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Adoption of adjustable pressure endoscopic diving technique in pituitary tumor resection after radiotherapy

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► ***Original article***

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ABSTRACT

Background: Endoscopic endonasal transsphenoidal pituitary adenoma resection faces challenges like bleeding and tissue folds that can reduce visual clarity, particularly in patients with prior radiotherapy, where altered tissue characteristics complicate the procedure. The adjustable-pressure endoscopic diving technique may help address these challenges by enhancing visualization through fluid medium regulation. The aim of this study is to assess the efficacy and safety of the adjustable-pressure endoscopic diving technique in pituitary tumor resection after radiotherapy. ***Materials and Methods:*** This retrospective multi-center study included 63 patients who underwent endoscopic endonasal tumor resection. The cohort consisted of patients with sellar and parasellar tumors, including pituitary adenomas, some of whom had previously received radiotherapy. Radiotherapy modalities included conventional fractionated external beam radiotherapy (EBRT) and/or stereotactic radiosurgery (SRS), depending on prior treatment history. During surgery, an adjustable-pressure saline irrigation system was used to fill the resection cavity, allowing enhanced visualization and detection of residual tumor tissue. ***Results:*** The diving technique was successfully implemented in 61 of 63 cases (96.8%). Following standard tumor debulking, intraoperative saline immersion allowed identification of residual tumor tissue in 53 of these cases (86.9%), primarily within recessed or irregular cavity surfaces. Tumor size was an independent predictor of intraoperative tumor residue (OR=5.15, P=0.010), and subtotal resection was linked to higher recurrence risk (OR=11.22, P=0.025). Complications included transient diabetes insipidus (22.2%) and cerebrospinal fluid leakage (14.3%). ***Conclusion:*** The adjustable-pressure endoscopic diving technique effectively identifies residual tumors, particularly in post-radiotherapy cases, and offers a favorable safety profile. It holds promise for wider clinical use.

INTRODUCTION

Endoscopic endonasal transsphenoidal surgery has become the preferred approach for pituitary adenomas, offering a minimally invasive route through the natural nasal passages to access the sella turcica. This technique has evolved from microscopic methods, providing significant advantages such as enhanced visualization, improved maneuverability, and minimal tissue disruption, particularly in assessing intrasellar and suprasellar structures [1, 2]. The direct surgical trajectory, rapid recovery, and reduced morbidity and mortality have made it a standard in clinical practice, particularly for large or invasive pituitary adenomas. Advanced neuroendoscopic systems, capable of delivering high-definition images and wide-field views, allow surgeons to precisely identify anatomical relationships between tumors and critical structures like the pituitary gland, optic nerves, and internal carotid arteries, ensuring functional preservation and complete tumor resection [3]. Neuromavigation further enhances surgical precision, reinforcing its role as a gold-standard procedure in neurosurgery.

However, endoscopic procedures face significant challenges in maintaining surgical field clarity, particularly in patients who have received prior radiotherapy. Radiation therapy can cause fibrosis and scarring, complicating the resection and visualization of the tumor [4]. Factors such as bleeding, tissue folds, and the altered anatomy of irradiated tissues can compromise the surgical field, making it difficult to achieve a complete tumor resection [5]. The cavity created by resecting large tumors may have multiple folds and recesses where residual tumor fragments can be hidden [6]. Additionally, persistent bleeding or tissue debris often contaminate the lens, requiring frequent cleaning and reducing surgical efficiency [7]. This poor visualization can lead to missed tumor remnants, particularly in areas where the tissue has become fibrotic or scarred, increasing the risk of postoperative recurrence [8].

To overcome these limitations, the adjustable-

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pressure endoscopic diving technique was developed. This technique involves immersing the endoscope in a saline-filled tumor cavity, using continuous irrigation to maintain lens clarity. The fluid medium helps remove blood and debris, keeping the lens clean, while the hydrostatic pressure helps to expand collapsed cavities and separate tissue folds, thus improving visualization and aiding in the identification and removal of residual tumors, even in the presence of scarring or fibrosis due to prior radiotherapy [9]. The technique has shown promise in providing superior visualization and facilitating the dislodgement of small tumor fragments through hydraulic irrigation [9].

