

Initial Experience with Ultra-Low-Field Intraoperative Magnetic Resonance Imaging in Endoscopic Endonasal Transsphenoidal Surgery for Pituitary Adenoma at Ramathibodi Hospital

Athikorn Thiabpha MD*,
Ake Hansasuta MD*

* Division of Neurosurgery, Department of Surgery, Faculty of Medicine Ramathibodi Hospital, Mahidol University, Bangkok, Thailand

Objective: To report our initial experience using ultra-low-field 0.15 Tesla PoleStar N-30 (Medtronic, Louisville, CO, USA) intraoperative magnetic resonance imaging (iMRI) in endoscopic endonasal transsphenoidal surgery (eTSS) for pituitary adenoma (PA) at the Faculty of Medicine Ramathibodi Hospital.

Material and Method: From September 2013 to August 2014, information from patients who underwent eTSS for PA with ultra-low-field iMRI was prospectively collected. Data of the scans, at the three point-of-times (before, during and after the eTSS), from the iMRI in these patients were subject to our analysis.

Results: A total of the 11 patients successfully underwent eTSS with iMRI during the study period. Two patients were found to have residual PA despite surgeon's opinion of complete resection of the tumor. Further resection yielded complete removal in one and subtotal removal in the other patient. No serious intra- or postoperative complication occurred in association with iMRI.

Conclusion: This is the first report of eTSS for PA with Polestar N-30 iMRI. Our results are similar to those previously published series utilizing earlier versions of, PoleStar N-10 and N-20, ultra-low-field iMRI. These findings, again, confirm the added value of iMRI for the extent of surgical resection in eTSS for PA. Step-by-step illustrations of the iMRI procedure are described.

Keywords: Ultra low field, Intraoperative, MRI, Transsphenoidal, Endoscopic, Pituitary, Adenoma

J Med Assoc Thai 2016; 99 (Suppl. 3): S30-S38

Full text. e-Journal: <http://www.jmatonline.com>

Pituitary adenoma (PA) is one of the most common intracranial neoplasms. Its current management consists of surgical resection, medication, radiotherapy and periodic observation. Transsphenoidal surgery (TSS) had proven efficacy and safety dealing with PA^(1,2). Advance in stereotactic navigation has been shown to aid tumor resection in addition to safe guidance for TSS⁽³⁻⁵⁾. However, navigation system lacks real-time feedback to properly assure surgeon of the complete PA resection. As a result, despite sophisticated surgical devices, residual PA after TSS has been reported to be 15% to 70%^(1,2,6).

For over a decade, use of intraoperative

magnetic resonance imaging (iMRI) has benefited near total or complete tumor resection⁽⁷⁻¹³⁾. At Ramathibodi hospital, an ultra-low-field 0.15 Tesla (T) PoleStar N-30 (Medtronic, Louisville, CO, USA) iMRI has been installed in our surgical unit since September 2013. This model of iMRI is the latest version from PoleStar product line. Based on Pubmed literature search, there was no prior report of this particular version (N-30) iMRI used in conjunction with endoscopic TSS (eTSS). We, therefore, describe our initial experience using iMRI in eTSS for PA.

Material and Method

After installation of the Polestar, latest version (N-30), ultra-low-field iMRI since September 2013, data of patients who underwent iMRI-related procedures were prospectively collected for 12 consecutive months. Patients who had different cranial surgeries other than eTSS for PA or those who had been attempted but

Correspondence to:

Hansasuta A, Division of Neurosurgery, Department of Surgery, Faculty of Medicine Ramathibodi Hospital, Mahidol University, Bangkok 10400, Thailand.
Phone: +66-2-2013571
E-mail: ake.han@mahidol.ac.th

could not successfully undergo iMRI were excluded from this present study. Preoperatively, most of the patients had navigator-protocol computerized tomography (CT) scan as well as MRI scan. The CT and MRI data (dicom files) were uploaded into Stealth station S7 navigator system (Medtronic, Louisville, CO, USA), with subsequent merging of both scans in preparation for patient registration. After general endotracheal tube anesthesia and then placement of a receiving coil (Fig. 1) inside the skull clamp, our usual steps of the iMRI usage are described as follows:

1) Patient's cranium is fixed with a MRI-compatible skull clamp. The head is rotated so that the chin turned toward the patient's right side. Then, a receiving coil is positioned so as to encircle the sellar region to its middle part for optimal scanning quality (Fig. 1).

