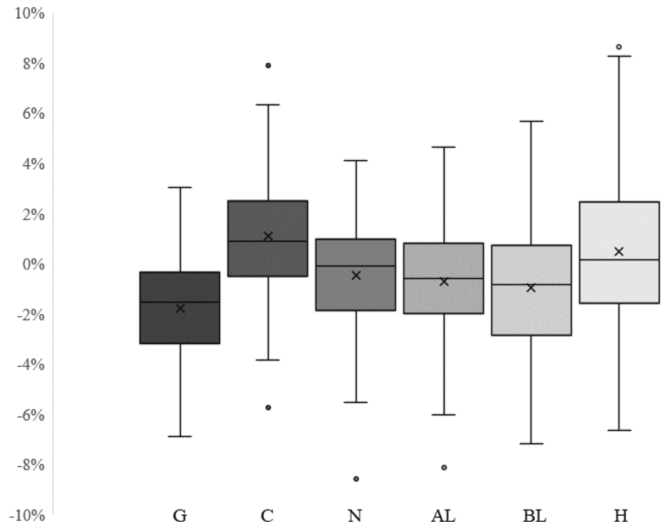

Fig. 4. Box-and-whisker plots for average dose difference deviations from prescription for all 103 patients. Abbreviations: *G: groin, C: oral cavity, N: neck, AL: apical lung, BL: basal lung, H: hips.*

Table 5
P-values obtained comparing dosimetric results from first and last treatment fractions in different anatomical regions. values are not reported if no significant differences were found.

	G	C	N	AL	BL	H
	p-values					
Group A	/	/	<0.05	/	/	/
Group B	<0.05	/	/	<0.05	<0.05	<0.05

Abbreviations: *G: groin, C: oral cavity, N: neck, AL: apical lung, BL: basal lung, H: hips.*

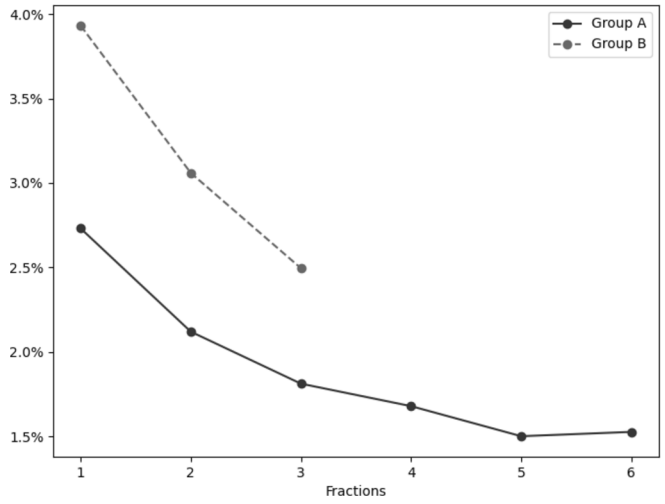

Fig. 5. Cumulative percentage median dose difference from prescription for patients in Group A (continuous line) and Group B (dashed line) over the course of treatment.

instance, in Group B, where all pediatric patients were treated under sedation to minimize treatment duration, cabled diodes were avoided due to their time-consuming "take off and put on" setup procedure for each patient's lateral positioning. Instead, TLDs are attached at the desired anatomical level and removed only after the fraction delivery.

In Group A, no statistically significant differences were observed between the delivered doses in the first and last treatment fraction, except for the neck region. This discrepancy could be attributed to occasional changes in the number and thickness of PMMA slabs used to shield the head and neck area between fractions. Differences in Group B could be explained by the fact that, following the first IVD measurement, there were only two fractions available for intervention to adjust the total dose delivery. Consequently, substantial interventions applied during these fractions could lead to notably different IVD results between the first and last fractions. Additionally, the influence of outliers may contribute to those differences, given the smaller size of Group B.

Furthermore, in Group B, there appears to be a slight underestimation of MUs predicted by the TPS, although within 5 %. Several factors could contribute to this effect, including challenges in maintaining patient positioning at the predetermined distance, which may be influenced by the use of medical devices for patient monitoring under sedation. Additionally, factors such as the bulk and weight of the bolus in relation to the small size of pediatric patients, or a possible overestimate of the bolus effect in treatment planning, could also play a role.

The cumulative trend of IVD indicated a slight reduction in the percentage dose difference from the prescribed dose over the treatment course. Evaluation of the impact of MUs and setup adjustments revealed that both methods marginally optimized dose delivery, however, their combined effect was very limited, resulting in improvements of up to 2 %.