This study retrospectively analyzes clinical data from 63 patients across multiple centers who underwent pituitary tumor resection using this adjustable-pressure diving technique. The research investigates the technique's effectiveness in improving resection rates, especially in post-radiotherapy cases, while also assessing the safety profile and identifying key factors influencing surgical outcomes. The study aims to provide evidence for further optimization and adoption of this technique, offering a new approach for minimally invasive treatment of pituitary tumors, especially for patients who have received radiotherapy. Additionally, the study explores the learning curve and training requirements for broader clinical application of this technique.

MATERIALS AND METHODOS

General information

A total of 63 patients with pituitary adenomas, including those who had received prior radiotherapy, were enrolled from the neurosurgery departments of our hospital and Xi'an People's Hospital (multi-center).

Patients included into the study with diagnosis of pituitary adenoma confirmed by preoperative magnetic resonance imaging (MRI) and postoperative pathological examination; had Primary endoscopic endonasal transsphenoidal surgery; planned intraoperative implementation of the adjustable-pressure endoscopic diving technique and a complete clinical and follow-up documentation.

Also, patients with coexisting intracranial malignancies or other sellar/parasellar pathologies, previous transsphenoidal surgery or cranial radiotherapy (for cases not receiving the technique post-radiotherapy), aborted diving technique due to intraoperative circumstances (e.g., observable hemorrhage, anatomical variations) and lost to follow-up or incomplete follow-up records were excluded from the study (figure 1).

Preoperative radiotherapy characteristics

Patients with a history of prior radiotherapy were treated at specialized oncology centers before undergoing endoscopic surgery. Radiotherapy modalities included conventional fractionated external beam radiotherapy (EBRT) and stereotactic radiosurgery (SRS), depending on tumor characteristics and institutional protocols. EBRT was delivered using a linear accelerator (LINAC) system (Varian Clinac® or Elekta Synergy®) with 6-10 MV photon beams. Treatment planning was performed using three-dimensional conformal radiotherapy (3D-CRT) or intensity-modulated radiotherapy (IMRT) techniques based on tumor location and proximity to critical structures. Patients received 1.8-2.0 Gy per fraction, five fractions per week, to a total cumulative dose of 45-54 Gy over approximately 5–6 weeks. CT simulation with thermoplastic immobilization masks was used for planning, and strict dose constraints were applied to the optic apparatus and adjacent neurovascular structures in accordance with institutional guidelines. In selected cases of residual or recurrent tumors, stereotactic radiosurgery was performed using either a Gamma Knife® (Elekta) platform or LINAC-based stereotactic systems. A single-fraction margin dose of 12–16 Gy was prescribed, tailored according to tumor size and distance from the optic pathways. Target delineation was based on high-resolution MRI with CT fusion, and treatment planning was conducted using dedicated stereotactic planning software with either frame-based or frameless image guidance systems.

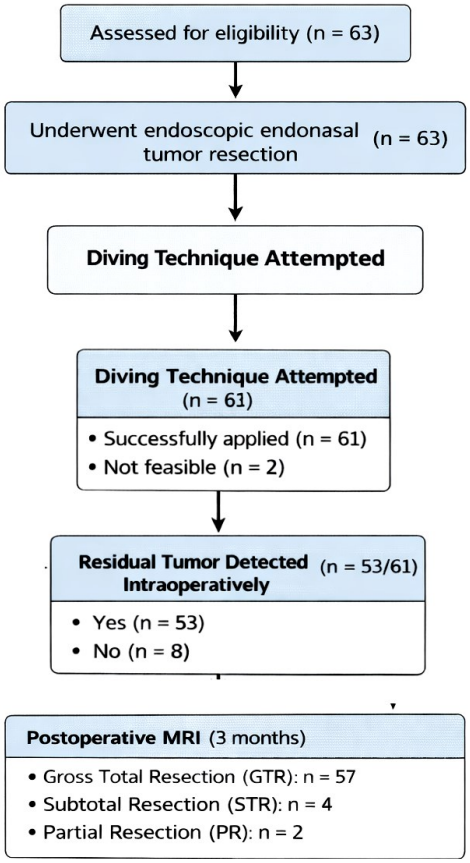


Figure 1. Flow diagram of patient inclusion and surgical outcomes.