2) The iMRI is mobilized under the patient's head and raised up emphasizing that the area of interest (sella) is at iMRI's center (Fig. 2). After favorable positioning of the iMRI, a Starshield (Medtronic, Louisville, CO, USA) is unfolded to fully cover the entire patient's body so as to minimize radiofrequency interference to the scanner (Fig. 3). Our first scan is typically obtained using a short (1 minute) unenhanced T1 image to verify the best possible position. If the entire pituitary adenoma is not well visualized, noted by this first scan, repositioning of the iMRI is carried out.

3) With satisfactory position of the patient for scanning, a full 11-minute gadolinium enhanced

T1 scan is subsequently performed. After the surgeon is contented with the quality of the scan, the Starshield



Fig. 2 Black arrow indicates elevation of the iMRI. It is positioned at the best possible spot so that the sellar region is near the iMRI's center for optimal scanning quality. The workstation's computer memorizes this particular position so that the next postoperative scan is performed at the exactly same area.

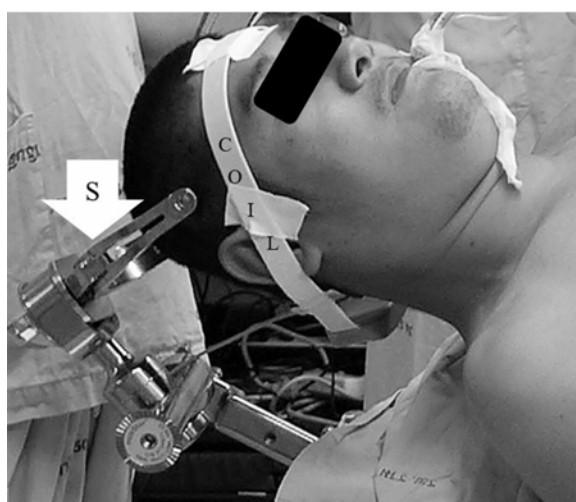


Fig. 1 The patient's head is fixed with MRI-compatible skull clamp (S). Note the receiving coil's position encircles sellar region which is the area of interest.

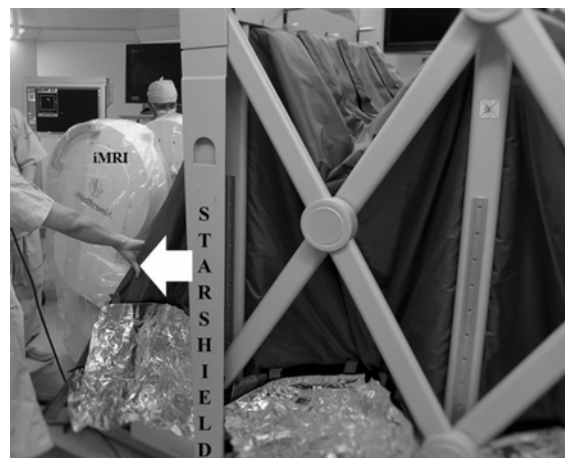


Fig. 3 A Starshield is unfolded. The white arrow shows toe-to-head direction of the Starshield that it eventually fully covers the patient's entire body so as to minimize radiofrequency interference to the scanner.

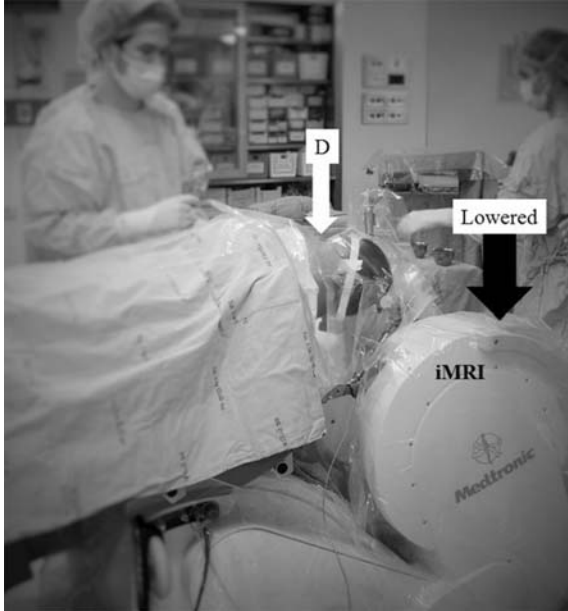


Fig. 4 After sterile preparation, the patient's face is covered with clear plastic sterile drape (D). Black arrow indicates lowered position of the iMRI where it will be kept during surgery.

