Accuracy evaluation of image-guided radiation therapy guided by optical surface monitoring system for treatment of intracranial tumors

การประเมินความแม่นยำของการฉายรังสีภาพนำด้วยระบบตรวจสอบพื้นผิวแสง ในการรักษาเนื้องอกที่สมอง

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Submitted: August 12, 2019

Revised: Oct 2, 2019

Accepted: Oct 7, 2019

Abstract

Background: Image-guided radiation therapy (IGRT) is an advanced radiation treatment that creates an image of the tumor to guide the radiation beam during radiation therapy. Importantly, the use of ionizing radiation for daily IGRT may subject patients to an unnecessarily cumulative dose of radiation. The optical surface monitoring system (OSMS) is a non-ionizing radiation IGRT technique that was developed to provide continuous motion tracking during real-time treatment without increasing patient exposure to ionizing radiation.

Objective: The aim of this study was to investigate the accuracy of IGRT guided by OSMS for the treatment of intracranial tumors.

Materials and Methods: This retrospective analysis of prospectively collected data included 62 consecutive patients that were treated for intracranial brain tumor with IGRT guided by OSMS at the Ramathibodi Radiosurgery Center during January 2016 to December 2017.
Results: A median prescribed dose of 50 Gy (range: 36-60) in 25 fractions (range: 22-30) was used. The median planning target volume was 20.65 cm^3 (range: 0.4-485). The mean set-up error measured on pretreatment cone beam computerized tomography (CBCT) and OSMS was very small (<1 mm, 1 degree) in all directions. The maximum mean difference of deviation between CBCT and OSMS was 0.29±0.17 mm in lateral direction, and 0.08±0.14° in pitch direction. Less than 5% of patients needed to be repositioned during treatment. The treatment was well-tolerated by all patients, and no severe treatment-associated toxicity was reported.
Conclusion: IGRT guided by OSMS was found to be an efficacious, radiation-limiting treatment method for the management of intracranial tumors.
Keywords: Image-guided radiation therapy, IGRT, intracranial tumors, optical surface monitoring system, OSMS

บทคัดย่อ

หลักการและเหตุผล: การฉายรังสีภาพนำ (Image guide radiation therapy; IGRT) เป็นการฉายรังสีก้าวหน้าที่ใช้ภาพถ่ายทางรังสีเพื่อนำไปสู่การฉายรังสีที่ถูกต้องแม่นยำ แต่ในการใช้ภาพถ่ายด้วยรังสีเอกซ์ในแต่ละวันของการฉายรังสีทำให้ผู้ป่วยได้รับปริมาณรังสีเอกซ์เพิ่มขึ้นโดยไม่จำเป็น จึงนำไปสู่การใช้ระบบตรวจสอบพื้นผิวแสง (optical surface monitoring system; OSMS) ในการฉายรังสีนำภาพ เพื่อลดการใช้รังสีเอกซ์แก่ผู้ป่วย
วัตถุประสงค์: เพื่อศึกษาความถูกต้องของการฉายรังสีภาพนำด้วยการใช้ระบบตรวจสอบพื้นผิวแสง ในการฉายรังสีผู้ป่วยเนื้องอกสมอง
วัสดุและวิธีการ: ศึกษาโดยเก็บข้อมูลย้อนหลังในผู้ป่วยเนื้องอกสมอง จำนวน 62 ราย ที่มาทำการฉายรังสีด้วยเทคนิครังสีนำภาพโดยระบบตรวจสอบพื้นผิวแสง ที่ศูนย์รังสีศัลยกรรม โรงพยาบาลรามาธิบดี ตั้งแต่เดือน มกราคม พศ. 2559 ถึง เดือน ธันวาคม พศ. 2560
ผลการศึกษา: ปริมาณรังสีที่ใช้ในผู้ป่วยเฉลี่ยคือ 50 เกรย์ ใน 25 ครั้ง โดยปริมาตรเฉลี่ยของเนื้องอกในการศึกษานี้ คือ 20.65 ลูกบาศก์เซนติเมตร จากการศึกษาพบว่าค่าความแตกต่างของความคลาดเคลื่อนเฉลี่ยที่มากที่สุดระหว่าง ภาพถ่ายรังสีคอมพิวเตอร์ส่วนตัดลำรังสีรูปกรวย (cone beam computerized tomography; CBCT) และ ระบบตรวจสอบพื้นผิวแสง (OSMS) มีค่าเท่ากับ 0.29±0.17 มม. ในแนวด้านข้าง และ 0.08 ± 0.14 องศา ในระดับพิทช์ โดยพบว่าน้อยกว่าร้อยละ 5 ของผู้ป่วยที่ต้องมีการจัดตำแหน่งใหม่ระหว่างการฉายรังสี และไม่พบรายงานว่าผู้ป่วยมีผลข้างเคียงเกิดขึ้นในการรักษาด้วยเทคนิคนี้
ข้อสรุป: การฉายรังสีภาพนำโดยการใช้ระบบตรวจสอบพื้นผิวแสง เป็นวิธีที่มีประสิทธิภาพและปลอดภัยในการรักษาผู้ป่วยเนื้องอกสมอง
คำสำคัญ: การฉายรังสีภาพนำ เนื้องอกที่สมอง ระบบตรวจสอบพื้นผิวแสง