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Surgical technique

All patients underwent endoscopic endonasal transsphenoidal tumor resection performed by experienced skull base surgeons using standard endoscopic techniques. The primary surgical objective was maximal safe tumor removal while preserving critical neurovascular structures. In patients with prior radiotherapy, tissue planes were frequently altered by fibrosis and scarring, increasing surgical complexity. After macroscopic tumor debulking, the resection cavity was systematically inspected for residual tumor tissue. The adjustable-pressure endoscopic diving technique was then applied by filling the cavity with saline to enhance visualization of recesses and irregular surfaces that could harbor residual fragments. The extent of resection was assessed intraoperatively and confirmed on postoperative MRI, categorized as gross total resection (GTR), subtotal resection (STR), or partial resection (PR).

Observation indexes

Postoperative extent of resection was evaluated within three months via plain and enhanced MRI of the sellar region, assessed by two blinded radiologists (figure 2). Resection was categorized as:

- Gross total resection (no residual tumor)
- Subtotal resection (≥90% tumor resection rate)
- Partial resection (<90% tumor resection rate)

Operative time (from nasal mucosa incision to completion of skull base reconstruction) and estimated intraoperative blood loss were recorded. Also, complications such as cerebrospinal fluid leakage, intracranial infection, transient diabetes insipidus (less than 6 months), permanent diabetes insipidus, and new-onset pituitary insufficiency within 30 days postoperatively were closely monitored. Preoperative and 6-month postoperative visual acuity, visual fields, headaches, and other major clinical symptoms were compared. For functional pituitary adenomas, the remission rate of hormone levels at six months postoperatively was assessed, defined as normalization of hormone levels or control within the normal range without medication assistance.

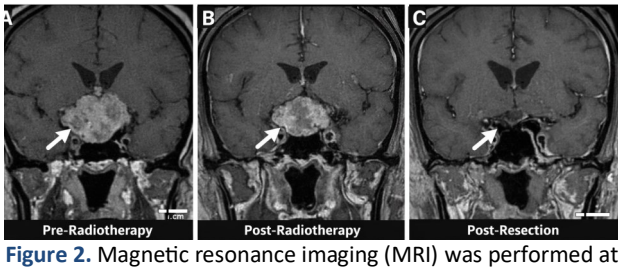


Figure 2. Magnetic resonance imaging (MRI) was performed at three key time points in patients who had received prior radiotherapy: (1) before radiotherapy, (2) after completion of radiotherapy and prior to surgical intervention, and (3) three months after endoscopic resection. Standard pituitary protocol MRI sequences were used, including contrast-enhanced T1-weighted imaging in sagittal and coronal planes.

Statistical methodologies

Data analysis was performed using SPSS 26.0. Measurement data (e.g., age, BMI, hospital stay duration), after normality testing confirmed a normal distribution, were expressed as mean ± standard deviation ($\bar{x} \pm s$). Count data (e.g., gender, tumor size, Knosp grade) were presented as number of cases and percentage (%). Univariate analysis was first conducted for factors influencing tumor residue and recurrence: independent samples t-test was used for measurement data, while the χ^2 test or Fisher's exact test was used for count data. Variables with a $P<0.1$ in the univariate analysis were included in a multivariate logistic regression analysis, using the forward stepwise regression method for variable selection. All statistical tests were two-sided, with a $P<0.05$ considered statistically significant.