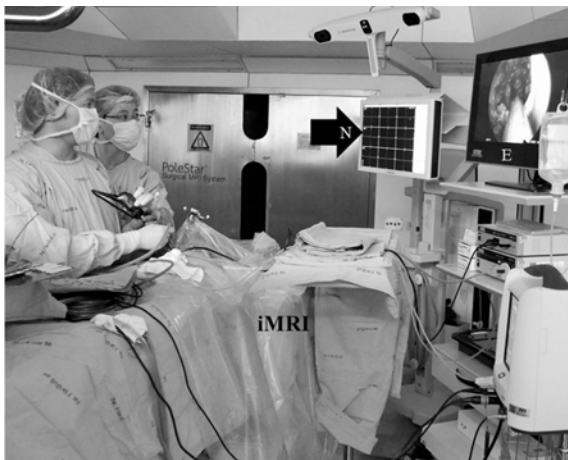


Fig. 5 Surgery is performed in the same manner as other non-iMRI endoscopic transsphenoidal surgery. Endoscope (E) and navigator (N) monitor screens are placed at the similar area as other standard cases.

is unfolded. The preoperative imaging CT and/or MRI data is merged into this newly acquired MRI for navigation during eTSS. After this point, the iMRI scanner is lowered to allow surgeons standing at the right side of the patient during eTSS.

4) After sterile preparation, the patient's face

is covered with clear plastic sterile drape (Fig. 4). Then, the rest steps of eTSS are performed with usual manner as non-iMRI eTSS (Fig. 5).

5) After the neurosurgeon (AH) believes that he achieves complete PA removal by eTSS, gadolinium-soaked cottonoids are packed into the tumor's resection cavity and sella employing similar steps as described by Ahn et al⁽¹⁴⁾. In order to minimize blood pooling into the sella, the nostrils are packed with gauze.

6) After covering the operative field with sterile towels, the iMRI is repositioned at its previously memorized scanning spot. Then, a postoperative 11-minute gadolinium-enhanced T1 scan is obtained using similar manner as described in the second and third steps.

7) The postoperative MRI scan is then used for verification of tumor's resection with navigator probe alongside direct vision via 0 or 30 degree endoscope at various areas of the resection cavity and sella (Fig. 6).

8) Based on the surgeon's analysis of residual tumor or complete resection, eTSS is either continued or finished. If further tumor resection is performed, additional MRI scan could be obtained by repeating the 6th and 7th steps.

Records of patient's preoperative data including gender, age, type of adenoma, primary vs. repeat TSS, size (transverse-anteroposterior-vertical widest diameter) and Knosp grade⁽¹⁵⁾ are summarized in Table 1.

Time consumption for preoperative scan started from immediately after general anesthesia until the end of preoperative iMRI scan (steps 1 to 4). As for the postoperative scanning time consumption, we recorded the time right after completion of the nostrils packing until the iMRI scanning process was ended (steps 6 and 7). The iMRI findings, additional tumor resection and the final residual or total tumor removal are described in Table 1. Any iMRI-related adverse event that occurred during eTSS was noted.

Results

From September 2013 to August 2014, a total of 29 patients had iMRI for their intracranial surgeries. Thirteen of 29 patients underwent eTSS with iMRI. Two of the 13 patients for eTSS were excluded from our analysis. One patient failed to obtain optimal visualization of the tumor due to the patient's extremely short neck whilst the other had non-pituitary adenoma pathology. The remaining 11 patients' data are shown in Table 1. Nine of 11 patients had concurring complete

