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Evaluation of Automated Segmentation of Intracranial Radiosensitive Structures in iPlan Image and its Effects on iPlan Dose

تقييم التحديد الآلي للأعضاء الحساسة للإشعاع داخل الجمجمة في برنامج الصور التابع لنظام iPlan وتأثيرها على برنامج حساب الجرعة التابع لنظام iPlan

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Abstract: The BrainLab iPlan Treatment Planning System (TPS) was used to model a clinac ×-ray photon beam with the BrainLab stereotactic radiosurgery (SRS) apparatus. The head and neck region of the anthropomorphic Rando phantom was scanned using both CT and MRI imaging modalities. Imaged slices were fused together for better contrast using the automatic image fusion provided with iPlan RT image software. A 1.25 cm^3 tumour was assumed and defined at the back of the brain. Nine intracranial radiosensitive structures were segmented manually and automatically by using the atlas-based auto-segmentation tool implemented in iPlan RT image software. The iPlan RT dose software was then employed to estimate the dose received by 50% of each of these structures and the tumour. Volumes and doses of automatically and manually segmented structures were then compared. Generally, it was found that iPlan RT image overestimates the volume of intracranial structures except two of them, the right and the left eye, were underestimated. The dose received by radiosensitive structures exposed to direct ×-ray beam were affected by segmentation discrepancies, while the off-beam structures were not. It was found that auto-segmentation helped in reducing the time required for segmentation by considerable amounts with acceptable accuracy. Finally, an important recommendation is to explore the possibility of predefining the radiological properties of different types of tumour cells in the code for quick and accurate auto-segmentation of Gross Tumour Volume (GTV), for better dose estimation.

Keywords: *iPlan treatment planning system, SRS/SRT, radiosensitive structures, radiotherapy, ×-ray.*

المستخلص: تم استخدام نظام التخطيط للعلاج الإشعاعي (iPlan) التابع لشركة BrainLab لنمذجة حزمة فوتونات أشعة-x الصادرة من المعجل الخطي الطبي بالاستعانة بمعدات شركة BrainLab الخاصة بالجراحة الإشعاعية SRS. كما تم مسبقاً مسح منطقة الرأس والرقبة لبديل جسم الإنسان Rando باستخدام كلا من التصوير المقطعي CT والرنين المغناطيسي MRI. بعد ذلك دمجت الشرائح المصورة باستخدام نظام دمج الصور الآلي المزود به برنامج الصور التابع لنظام iPlan. تم فرض وجود ورم في مؤخرة الرأس بحجم قدره 1.25 سم^3. بعد ذلك تم رسم الحدود الخارجية لتسعة أعضاء حساسة للإشعاع داخل الجمجمة مرة

بالطريقة اليدوية ومرة باستخدام أداة التحديد الآلي المعرفة مسبقاً بواسطة أطلس التشريح المتضمنة في برنامج الصور التابع لنظام iPlan. بعدها تم استخدام برنامج حساب الجرعة التابع لنظام iPlan لتقدير الجرعة الواصلة إلى 50 % من كل من هذه الأعضاء إضافة إلى الورم. أحجام الأعضاء المحددة يدوياً والمحددة آلياً وكذلك الجرعات الواصلة إليها تم مقارنتها فيما بعد. بشكل عام وجد أن برنامج الصور التابع لنظام iPlan يبالغ في تقدير أحجام الأعضاء داخل الجمجمة عدا اثنين منهم فقد قلل من حجميهما وهما العين اليمنى والعين اليسرى. أما الجرعات الواصلة للأعضاء الحساسة للإشعاع المعرضة لحزمة فوتونات أشعة-x المباشرة فقد وجد أنها تأثرت بالاختلافات في تحديد أحجام الأعضاء بينما الأعضاء الغير واقعة في طريق الحزمة فلم تتأثر. كما وجد أن التحديد الآلي ساعد في تقليل الزمن المستغرق لذلك إلى أوقات معقولة وبدقة مقبولة. أخيراً توصي هذه الدراسة باستطلاع إمكانية تعريف النظام مسبقاً بالخواص الإشعاعية لأنواع مختلفة من الخلايا السرطانية من أجل التحديد الآلي الدقيق والسريع للحجم الفعلي للورم GTV في سبيل تحسين تقدير الجرعة.