RESULTS

Baseline characteristics of patients

A total of 63 patients with pituitary adenomas, including those who had received prior radiotherapy, were enrolled from the neurosurgery departments of our hospital and Xi'an People's Hospital (multi-center). The cohort included 28 males (44.4%) and 35 females (55.6%), aged 23-72 years (mean 49.2 ± 10.5 years). The mean body mass index (BMI) was 24.1 ± 3.2 kg/m^2, and the mean hospital stay was 8.5 ± 2.3 days (range: 5-14 days). According to tumor size, 9 cases (14.3%) were giant adenomas, 38 cases (60.3%) were macroadenomas, and 16 cases (25.4%) were microadenomas. Based on Knosp classification, 41 cases (65.1%) were grades 0-2 and 22 cases (34.9%) were grades 3-4. Postoperative pathology identified 35 non-functioning adenomas (55.6%), 9 prolactinomas (14.3%), 6 growth hormone-secreting adenomas (9.5%), 3 thyrotropin-secreting adenomas (4.8%), and 10 adrenocorticotropic hormone-secreting adenomas (15.9%). Clinical presentations included headache in 47 cases (74.6%), visual impairment/visual field defects in 34 cases (54.0%), acromegaly in 6 cases (9.5%), amenorrhea in 4 cases (6.3%), galactorrhea in 9 cases (14.3%), hyperthyroidism in 3 cases (4.8%), and decreased libido in 2 cases (3.2%). All patients underwent routine CT, MRI, endocrine hormone testing, and visual field examinations.

Implementation and exploration results of intraoperative diving technique

A total of 63 patients with pituitary tumors, including those who had received prior radiotherapy, were enrolled in this cohort and scheduled for the intraoperative adjustable-pressure endoscopic diving technique. The procedure was successfully completed in 61 patients, with 2 cases unable to be completed. One case was due to an excessively small tumor cavity preventing endoscopic access, and the other

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was due to cavernous sinus hemorrhage precluding the diving technique. Among the 61 patients who successfully underwent the procedure, residual tumor was identified in 53 cases (86.9%). This included 9 giant adenomas, 38 macroadenomas, and 6 microadenomas. No residual tumor was observed in 8 cases (13.1%), all of which were microadenomas. Notably, patients who had undergone prior radiotherapy showed higher rates of tumor fibrosis and tissue scarring, which affected visualization and the accuracy of conventional resection methods (figure 3).

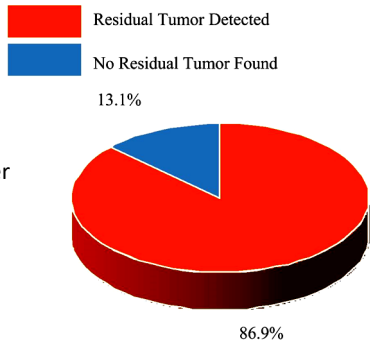


Figure 3. Exploration results of the underwater technique.

Postoperative complications

The main postoperative complications were transient diabetes insipidus and cerebrospinal fluid (CSF) leakage. Among the 63 patients, transient diabetes insipidus occurred in 14 cases (22.2%), all of which resolved with pharmacological intervention. Cerebrospinal fluid leakage occurred in 9 cases (14.3%); in 8 cases, it was directly related to tumor resection maneuvers, while in 1 case (11.1% of the leakage cases), it was associated with the intraoperative diving technique. Notably, radiotherapy-induced changes to the tissue may have contributed to higher risks of CSF leakage, particularly in the presence of scarring in the sellar region. All cases of CSF leakage were repaired using a nasal mucosal flap combined with muscle fascia, supplemented by 5 days of postoperative continuous lumbar drainage. Healing was achieved after a single repair in 7 cases, while recurrence occurred in 1 case (11.1% of leakage cases), which improved after a second repair. Additionally, intracranial infection occurred in 2 cases (3.2%), both of which recovered following targeted antibiotic therapy. There were no mortalities in this cohort. The complication rates were consistent with those reported in previous studies, although there was a slight increase in CSF leakage in post-radiotherapy patients, likely due to tissue fragility and changes in the surgical anatomy (figure 4).