J Thai Assoc Radiat Oncol 2019; 25(2): 28-36.

Introduction

Image-guided radiation therapy (IGRT) is an advanced radiation treatment that creates an image of the tumor to guide the radiation beam during radiation therapy. The images of the tumor are created using X-ray, ultrasound, or other imaging techniques designed to increase the accuracy of the radiation treatment, and to decrease the level of collateral damage caused to healthy tissue. Even when exposed at a low dose, daily IGRT guided by X-ray, which is a type of ionizing radiation, can expose patients to a cumulative dose of radiation that is potentially unsafe[1]. In response to this radiation exposure concern, the optical surface monitoring system (OSMS) was developed. OSMS uses non-ionizing radiation to guide IGRT, which facilitates continuous motion tracking during real-time treatment without patient exposure to unnecessary ionizing radiation. An IGRT system was installed at our center in 2015, and that system is guided by OSMS for cases that require IGRT by IMRT or VMAT technique. The aim of this study was to investigate the accuracy of IGRT guided by OSMS for the treatment of intracranial tumors.

Materials and Methods

This retrospective analysis of prospectively collected data included 62 consecutive patients that were diagnosed with and treated for intracranial tumor by IGRT guided by OSMS at the Ramathibodi Radiosurgery Center, Department of Radiology, Faculty of Medicine, Ramathibodi Hospital, Mahidol University, Bangkok, Thailand during the January 2016 to December 2017 study period. All patients were counseled, and written informed consent was obtained. The protocol for this study was approved by the Ramathibodi Institutional Review Board. This study complied with all of the principles set forth in the Declaration of Helsinki (1964) and all of its subsequent amendments.

The Edge® Radiosurgery System (Varian Medical Systems, Palo Alto, CA, USA) that has been used at our center since 2015 is a novel treatment platform for frameless, image-guided stereotactic radiosurgery (SRS) and stereotactic body radiotherapy (SBRT). The linear accelerator is equipped with 120 multileaf collimators, 3 energies (6 and 10 Megavoltage flattening filter-free, and 6 Megavoltage), 6 degrees of freedom couch with a Calypso® couch top (Varian Medical Systems), and the integrated kilovoltage (KV) and megavoltage (MV) imaging system[2].

AlignRT® (Vision RT Ltd, London, United Kingdom) is the optical surface monitoring system (OSMS) that is used to guide IGRT for intracranial SRS/SRT at our center. The AlignRT® system consists of 3 ceiling-mounted nonionizing camera pods to create a three-dimensional surface image of the patient. The surface imaging software reconstructs the patient surface, and it tracks the surface motion by comparing the real-time surface imaging with the reference image. The reference image can be surface contour-generated from the planning CT image, or can be a surface image acquired with AlignRT®. Finally, the program displays the real-time deviation from the reference in the direction of 3 translations and 3 rotations[3].

A treatment approach included simulation, planning and subsequent delivery of radiation. During simulation process, a customizable open-face thermoplastic mask (Qfix, Avondale, PA, USA) was individually constructed for patients to wear while lying in the supine position **(Figure 1a, 1b).** A computerized tomography (CT) and magnetic resonance imaging (MRI) simulation, with or without contrast, was generated with 1.25 mm slice thickness. The set of CT and MRI simulation images was transferred to the treatment planning workstation using inverse planning by Eclipse software, version 13.6 (Varian Medical Systems). Gross tumor volume (GTV), clinical target volume (CTV), and critical structures were contoured in each consecutive slice of CT or MRI by the treating radiation oncologist and neurosurgeon. A 3-5 mm margin was added to generate the planning target volume (PTV). The body contour was carefully reviewed, because it gets imported into the surface imaging system for patient set-up at the time of treatment. The treatment delivery methods were intensity-modulated radiation therapy (IMRT) or volumetric arc therapy (VMAT). Radiation was delivered in conventional fractionation at 1.8-2 Gy/fraction for a total dose of 50-60 Gy in 25-30 fractions. Treatment planning was determined and finalized by a radiosurgery team consisting of neurosurgeons, radiation oncologists, and medical physicists.