كلمات مدخلية : *نظام التخطيط للعلاج الإشعاعي، الجراحة الإشعاعية، الأعضاء الحساسة للإشعاع، العلاج الإشعاعي، الأشعة السينية.*

INTRODUCTION

The principle of radiation therapy is to use high energy radiation to deliver maximum destruction to cancer cells while keeping healthy tissue at minimum destruction. This high energy radiation can be delivered to the tumour either via external sources or internal sources. External sources of radiation are widely used in oncology centres and can be considered as an effective technique in treating deep malignant tumours. However, in the last two decades or so, new techniques have been introduced to deliver extensive doses to well-defined volumes. These new techniques made it much easier for the physicists to deliver most of the radiation dose to the Planning Target Volume (PTV). Moreover, radiosensitive structures can be shielded and avoided, to a high extent, during treatment. These new techniques include stereotactic radiosurgery/stereotactic radiotherapy (SRS/SRT).

This type of treatment is applied to brain tumours where a concentrated dose of high energy radiation is focused on the lesion with a sudden dose falloff external to the treated volume. The fast dose gradient at the edge of the treatment volume provides remarkable sparing of healthy brain tissue.

Stereotactic radiosurgery (SRS), or simply radiosurgery, is a technique for the treatment of an intracranial lesion where it combines the use of a stereotactic apparatus and an energetic radiation beam to irradiate the lesion with a single treatment. On the other hand, Stereotactic Radiotherapy (SRT) utilizes the same apparatus of SRS and many radiation beams for multiple fractions or treatments. These techniques (SRS and SRT) are basically two-step processes consisting of:

- an accurate definition of the shape and location of the lesion and the neuroanatomy in the reference frame of a stereotactic frame system with the suitable imaging modalities, namely CT, MRI or angiography.
- modelling and delivering the treatment with radiation.

The history of SRS started in the late 1940s when Leksell developed SRS to destroy dysfunctional loci in the brain using orthovoltage x-rays (Leksell, 1951). Heavilly charged particles, gamma rays, and megavoltage x-rays have also been used to irradiate arteriovenous abnormalities as well as benign and malignant tumours.

Examples of abnormalities treated with SRS are single metastasis (Alexander, *et al*. 1995), solitary primary brain tumours (Larson, *et al*. 1990; Li, *et al*. 2006), arteriovenous malformations (Fabricant, *et al*. 1984, 1985; Kjellberg, *et al*. 1986; Steinar, 1986; Colombo, *et al*. 1987; Saunders, *et al*. 1988; Betti, *et al*. 1989) and benign conditions (Andrews, *et al*. 2004) or tumours, such as pituitary adenoma and acoustic neuroma (Kondziolka, *et al*. 1999). Overviews of clinical applications of SRS/SRT have been presented by (Podgorsak, *et al*. 1987, 1988, 1989, 1990, and 1992; Flickinger and Loeffler, 1992; McKenzie, *et al*. 1992; and Luxton, *et al*. 1993).

Three-dimensional treatment of a brain lesion with a megavoltage unit first took place in 1948 (Kerst, 1975). The first combined use of an ×-ray unit and stereotactic frame was in 1950 (Leksell, 1951, 1983). Quality assurance in every step of the SRS treatment processes is extremely important. Usually different institutes develop their own processes and methods of quality assurance program for SRS (Chang, *et al*. 2009). Safety precautions include the introduction of interlocks on the patient support assembly (couch) motion and motion of the gantry, which limit the arc or rotation of the equipment and prevent patient disturbance (Salter, *et al*. 2008; Ali, *et al*. 2009; Bednarz, *et al*. 2009). According to the recommendation of the American Association of Physicists in Medicine (AAPM), SRS should not be applied in any radiation therapy clinic without the presence of at least one clinical medical physicist at each procedure (AAPM, 1985). It is strongly recommended that quality assurance requirements are checked by a physicist and independently rechecked by a second professional clinical medical physicist or a board-eligible medical physicist. This recommendation was supported by the joint statement issued by the American Association of Neurological Surgeons (AANS) and the American Society for Therapeutic Radiology and Oncology (ASTRO), (Lunsford and Larson, 1994).