This prompted an assessment of the potential impact of omitting IVD during therapy sessions. Some published studies have described IVD omission as implemented in clinical practice [24]. To the authors' knowledge, this study represents the first analysis of current clinical data applying a theoretical hypothesis of IVD omission. Under the described hypotheses, IVD_{hyp} closely mirrored the actual IVD, suggesting potential time and resources savings. However, omitting IVD would lead to approximately 7 more patients experiencing a dose difference from prescription exceeding 5 % in at least one anatomical region. Specifically, 3 patients would exceed the 5 % dose range in the lung IVD_{hyp} and 1 out of 76 patients would register a dose difference of more than 10 % at one anatomical location, deviating from the AAPM-TG29 guidelines. It is noteworthy that IVD_{hyp} yielded acceptable results primarily because the hypothesis retained the first fraction IVD, which typically guides the course of the entire treatment in actual IVD.

Some limitations should be acknowledged in this study. Firstly, TBI treatments were overseen by various medical physicists over the analyzed 10 years, potentially resulting in variations in the application of setup and compensations adjustments, which might have influenced IVD results. Additionally, minor changes in diode positioning between fractions, aimed at mitigating dose attenuation from to the build-up cap, could have affected dose measurements due to angular dependance and tissue inhomogeneity. Furthermore, the analysis was based on monitoring six anatomical positions. Increasing the number of monitored positions, especially in regions with significant non-uniformity, could provide deeper insights into dose distribution and accuracy.

5. Conclusions

This mono-institutional retrospective analysis of IVD data collected over 10 years of TBI treatments at our Institution confirms the robustness, accuracy, and efficiency of the LINAC-based technique based on CT-planning. The data consistently showed that the majority of dose variations remained within ±5 %, aligning closely with internal criteria. Exceptions were noted primarily in the neck region, where occasinal dosimetric readouts exceeded the ±10 % threshold in fewer than 5 % of total events. Minor discrepancies in total MUs between planning and delivery were observed, suggesting the robustness and reliability of the TPS estimates.

The evaluation of IVD omission, while retaining the first fraction's IVD, suggested a potential time and resources saving. Nevertheless, an ongoing study is implementing an extended distance IMRT-TBI technique. Nonetheless, the current technique achieved acceptable results

Table 6
The percentage dose difference from the prescribed as midline estimate in six different anatomical regions. Data were divided in four groups: one where only MUs adjustments were made (MU), one where only treatment setup changes were made (PMMA), one with both actions and a last where no actions were taken. Number of patients falling in these groups was also reported.

	Nr of patients	Dose difference					
		G	C	N	AL	BL	H
Both	41	0.28 %	−1.75 %	0.73 %	0.28 %	−0.48 %	−0.28 %
PMMA	6	1.38 %	−1.43 %	2.10 %	0.56 %	0.98 %	−1.04 %
MU	24	0.27 %	−1.17 %	0.58 %	0.40 %	−0.49 %	−0.47 %
None	5	−1.76 %	0.75 %	2.65 %	−1.68 %	−0.13 %	−0.20 %

Abbreviations: *G: groin, C: oral cavity, N: neck, AL: apical lung, BL: basal lung, H: hips*.

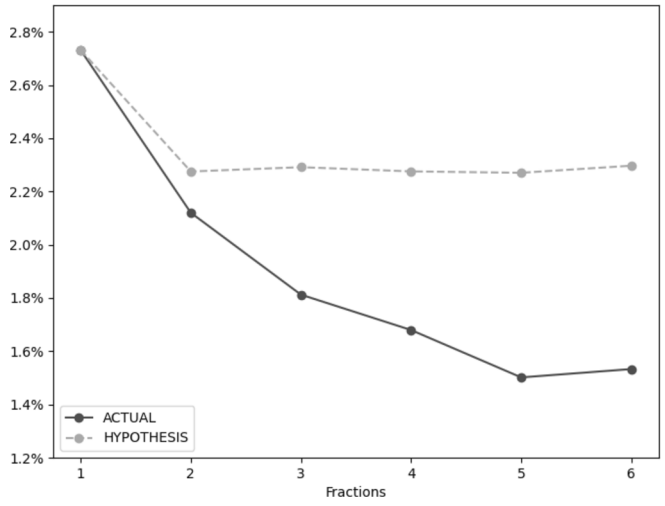

Fig. 6. Absolute percentage dose difference from prescription for all patients of Group A during treatment course with the actual dosimetry (IVD, continuous line) and with the dosimetry obtained according to hypothesis (IVD_{hyp}, dashed line).

Table 7
Impact of in-vivo dosimetry (IVD) omission at the end of treatment: number of patients falling inside and outside the considered dose difference from prescribed dose, with a focus on the lungs.

Measured IVD		IVD_{hyp}	
Inside 5 % range	56	Inside 5 % range	49
Outside 5 % range	20	Outside 5 % range	27
Lungs outside 5 % range	5/20 (25 %)	Lungs outside 5 % range	8/27 (30 %)
Outside 10 % range	0	Outside 10 % range	1

and remains a safe and robust treatment option.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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