On the first day of treatment, the treatment plan and body contour were imported into the OSMS. The region of interest to be monitored included the forehead, orbits, nose, zygoma, and temporal bones. Initial patient position was determined based on guidance from the OSMS, with the body contour from the planning CT used as a reference. Real-time KV and CBCT imaging was performed for bone and skull matching. The auto matching tool was applied, after which the couch was adjusted to correct for translation error and rotation error detected by KV/KV and CBCT. The OSMS was then acquired. This OSMS from the first day was recorded and used as the set-up reference for the entire treatment. On the next treatment, therapists adjusted the patient position until the deviation of the reference OSMS was as close to 0 as possible. The OSMS was continuously monitored and tracked in real-time during treatment delivery. The real-time difference from the reference surface contour extracted from the planning CT is shown on the screen **(Figure 1c)**. Beam hold was set to automatically initiate when intrafraction deviation exceeded a translational delta of 2 mm or a rotational delta of 1 degree

All data analyses were performed using SPSS Statistics version 18 (SPSS, Inc., Chicago, IL, USA). Categorical data are presented as frequency and percentage, and continuous data are shown as median and range. The data collected were: (1) baseline patient characteristics; (2) CBCT deviation; and, (3) OSMS deviation before CBCT. In addition, we aimed to calculate a margin that optimized the PTV margins for conventional IMRT/VMAT with open mask and the OSMS system. PTV margin calculation was performed using the following simplified PTV margin formula proposed by van Herk, et al [4]:

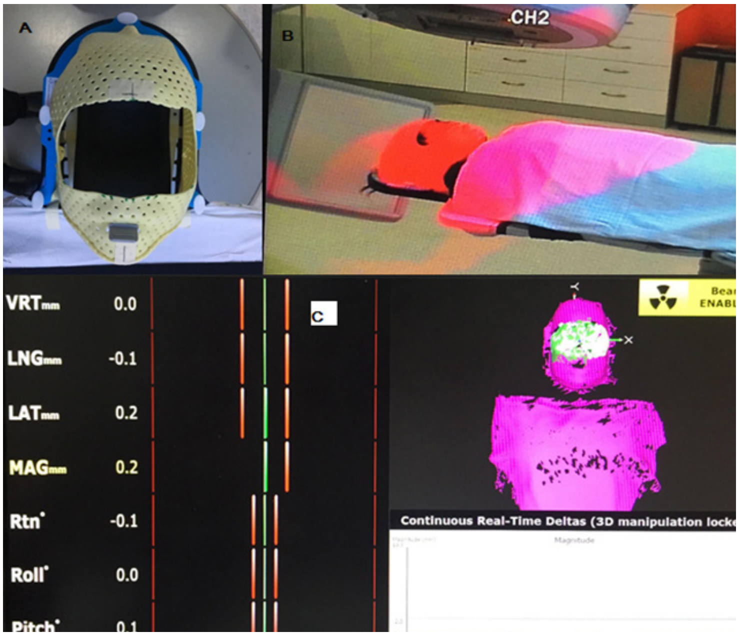

Figure 1. Image-guided radiation therapy (IGRT) guided by optical surface monitoring system (OSMS). (A) Customizable open-face thermoplastic mask; (B) Overall patient set-up in the treatment room; and, (C) Screen capture of the OSMS tracking system.

PTV margin = $(2.5 \times \Sigma) + (0.7 \times \sigma)$

Σ= quadratic sum of SD for population systematic errors

σ = quadratic sum of SD for population random errors

Results

Sixty-two consecutive intracranial tumor patients treated with IGRT guided by OSMS were included. Fifty-six (90%) patients had previously undergone surgery. A median prescribed dose of 50 Gy (range: 36-60) in 25 fractions (range: 22-30) was used. The median planning target volume was 20.65 cm^3 (range: 0.4-485). The treatment was well-tolerated by all patients, and no severe (> grade 3) treatment-associated toxicity was reported. The proportion of patients that require repositioning due to motion that exceeds a predefined tolerance is very low (<5%). The Patient demographic and diagnostic data are given in **Table 1.**

CBCT and OSMS deviation

A total of 656 CBCT and 628 OSMS data were recorded and analyzed. Deviation from the reference image compared between CBCT and OSMS in 3 translation and 3 rotation directions is shown in **Table 2.** The mean set-up error measured on pretreatment CBCT and OSMS was very small (<1 mm, 1 degree) in all directions. The maximum mean difference of deviation between CBCT and OSMS was 0.29±0.17 mm in lateral direction, and 0.08±0.14° in pitch direction. The mean difference between CBCT and OSMS positioning in each direction is shown in **Table 3.**