MATERIALS AND METHODS

Stereotactic radiosurgery is increasingly used in oncology centres in Saudi Arabia. Many specialized companies in medical equipments produce SRS apparatus; BrainLab is one of them. In this work BrainLab apparatus and the iPlan Treatment Planning System (TPS) were used. This planning system consists of two softwares, iPlan RT image and iPlan RT dose. In this study, the two softwares were tested for their accuracy in utilizing the atlas-based auto-segmentation of nine pre-defined intracranial radio-sensitive structures and consequently in dose estimation.

Brain Lab Apparatus

Frame System

A stereotactic frame is fixed to the patient's skull in order to identify the treated target. Imaging techniques, such as computerized tomography (CT), magnetic resonance imaging (MRI) and/or angiography, pinpoint the target within the fixed frame. The location and geometry of the target is then transferred to the BrainLab iPlan treatment planning system for beam modelling in order to calculate dose distributions in three dimensions. For linac-based radiosurgery, the arc geometry can be varied to grant a concentrated dose to the selected target while minimizing the dose to radio-sensitive structures surrounding the target.

The performance of the components relating to the frame coordinate system must be verified as to compliance with the manufacturer's specifications. The CT, MRI, and angiographic localization procedures must yield target coordinates that differ by less than the total uncertainty of the frame system and imaging procedures over the coordinate domain of the frame system.

Patient Docking Device

The patient docking device couples the frame to the treatment machine, with the pedestal or the couch-mount bracket. The patient docking device must be as mechanically rigid as possible. Notably, the docking position on the frame should minimize torque caused by the patient. For the pedestal-mounted frame system, the origin of the pedestal's coordinate system should be aligned to within 1 mm of the gantry/collimator/PSA axes' locus. For the couch-mounted frame, the patient is brought in alignment with the linac isocenter using the standard couch motors. These motors, however, are not accurate or sensitive enough to assure accurate positioning. The patient docking device thus must allow a vernier-based or fine adjustment system to precisely align the patient at the desired isocenter/target position. It is the experience of the task group members that aligns the frame system to within 1 mm of the linac coordinate system.

Target Verification Devices

The target verification devices ensure that the patient is treated at the correct target coordinate, that the target coordinate is aligned with the isocenter, and that the patient is aligned with the isocenter. These devices are calibrated with respect to the frame-based coordinate system. This calibration have been verified and documented upon acceptance.

iPlan Treatment Planning System

The iPlan treatment planning system is the BrainLab's beam modeling system specially designed for calculating dose distribution within the target volume in SRS/SRT. This code was designed to simulate BrainLab apparatus and patient's head. It works in two different environments. These are: ***iPlan RT Image*** and ***iPlan RT Dose***.

iPlan RT Image is an advanced contouring software capable for faster contouring and consistent segmentation outcomes. Using the automatic features and optimized workflow guidance, anatomical structures and treatment volumes can be defined. Intracranial structures are created with greater accuracy and consistency in comparison to manual "slice-by-slice" contouring. Automatic atlas segmentation is available in this software for cranial, spine, prostate cases and head & neck lymph level. The *Smart Brush* contouring tool implemented into the iPlan RT image software was utilized for automatic target delineation for sensitive structures.

iPlan RT Dose software offers a multiple selection of treatment techniques with a versatile tool for defining an acceptable treatment plan. Stereotactic dose planning with conformal beam, dynamic conformal arc, IMRT, or a combined plan including several treatment modalities give total control in determining the optimal treatment for each patient. The software relies on a user-defined template library which helps in fast planning results.

In Saudi Arabia brain tumour treatments account for a large percentage of surgeries in radiotherapy departments. Traditional treatment planning methods require a manual analysis of multiple CT scans of the brain and surrounding tissues and structures, a process which is labour intensive, time consuming and often inconsistent. The iPlan RT image software with its automatic segmentation software contains an "anatomical atlas" which used as a template, can be manipulated to visualize a patient's precise internal dimensions through a process called "elastic fusion". The contouring process allows for clearer evaluations and a more accurate course of treatment.