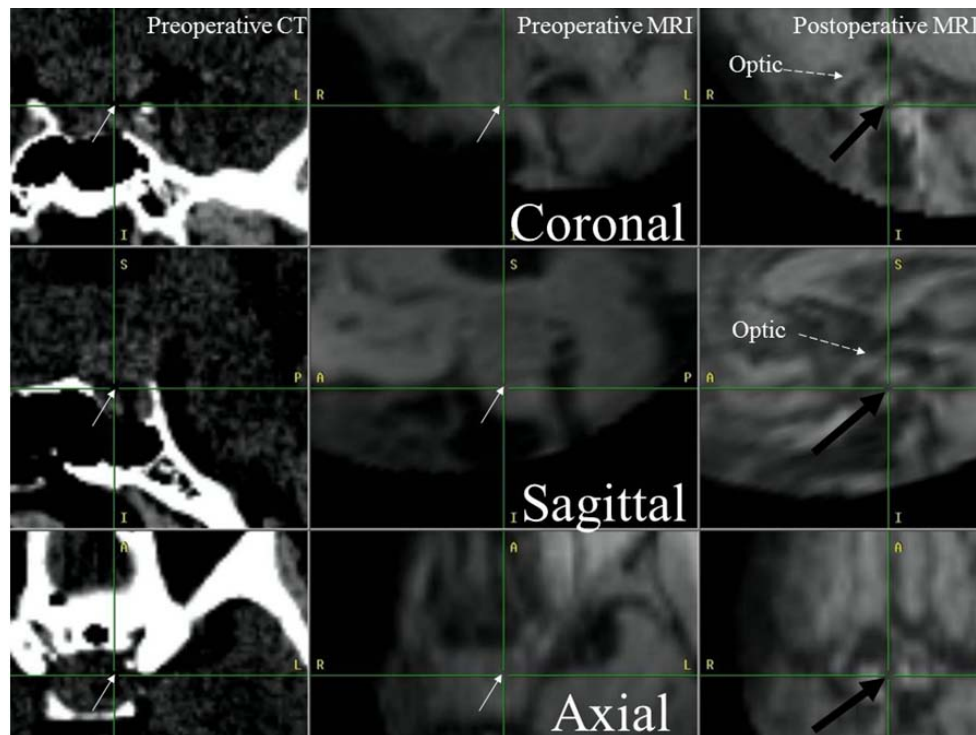


Fig. 6 A snapshot taken from navigator screen shows preoperative CT, MRI (the two most left side columns) and postoperative MRI (the most right side column) scans. Small white arrows and heavy black arrows represent the tip of navigator probe at the same location in three dimensions. Of note, the decompressed optic pathway was seen on the postoperative MRI scans (dotted white arrows) whilst invisible on the preoperative scans.

tumor resection with both direct endoscopic visualization along with iMRI confirmation. Two patients, both with giant PA, had residual tumors, found by postoperative iMRI. One of the two patients had total tumor resection after continued surgery. The other patient, despite furthered PA resection, had intraventricular remnant due to lacks of sufficiently long instrument to reach it. This patient, with concerns of neurovascular injury, also had residual tumor in cavernous sinus, which we intentionally left, due to unresectable Knosp grade 4 PA.

The preparation for preoperative iMRI scan always requires longer time than the postoperative one. With our following cases, both of the pre- and postoperative time consumption was significantly shorter than our first few patients. There was no serious intra- and postoperative iMRI-related complication in all patients.

Case illustration

A 24-year-old male patient (case No. 2 from Table 1), with progressive deterioration of vision, was

found to have giant non-functioning pituitary macroadenoma. His preoperative MRI scans are shown in Fig. 7. The patient underwent eTSS using iMRI. Preparation of the MRI and surgery was carried out in similar fashion as earlier described in the method section. At the end of tumor resection, after the surgeon believed there was no endoscopically-visible residual PA, the first postoperative iMRI scan was obtained. Column 3 in Fig. 8 clearly demonstrated tumor remnant in spite of surgeon's impression of total tumor removal. This finding prompted further resection using guidance from a navigator, based on the newly acquired data of the first postoperative iMRI scanning, until there was no tumor left. Column 4 in Fig. 8 revealed no tumor remnant by the second postoperative iMRI. Surgery was therefore finished after this iMRI findings. One year after his eTSS, there was no evidence of residual tumor (Fig. 9).

Discussion

Surgical resection of PA has tremendously evolved over the last few decades. Advance in

Table 1. Demographic data of the eleven patients who underwent iMRI scans before and after pituitary adenoma resection