Table 1. Patient demographic

Patient data	n (%)
Patients	62
Gender	
Male	20 (32.3%)
Female	42 (67.7%)
Age (yrs), median (range)	45 (3-81)
Pathologic diagnosis	
Meningioma	29 (46.8%)
Pituitary adenoma	12 (19.4%)
High-grade astrocytoma	10 (16.1%)
Low-grade astrocytoma	5 (8.1%)
Germinoma	4 (6.5%)
Craniopharyngioma	2 (3.2%)

Table 2. Deviation from the reference image compared between CBCT and OSMS

Variable	Vertical (mm)		Longitudinal (mm)		Lateral (mm)		Rotation (°)		Roll (°)		Pitch (°)	
	CBCT	OSMS	CBCT	OSMS	CBCT	OSMS	CBCT	OSMS	CBCT	OSMS	CBCT	OSMS
Mean deviation	0.17	0.03	-0.095	-0.10	-0.031	-0.06	0.02	0.024	-0.04	0.002	-0.02	0.09
SD	0.37	0.42	0.55	0.42	0.40	0.35	0.39	0.29	0.41	0.29	0.49	0.33
Mean absolute deviation	0.31	0.33	0.43	0.38	0.03	0.29	0.31	0.26	0.32	0.26	0.37	0.29
SD	0.26	0.24	0.045	0.27	0.027	0.2	0.23	0.18	0.26	0.18	0.34	0.2

Abbreviations: CBCT, cone beam computed tomography; OSMS, optical surface monitoring system; SD, standard deviation

Table 3. The mean absolute difference between CBCT and OSMS positioning in each direction

Difference	Vertical (mm)	Longitudinal (mm)	Lateral (mm)	Rotation (°)	Roll (°)	Pitch (°)
Mean	0.02	0.05	0.29	0.05	0.06	0.08
SD	0.02	0.23	0.17	0.05	0.08	0.14

Abbreviations: CBCT, cone beam computed tomography; OSMS, optical surface monitoring system; SD, standard deviation

PTV margin calculation was performed using the following simplified PTV margin formula proposed by van Herk, *et al*[4]. The systematic and random error in anterior/posterior were 0.215 and 0.269 mm, in inferior/superior were 0.356 mm and 0.408 mm, and in right/left were 0.241 mm and 0.304 mm. Based on these data, the calculated PTV margins in the anterior/posterior, inferior/superior, and right/left direction were 0.743 mm, 1.195 mm, and 0.83 mm, respectively.

Discussion

Advances in image-guided radiation therapy (IGRT) have contributed to the development of several image guidance techniques (including X-ray and non-X-ray imaging) that can be used to obtain accurate target positioning. Cone beam computed tomography (CBCT) is a standard method for position verification prior to and during radiotherapy due to its high level of accuracy. However, the imaging dose of ionizing radiation delivered to patients from CBCT became an issue of concern soon after its introduction as an imaging guidance technique. Clinical study reported an imaging dose from CBCT of 1-7cGy for skin dose, and of 2-3 cGy for rectal dose in each fraction[1]. These values are in the same range as those measured in phantom study. The imaging dose was also reported to vary according to location of the target, technique, and patient size[1].

The introduction of a zero-dose, non-X-ray IGRT technique (OSMS) that was developed to capture the patient surface was clinically implemented in various tumor locations, including the brain, head and neck, breast, and pelvis[5-11]. Previous studies recently reported the use of open-face mask with OSMS for intracranial tumor; however, most of those studies focused phantom-based or brain SRS treatment [3,7,12-15]. The present study reports our initial clinical experience with the Edge® IGRT system guided by AlignRT® OSMS for conventional fractionation IMRT or VMAT treatment.

The OSMS continuously monitors patient movement when the radiation beam is on during treatment. The radiation beam was set to automatically turn off whenever patient motion exceeded a predefined tolerance. From our experience, the proportion of patients that require repositioning due to motion that exceeds a predefined tolerance is very low (<5%).

The results from phantom-based studies revealed the accuracy of OSMS to be comparable with that of CBCT. By way of example, the maximum difference of CBCT relative to OSMS positioning was 0.6±0.3 mm and 0.3° by Mancosu, *et al*[12], and 0.2±0.3 mm and 1.3° by Peng, *et al*[3]. Our data are in the similar value of those reported in phantom and clinical studies[8, 9, 15].