In this work, CT and MRI images were obtained with the BrainLab apparatus for the Rando phantom and transferred to the treatment planning workstation. Automatic segmentation was performed using iPlan RT image software and manual contouring was carried out by an experienced radiation oncologist. Contours were created for brainstem, chiasm, left eye, right eye, medulla oblongata, left optic nerve, right optic nerve, left optic tract and right optic tract. The volume of each structure was estimated by the code in the two situations. A 1.25 cm^3 cranial tumour was postulated and defined at the back of the skull. One thousand cgy have been prescribed to be delivered to the PTV. The dose received by each structure was estimated by the code in the two situations, auto and manual segmentation.

RESULTS AND DISCUSSION

The atlas-based auto-segmentation tool implemented in iPlan RT image was utilized to define nine intracranial radiosensitive structures. The dose delivered to each of these structures were estimated later, using iPlan RT dose software. With the aid of an experienced radiation oncologist, the same procedures were repeated, except that segmentation of these structures was performed manually using the outlining tools in iPlan RT image. Because brain visualization is generally better on MRI than on CT, both imaging modalities were used for intracranial planning and automatic image fusion in iPlan RT image to benefit from both modalities. Table (I) shows volumes (in cubic centimetres) for both auto and manually segmented structures together with the estimated doses (in cGy) received by 50% of the volume of each of these structures and the tumour. For comparison, percentage differences in volumes of the auto and manually-segmented radiosensitive structures were also calculated and listed. Doses delivered to these structures have shown some discrepancies for auto and manual segmentation. These discrepancies are also listed as percentage differences in the last column of the Table. Equations (1) and (2) were used in calculating percentage differences in volume segmentation and dose estimation, respectively.

Percentage differences in volume segmentation =

$$\frac{\textit{iPlan}\text{ volume - manual volum}}{\text{manual volum}} \times 100\ \% \qquad (1)$$

Percentage differences in dose estimation =

$$\frac{\textit{iPlan}\text{ does - manual does}}{\text{manual does}} \times 100\ \% \qquad (2)$$

Generally, when auto-segmented volumes are compared with manually segmented volumes, it was noticed that iPlan RT image overestimates the volumes of radiosensitive structures with the exception of two, the left and the right eyes. Percentage differences in volume estimation lay between a minimum value of 3.2% in the right eye segmentation and a maximum value of 29.6% in the chiasm segmentation. The high discrepancies in chiasm segmentation may be attributed to its small volume and the difficulty in distinguishing between nearby tissue by the oncologist, which could mean that iPlan RT image is more accurate in contouring this structure in particular.

Since the dose delivered to different tissues and structures is mainly dependent on the path of the treating beam (Figure [1] shows the treating beam directed to the tumour), the dose delivered to each radiosensitive structure has not necessarily been affected by discrepancies in segmentation. Although the maximum percentage discrepancies in dose estimation approached 10.2% in the left optic nerve, it did not correspond to the maximum discrepancies in segmentation. On the other hand, maximum discrepancies in volume segmentation was found in chiasm segmentation (29.6%), though discrepancies in dose to this structure was not increased by more than 8.5%. Finally, and excluding the zero discrepancies, the minimum discrepancies in dose was in the left optic tract (1.3%) while discrepancies in its segmentations was a considerable amount (14%).

Although the percentage discrepancies in volume segmentation of certain radiosensitive structures achieved considerable levels (as in left eye, right eye, right optic nerve, right optic tract, medulla oblongata and brainstem), it was found that dose received by these structures were not totally affected. Structures lying in the path of the treating radiation (such as chiasm, left optic nerve and, to less extent, left optic tract) were found at higher risk in getting a dose different from that calculated by auto-segmentation, as shown in (Figure 2). The negative part of the diagram shows that doses were reduced by discrepancies in volume segmentation.

Table 1. Volumes and doses to intracranial radiosensitive structures using automatic and manual segmentation.