Postoperative efficacy evaluation

Postoperative follow-up demonstrated significant improvement in both clinical symptoms and endocrine function. Among the 34 patients with preoperative visual acuity or visual field deficits, symptoms improved in 31 cases (91.2%), remained unchanged in 2 cases (5.9%), and worsened in 1 case (2.9%). All 47 patients (100%) with preoperative headache reported significant relief or complete resolution of symptoms postoperatively. Of the 28 patients with hormonal abnormalities due to functional pituitary adenomas, hormone levels improved in 27 cases (96.4%), remained unchanged in 1 case (3.6%), and no cases exhibited worsening of hormonal abnormalities. Postoperative imaging follow-up at 3 to 6 months revealed gross total resection in 57 cases (90.5%), subtotal resection in 4 cases (6.3%), and partial resection in 2 cases (3.2%). Notably, post-radiotherapy patients showed a higher likelihood of residual tumor detection due to fibrosis and altered tissue structure, which made conventional resection techniques less effective. The adjustable-pressure diving technique proved particularly valuable in identifying these hidden tumor fragments (figures 5 and 6).

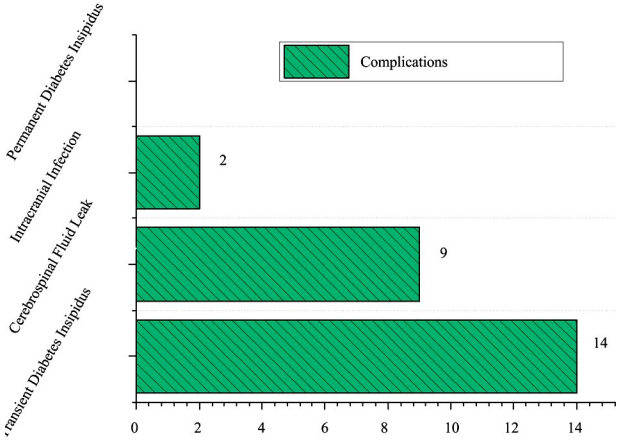


Figure 4. Postoperative complications.

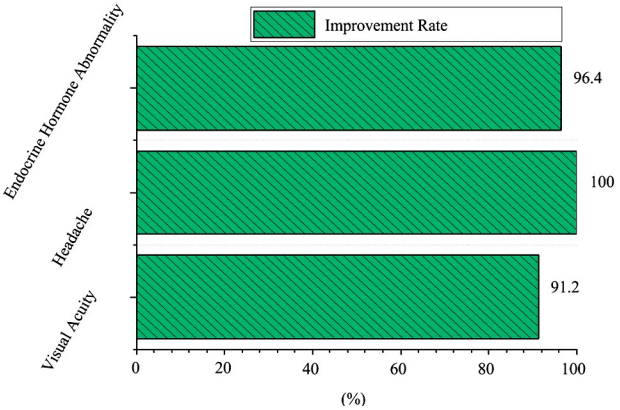


Figure 5. Improvement of postoperative clinical symptoms.

Analysis of factors affecting tumor residue during operation

Univariate analysis indicated that tumor size, Knosp grade, and hospitalization duration were associated with the detection of residual tumor using the diving technique (P<0.1). Multivariate analysis, adjusting for potential confounding factors, confirmed that tumor size (macroadenoma/giant adenoma) (OR=5.15, 95% CI: 1.48-17.89, P=0.010) and

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prolonged hospitalization duration (OR=1.38, 95% CI: 1.02-1.86, P=0.039) were independent predictive factors for the detection of residual tumor during surgery. Additionally, post-radiotherapy patients, especially those with larger tumors or complex fibrosis, were more likely to show residual tumor detection compared to those with tumors that had not been treated with radiation (tables 1 and 2).