We aimed to calculate a margin that optimized the PTV margins for conventional IMRT/VMAT with open mask and the OSMS system. PTV margin calculation was performed using the following simplified PTV margin formula proposed by van Herk, *et al*.[4] Based on our data, the calculated PTV margin in the anterior/posterior, inferior/superior, and right/left direction was 0.743 mm, 1.195 mm, and 0.83 mm, respectively. These results confirm that the addition of a 3 mm margin to the PTV is enough to ensure target coverage. Furthermore, reducing the routine use of 3-5 mm PTV margin to 3 mm margin is acceptable in intracranial brain tumor using the Edge® IGRT guided by AlignRT® OSMS.

Conclusion

The OSMS system is an efficient image guidance tool for daily IGRT that does not expose the patient ionizing radiation. Based on our study, reducing the routine use of 3-5 mm PTV margin to 3 mm margin is encouraged in intracranial brain tumor using the Edge® IGRT guided by AlignRT® OSMS. Additional study with long-term follow-up in a clinical setting is needed to identify any adverse effects associated with OSMS.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this artic

References

1. Alaei P, Spezi E. Imaging dose from cone beam computed tomography in radiation therapy. Phys Med. 2015;31:647-58.
2. Wen N, Li H, Song K, Chin-Snyder K, Qin Y, Kim J, *et al*. Characteristics of a novel treatment system for linear accelerator-based stereotactic radio-surgery. J Appl Clin Med Phys. 2015;16:125-48.
3. Peng JL, Kahler D, Li JG, Samant S, Yan G, Amdur R, et al. Characterization of a real-time surface image-guided stereotactic positioning system. Med Phys. 2010;37:5421-33.
4. Van Herk M, Remeijer P, Rasch C, Lebesque JV. The probability of correct target dosage: dose-population histograms for deriving treatment margins in radiotherapy. Int J Radiat Oncol Biol Phys. 2000;47:1121-35.
5. Cervino LI, Detorie N, Taylor M, Lawson JD, Harry T, Murphy KT, *et al*. Initial clinical experience with a frameless and maskless stereotactic radiosurgery treatment. Pract Radiat Oncol. 2012;2:54-62.
6. Oliver JA, Kelly P, Meeks SL, Willoughby TR, Shah AP. Orthogonal image pairs coupled with OSMS for noncoplanar

beam angle, intracranial, single-isocenter, SRS treatments with multiple targets on the Varian Edge radiosurgery system. Adv Radiat Oncol. 2017;2:494-502.
7. Li G, Ballangrud A, Chan M, Ma R, Beal K, Yamada Y, et al. Clinical experience with two frameless stereotactic radiosurgery (fSRS) systems using optical surface imaging for motion monitoring. J Appl Clin Med Phys. 2015;16:149-62.
8. Zhao B, Maquilan G, Jiang S, Schwartz DL. Minimal mask immobilization with optical surface guidance for head and neck radiotherapy. J Appl Clin Med Phys. 2018;19:17-24.
9. Ma Z, Zhang W. Optical surface management system for patient positioning in interfractional breast cancer radiotherapy. Biomed Res Int. 2018;6415497.
10. Wikstrom K, Nilsson K, Isacsson U, Ahnesjo A. A comparison of patient position displacements from body surface laser scanning and cone beam CT bone registrations for radiotherapy of pelvic targets. Acta Oncol. 2014;53:268-77.
11. Gaisberger C, Steininger P, Mitterlechner B, Huber S, Weichenberger H, Sedlmayer F, et al. Three-dimensional surface scanning for accurate patient positioning and monitoring during breast cancer radiotherapy. Strahlenther Onkol. 2013;189:887-93.
12. Mancosu P, Fogliata A, Stravato A, Tomatis S, Cozzi L, Scorsetti M. Accuracy evaluation of the optical surface monitoring system on EDGE linear accelerator in a phantom study. Med Dosim. 2016;41:173-9.
13. Lau SK, Patel K, Kim T, Knipprath E, Kim GY, Cervino LI, et al. Clinical efficacy and safety of surface imaging guided radiosurgery (SIG-RS) in the treatment of benign skull base tumors. J Neurooncol. 2017;132:307-12.
14. Pan H, Cervino LI, Pawlicki T, Jiang SB, Alksne J, Detorie N, et al. Frameless, real-time, surface imaging-guided radiosurgery: clinical outcomes for brain metastases. Neurosurgery. 2012;71:844-51.
15. Li G, Ballangrud A, Kuo LC, Kang H, Kirov A, Lovelock M, et al. Motion monitoring for cranial frameless stereotactic radiosurgery using video-based three-dimensional optical surface imaging. Med Phys. 2011;38:3981-94.