Case No.	Gender/age (year)	Tumor type	Primary vs. reoperation	Diameter (x, y, z) (cm)	Knosp grade	Time for pre-op scan (min)	Time for post-op scan (min)	Residual tumor after first post-op scan	Additional resection/residual tumor after additional resection
1	M/19	NF	Primary	2.4, 2.5, 6.3	4	173	74	Yes	Yes/yes
2*	M/24	NF	Primary	2.2, 2.8, 5.2	2	168	69	Yes	Yes/no
3	F/52	NF	Primary	2.2, 2.3, 3.0	2	134	63	No	No
4	F/61	NF	Primary	2.1, 2.0, 2.3	3	122	57	No	No
5	F/44	GH	Primary	1.6, 2.3, 2.0	2	100	52	No	No
6	F/33	NF	Primary	1.9, 2.1, 2.2	2	95	49	No	No
7	M/58	NF	Primary	2.1, 2.0, 2.5	3	82	46	No	No
8	F/47	NF	Reoperation	1.7, 2.0, 2.7	2	75	22	No	No
9	M/38	NF	Primary	1.6, 1.7, 2.0	2	69	39	No	No
10	F/31	NF	Primary	1.4, 1.8, 1.7	1	118	37	No	No
11	M/41	NF	Reoperation	2.1, 1.6, 2.0	1	58	29	No	No

The time consumption for preoperative scan was typically longer than postoperative scan because it included satisfactory positioning of the patient and iMRI. The trend for less amount of time spent for scanning in subsequent cases is noted.

M = male, F = female, NF = non-functioning, GH = Growth hormone producing, x = transverse diameter, y = anteroposterior diameter, z = vertical diameter, cm = centimeter, min = minutes

* case illustration

technology, such as endoscopy or navigation system, allows more radical resection of the tumor with fewer complications⁽¹⁶⁾. Nevertheless, the incidence of postoperative residual tumor remains at the range of 20% to 25%. As a consequence, with long-term follow-

ups, residual PA was found to have 7% to 70% rate of recurrence/regrowth^(6,17-20).

Intraoperative MRI has been reliably effective for detecting tumor remnant after conclusion of surgery despite surgeon's belief of "total" resection. From 15% to 66% of unexpected residual PA was found by iMRI⁽²¹⁻²⁴⁾. Consequently, supporting literatures reported increased degree of PA resection with iMRI⁽²⁴⁻²⁷⁾. Whilst high-field iMRI offers resolution that is similar to a standard 1.5 T MRI scanner, the ultra-low-field 0.15 T iMRI, for its compact size, provides the simplicity. Notably, there is no need to move the patient out of the operating room to iMRI suite, but rather to reposition it back to the preoperative scanning location. The other clear advantage of this type of iMRI is the total installation cost. The ultra-low-field is generally less than half the price of high-field iMRI. In particular at our institute, there was no need to completely shield the operating room for the fact that we covered the MRI scanning field and the patient's body utilizing the Starshield. Consequently, it even reduced the cost of operating room construction. In

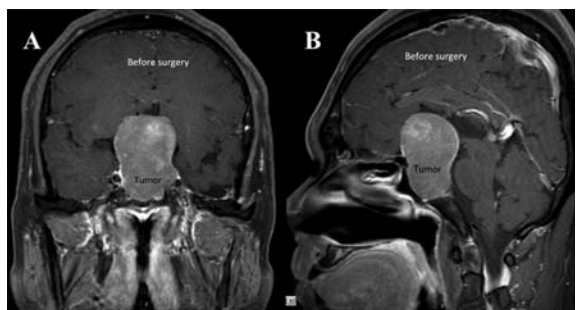


Fig. 7 Coronal (A) and sagittal (B) views of preoperative MRI scan from case illustration (patient No. 2 in Table 1) who underwent endoscopic transsphenoidal surgery for giant pituitary adenoma utilizing iMRI.