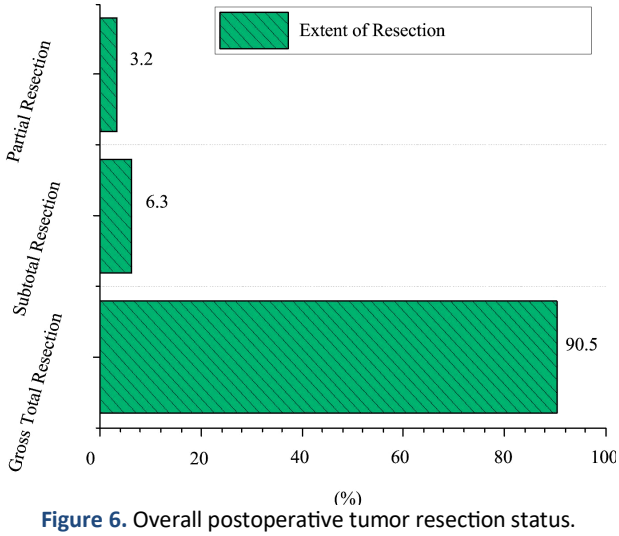


Figure 6. Overall postoperative tumor resection status.

Table 1. Univariate analysis of factors affecting the detection of residual tumor by the underwater technique.

Variable	Residual group (n=53)	No residual group (n=8)	Statistic	*P*
Age (>50 years), n (%)	29 (54.7%)	3 (37.5%)	χ^2=0.855	0.355
Gender (Male), n (%)	25 (47.2%)	3 (37.5%)	χ^2=0.263	0.608
BMI (kg/m²), ($\bar{x}$ ± s)	24.2 ± 3.3	23.5 ± 2.8	t=0.574	0.568
Tumor size (Macro/ Giant), n (%)	47 (88.7%)	3 (37.5%)	χ^2=12.381	<0.001
Knosp grade (3-4), n (%)	20 (37.7%)	0 (0.0%)	Fisher	0.037
Pathology type (Functional), n (%)	22 (41.5%)	2 (25.0%)	χ^2=0.758	0.384
Hospital stay (days), ($\bar{x}$ ± s)	8.8 ± 2.4	6.6 ± 1.1	t=2.589	0.012

Table 2. Multivariate logistic regression analysis of factors affecting the detection of residual tumor by the underwater technique.

Variable	β	Standard error	Wald χ^2	*P*	OR	95% CI
Constant	-6.884	2.874	5.737	0.017	0.001	-
Tumor size (Macro/Giant vs. Microadenoma)	1.639	0.637	6.623	0.01	5.15	1.478 - 17.892
Knosp grade (3-4 vs. 0-2)	1.284	0.684	3.525	0.06	3.612	0.945 - 13.804
Hospital stays (days)	0.32	0.155	4.264	0.039		

Analysis of factors affecting postoperative tumor recurrence

Univariate analysis revealed that Knosp grade, pathological type, and extent of resection were associated with postoperative recurrence (P<0.1). Multivariate analysis demonstrated that subtotal/ partial resection was an independent risk factor for postoperative tumor recurrence (OR=11.22, 95% CI:1.36-92.55, P=0.025). Post-radiotherapy patients, particularly those with macroadenomas or giant adenomas, were more likely to experience incomplete resections, which were significantly associated with higher recurrence rates. Radiotherapy-induced changes such as tissue scarring and fibrosis made total resection more challenging and were identified as major risk factors for recurrence in this cohort (tables 3 and 4).

Table 3. Univariate analysis of factors affecting postoperative tumor recurrence.

Variable	Recurrence group (n=2)	Non-recurrence group (n=61)	Statistic	*P*
Age (>50 years), n (%)	2 (100.0%)	30 (49.2%)	Fisher	0.2
Gender (Male), n (%)	1 (50.0%)	27 (44.3%)	Fisher	1
BMI (kg/m²), ($\bar{x}$ ± s)	25.3 ± 1.2	24.0 ± 3.2	t=0.621	0.537
Tumor size (Macro/ Giant), n (%)	2 (100.0%)	48 (78.7%)	Fisher	1
Knosp grade (3-4), n (%)	2 (100.0%)	18 (29.5%)	Fisher	0.073
Pathology type (Functional), n (%)	2 (100.0%)	22 (36.1%)	Fisher	0.112
Extent of resection (Subtotal/Partial), n (%)	2 (100.0%)	4 (6.6%)	Fisher	0.012
Hospital stays (days), ($\bar{x}$ ± s)	10.5 ± 2.1	8.4 ± 2.3	t=1.455	0.151

Table 4. Multivariate logistic regression analysis of factors affecting postoperative tumor recurrence.