Organs	**Volume (cm^3)**			**Dose$_{50\%}$ (cGy)**		
	iPlan RT Image	**Manual**	**% Difference**	**iPlan RT Dose**	**Manual**	**% Difference**
Brainstem	21.714	20.013	+8.5	40	40	0
Chiasm	0.280	0.216	+29.6	183	200	-8.5
Lt. Eye	6.833	7.227	-5.5	30	30	0
Rt. Eye	7.345	7.585	-3.2	21	21	0
Medulla Oblongata	3.046	2.755	+10.6	20	20	0
Lt. Optic Nerve	0.451	0.421	+7.1	159	177	-10.2
Rt. Optic Nerve	0.418	0.385	+8.6	30	30	0
Lt. Optic Tract	0.203	0.178	+14	1644	1665	-1.3
Rt. Optic Tract	0.156	0.139	+12.2	40	40	0
Tumour	1.25	1.25	0	1000	1000	0

dose$_{50\%}$: dose to 50% of the structure

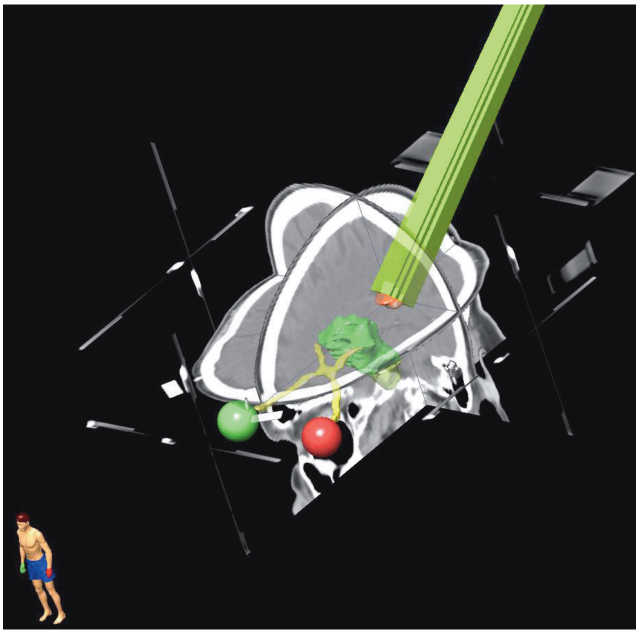

Fig. 1. A snap-shot of the ×-ray beam showing that most of the radiosensitive structures are off-beam.

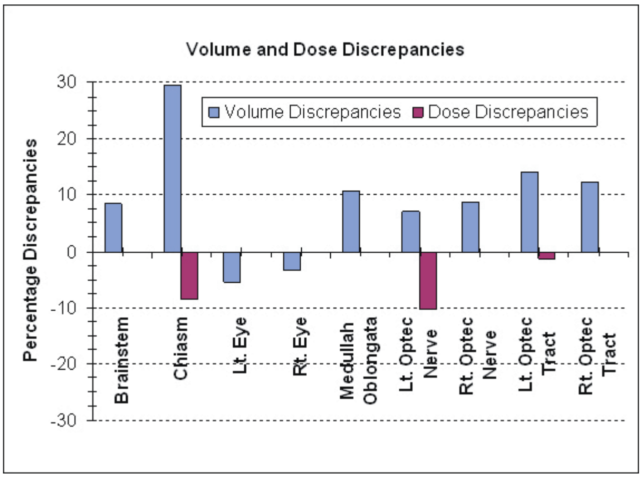

Fig. 2. Volume and dose discrepancies for each radiosensitive structure.

CONCLUSIONS

Generally auto-segmentation implemented in iPlan RT image software is a quick and reliable tool in defining intracranial structures. The final outlining result was achieved much faster, and the automatic segmentation tool greatly enhanced the overall efficiency of the contouring process and clearly reduced the time required for contouring.

Since most of the radiosensitive structures are usually away from direct radiation in SRS, the effect of dose discrepancies to these structures was not pronounced by discrepancies in segmentation. It is recommended that more attention should be paid by the oncologist in fine contouring structures lying in the path of the treating radiation. Hence, in complicated and small structures, manual verification is necessary to delineate outer boarders to a better extent.

Finally, by defining the radiological properties of different types of tumours, it is recommended to explore the possibility of modifying iPlan RT image software to distinguish between normal and tumour cells. So, Gross Tumour Volume (GTV) will be more easily defined by auto-segmentation which could make it a more reliable tool for better dose estimation.

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