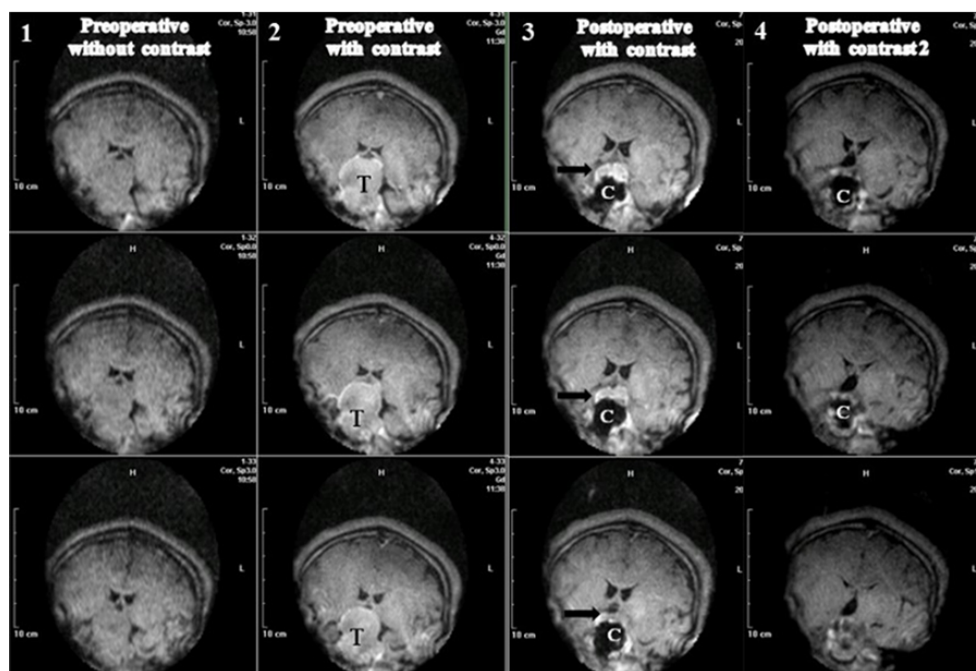


Fig. 8 Coronal views of intraoperative MRI scans from the case illustration are shown. Column 1 and 2 illustrate the preoperative scans. After the surgeon thought that total tumor removal was achieved, postoperative scan was obtained (repetition of the steps in Fig. 2 and 3). Tumor's cavity (C), created by hypo-intensity signal from the gadolinium-soaked cottonoids, was indicative of already resected area without tumor. Column 3 clearly shows residual adenoma (black arrows). Subsequently, further tumor resection was carried out with guidance from the navigator. Column 4 demonstrates the second postoperative scan with no residual adenoma.

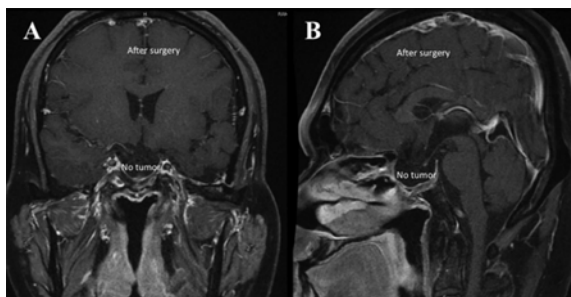


Fig. 9 After one year, the patient's MRI scan, coronal (A) and sagittal (B) views, shows no evidence of residual tumor.

addition, there is no special surgical equipment required. Surgery can be performed using standard tools. Several centers published their results of ultra-low-field iMRI, noting 20% to 25% of post resection residual tumor, in spite of surgeon's assumption of total or expected removal⁽⁸⁻¹³⁾. Yet, all published data regarding the use of Polestar (N-10 and N-20) ultra-low-field iMRI for PA had been from microscopic TSS series⁽⁸⁻¹⁴⁾. Thus, our study is the first to report pure endoscopic TSS and Polestar (N-30) ultra-low-field iMRI.

With regards to the latest product line of the ultra-low-field iMRI, this Polestar N-30 at our facility is the first machine installed in Southeast Asia region. For the first 12 months, eleven patients successfully underwent eTSS for PA with this iMRI. Nevertheless, because of the lesson learned from our first case, no higher than Knosp grade 3 was selected for our subsequent case to undergo eTSS with iMRI. This decision was based on the fact that once the tumor reaches beyond lateral border of internal carotid artery, it is unlikely that complete tumor resection can be accomplished without undue neurovascular risk. Hence, we elected not to include Knosp grade 4 into this series after the first patient. In addition, the first case was also our only PA that had tremendous, superior, intraventricular extension beyond foramen of Monro with a lack of sufficiently long instrument to reach its margin. Because of these facts, the rest of our iMRI for PA patients were only those with Knosp grade 1 to 3 and without extreme superior extension. Moreover, we had to abandon multiple attempts for iMRI in one patient due to her extremely short neck which precluded us from obtaining optimal visualization of the PA.

Our pre-, intra- and post-operative data suggested comparable findings with other series, having two of 11 cases (approximately 20%) with

unplanned residual PA. Although iMRI improves extent of PA resection, it comes with significantly increased operative time (notably, our first few patients). The subsequent cases consumed significantly fewer minutes as one would expect with learning curve. Acquiring more experience, it is our hope to minimize the time spent in preparation for iMRI. Therefore, in order to justify the use of iMRI, operating surgeon should individually weigh the risks of prolonged anesthetic time and benefits from total PA resection. Apart from identifying residual PA, some reported detectable and clinically-relevant intra-tumoral bleeding which the patient subsequently required craniotomy though we did not observe this in our patients⁽²¹⁾.