Variable	β	Standard error	Wald χ^2	*P*	OR	95% CI
Constant	-4.501	1.721	6.839	0.009	0.011	-
Knosp grade (3-4 vs. 0-2)	1.512	0.995	2.31	0.129	4.535	0.646 - 31.829
Pathology type (Functional vs Non-functional)	0.987	0.934	1.117	0.291	2.683	0.430 - 16.731
Extent of resection (Subtotal/Partial vs. Total)	2.418	1.077	5.04	0.025		

DISCUSSION

This study systematically analyzed 63 patients with pituitary tumors, including those who had received prior radiotherapy, treated with the adjustable-pressure endoscopic diving technique. The results confirmed the significant value of this technique in enhancing surgical precision and safety, particularly in the context of post-radiotherapy complications such as fibrosis and scarring. The technique achieved a gross total resection rate of 90.5%, identifying residual tumors that were difficult to detect by conventional endoscopic surgery in 86.9% of cases. This highlights the importance of the adjustable-pressure diving technique in improving surgical outcomes, especially for post-radiotherapy patients where tissue changes complicate tumor resection.

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Notably, the technique demonstrated greater advantages in the management of macroadenomas and giant adenomas, which are often more prevalent in post-radiotherapy cases. These tumors are frequently associated with complex tumor cavities and tissue scarring, which can obscure visualization and complicate resection. The adjustable-pressure diving technique addresses these challenges by improving visualization and allowing for better exploration of the tumor cavity. Compared to conventional endoscopic surgery, this technique provides a liquid medium environment that rapidly disperses blood and tissue debris, effectively maintaining sustained clarity of the surgical field [10, 11]. This mechanism is particularly useful for post-radiotherapy tumors, which often present with increased vascularity or fibrosis, further obstructing the surgical view.

In terms of tumor exploration, the 86.9% residual tumor detection rate in this study was significantly higher than reported in conventional surgery, particularly in post-radiotherapy cases. Radiation can lead to tissue thickening, scar formation, and tissue folds, making it more difficult to detect residual tumors with traditional methods. The adjustable-pressure diving technique leverages the refractive properties of water to separate these tissue folds, enabling better identification of tumor fragments that may have been missed in conventional procedures. This advancement significantly reduces postoperative recurrence rates, which are higher in irradiated tumors due to the increased difficulty of achieving complete resection [12, 13].

The core innovation of this technique lies in its unique pressure regulation system. Unlike fixed-pressure irrigation systems, the adjustable-pressure system allows for real-time manual adjustments, tailored to the surgical needs of the moment. This is especially important in post-radiotherapy patients, where varying tissue characteristics require precise control of irrigation pressure to avoid damaging delicate structures such as the optic nerve and carotid arteries. For instance, higher pressure can be applied to separate dense fibrotic tissue planes or dislodge small tumor fragments, while lower pressure can be used to carefully inspect and protect critical structures [14, 15]. This flexibility makes the adjustable-pressure endoscopic diving technique particularly valuable in complex post-radiotherapy cases, where tissue properties can vary significantly.

Multivariate analysis revealed that tumor volume is a significant factor influencing surgical outcomes, especially in post-radiotherapy patients. Macroadenomas and giant adenomas, which often exhibit irregular growth patterns and are frequently seen in post-radiotherapy patients, present significantly increased challenges for achieving gross total resection. These tumors often form multilocular structures and can invade surrounding tissues, making thorough exploration difficult with conventional methods. The diving technique, by utilizing the expansive effect of water flow, enables access to these areas that are typically inaccessible with standard instruments, significantly improving resection outcomes [16, 17]. This is particularly important in post-radiotherapy cases, where scarring and fibrosis can create complicated anatomical distortions that challenge traditional surgical methods.