Conclusion

Using iMRI for TSS has proven its efficacy, confirmed again by our results. This present study reports the latest version of PoleStar N-30 ultra-low-field iMRI used in conjunction with endoscopic TSS which enabling total or maximal pituitary adenoma resection.

What is already known in this topic?

Pituitary adenoma surgery via transsphenoidal approach has been popularized for several decades. Recent advance in technology allows more complete tumor removal. Intraoperative MRI, high-, low- or ultra-low-field, yields even higher percentage of tumor resection.

What this study adds?

Our study results are in agreement with other published data reiterating the advantages of iMRI used in conjunction with transsphenoidal surgery for pituitary adenoma. This is the first report of pure endoscopic transsphenoidal surgery using the latest version of PoleStar N-30 ultra-low-field intraoperative MRI.

Acknowledgements

The authors would like to thank all the support from our operating room staffs and anesthesiology team in being exceptionally patient with all of the iMRI cases which took significantly longer time to complete. Their dedication is greatly appreciated.

Potential conflicts of interest

Ake Hansasuta received honoraria from Medtronic. He was invited speaker for lectures related to sharing his experience from clinical application of

Polestar N-30 ultra-low-field iMRI in cranial surgeries.

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ประสบการณ์ขั้นต้นในการใช้เครื่องมืออาร์ไอในห้องผ่าตัดสำหรับการผ่าตัดเนื้องอกต่อมใต้สมองด้วยกล้องเอ็นโดสโคปที่โรงพยาบาลรามารินทร์

อิทธิกร เทียบพา, เอก หังสสุต

วัตถุประสงค์: เพื่อนำเสนอประสบการณ์ขั้นต้นในการใช้เครื่องมืออาร์ไอในห้องผ่าตัดสำหรับการผ่าตัดเนื้องอกต่อมใต้สมองด้วยกล้องเอ็นโดสโคปที่โรงพยาบาลรามารินทร์

วัสดุและวิธีการ: รวบรวมข้อมูลผู้ป่วยที่ได้รับการผ่าตัดเนื้องอกต่อมใต้สมองด้วยกล้องเอ็นโดสโคปที่รวมกับการใช้เครื่องมืออาร์ไอในห้องผ่าตัดรุ่นใหม่ล่าสุด (PoleStar N-30) ตั้งแต่เดือนกันยายน พ.ศ. 2556 ถึง เดือนสิงหาคม พ.ศ. 2557

ผลการศึกษา: มีผู้ป่วยจำนวน 11 ราย ที่ได้รับการผ่าตัดเนื้องอกต่อมใต้สมองด้วยกล้องเอ็นโดสโคปที่รวมกับการใช้เครื่องมืออาร์ไอในห้องผ่าตัด พบว่าเครื่องมืออาร์ไอในห้องผ่าตัดสามารถตรวจพบเนื้องอกต่อมใต้สมองที่เหลืออยู่สองรายหลังจากที่เชื่อว่าได้ผ่าตัดเนื้องอกออกหมดแล้ว เมื่อตรวจพบเนื้องอกที่เหลืออยู่นี้ทำให้ศัลยแพทย์ดำเนินการผ่าตัดเลาะเนื้องอกเพิ่มเติมได้อีก ทำให้เนื้องอกหมดในหนึ่งรายและเหลือในบริเวณที่ไม่สามารถผ่าตัดได้ในอีกหนึ่งราย

สรุป: รายงานนี้เป็นรายงานแรกที่แสดงผลการใช้เครื่องมืออาร์ไอในห้องผ่าตัดรุ่นใหม่ล่าสุด (PoleStar N-30) ร่วมกับการผ่าตัดเนื้องอกต่อมใต้สมองด้วยกล้องเอ็นโดสโคป พบว่าได้ผลที่ใกล้เคียงกับรายงานการใช้เครื่องมืออื่นจากต่างประเทศที่เคยได้รับการตีพิมพ์ในวารสารการแพทย์ เมื่อเครื่องมือตรวจพบเนื้องอกที่เหลืออยู่ ศัลยแพทย์สามารถดำเนินการผ่าตัดเลาะเนื้องอกเพิ่มเติมได้อีก ผู้บริหารได้บรรยายรายละเอียดของแต่ละขั้นตอนในการใช้เครื่องมือนี้เพื่อช่วยในการผ่าตัดสมอง