In the context of recurrence risk, patients who underwent subtotal resection had a significantly higher risk of recurrence. This underscores the importance of achieving gross total resection whenever possible, especially in post-radiotherapy patients, where incomplete resection can lead to more frequent recurrence due to altered tissue characteristics and hidden tumor remnants. Although the Knosp grade did not reach statistical significance in the multivariate analysis, the difficulty of treating tumors that invade the cavernous sinus or encase critical vessels remains a challenge in post-radiotherapy patients. The diving technique facilitates the separation of tumor tissue from these critical structures by regulating water pressure, an essential feature when managing tumors affected by radiation-induced fibrosis [18].

Regarding safety, the incidence of complications in this study remained within a controllable range, and the adjustable-pressure diving technique performed similarly to conventional surgery in terms of complications like transient diabetes insipidus. However, post-radiotherapy patients had a slightly higher rate of cerebrospinal fluid leakage, likely due to the altered tissue and scarred structures resulting from previous radiation treatment. The adjustable-pressure technique can aid in early detection and management of such complications by precisely adjusting irrigation pressure, which helps detect potential leakage sites during surgery, leading to timely repair. These findings suggest that, when the operational essentials are mastered, the technique is both safe and effective, even in post-radiotherapy cases [19].

This technique does present a learning curve, especially when applied in post-radiotherapy cases, as surgeons must adapt to the unique visual environment and handle tissue response under varying pressures. Coordination between the surgeon and assistant is crucial for the proper application of pressure adjustments. Training and repeated practice are necessary for optimal results, particularly when handling radiation-altered tissues.

Looking forward, the adjustable-pressure endoscopic diving technique has potential for further optimization. Advances in pressure feedback systems could enhance operational precision, and the integration of technologies like intraoperative neuronavigation and fluorescence imaging may

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further improve the technique's effectiveness, especially in post-radiotherapy cases. Additionally, establishing standardized training protocols will help facilitate its broader adoption, particularly in centers treating a high volume of post-radiotherapy pituitary tumors.

In summary, the adjustable-pressure endoscopic diving technique provides valuable support for pituitary adenoma surgery, particularly in post-radiotherapy patients. By improving surgical field clarity and tumor detection, this technique holds significant promise for managing complex pituitary adenomas. As it continues to mature and gain wider clinical adoption, it is expected to become an important tool in the surgical treatment of pituitary tumors, offering benefits to more patients, especially those with a history of radiotherapy. Future studies with larger sample sizes are needed to further refine the technique's indications and optimize its clinical use.

CONCLUSION

This study analyzed 63 pituitary adenoma cases, including those with prior radiotherapy, treated with the adjustable-pressure endoscopic diving technique. The technique achieved a gross total resection rate of 90.5%, detecting residual tumors in 86.9% of cases, particularly in post-radiotherapy patients, where fibrosis complicates resection. Multivariate analysis identified tumor size as a key factor for successful resection, with larger tumors posing greater challenges. Subtotal or partial resections increased recurrence risk, underscoring the importance of gross total resection.

In conclusion, the adjustable-pressure diving technique improves surgical outcomes by enhancing tumor resection and visualization in post-radiotherapy cases, offering a safer and more effective approach to treating complex pituitary tumors.

***Conflicts of interest*:** Authors declare no conflicts of interest.

***Ethical approval statement*:** This retrospective chart review study involving human participants was conducted in accordance with the ethical standards of the institutional and national research committees and in line with the 1964 Helsinki Declaration and its later amendments, or comparable ethical standards. The study was approved by the Human Investigation Committee (IRB) of the First Affiliated Hospital of Xi'an Medical University, School of General Medicine.

***Informed consent*:** The authors affirm that human research participants provided informed consent for the publication of the images in Figures 1A, 1B, and 1C. The participant has consented to the submission of the case report to the journal. Patients signed informed consent for the publication of their data and photographs.

***Ethical standards*:** The authors declare that they have no relevant financial or non-financial interests to disclose.

***Availability of data and materials*:** The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

***Author contributions*:** All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by H.Z., Z.D., and W.X. The first draft of the manuscript was written by J.Z., G.S., and W.L. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

***AI declaration*:** ChatGPT 5.2 was used solely for language editing and polishing the writing.

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