Comparison of Constructive Interference in Steady-State and T1-Weighted MRI Sequence at Detecting Pituitary Adenomas in Cushing's Disease Patients

Min Lang^{1,2} Ghaith Habboub^{2,3} Doksu Moon⁴ Abin Bandyopadhyay⁴ Danilo Silva^{2,3}
Laurence Kennedy⁵ Varun R. Kshetry^{2,3,6} Pablo F. Recinos^{2,3,6}

¹ School of Medicine, Case Western Reserve University, Cleveland, Ohio, United States

² Department of Neurosurgery, Neurological Institute, Cleveland Clinic, Cleveland, Ohio, United States

³ Minimally Invasive Cranial Base and Pituitary Surgery Program, Rose Ella Burkhardt Brain Tumor and Neuro-Oncology Center, Cleveland Clinic, Cleveland, Ohio, United States

⁴ Department of Diagnostic Radiology, Imaging Institute, Cleveland Clinic, Cleveland, Ohio, United States

Address for correspondence Pablo F. Recinos, MD, Section Head – Skull Base Surgery, Minimally Invasive Cranial Base and Pituitary Surgery Program, Rose Ella Burkhardt Brain Tumor and Neuro-Oncology Center, CCLCM at CWRU, 9500 Euclid Avenue, CA-51, Cleveland, OH, 44195, United States (e-mail: recinop@ccf.org).

⁵ Department of Endocrinology, Diabetes, and Metabolism, Cleveland Clinic, Cleveland, Ohio, United States

⁶ Section of Rhinology, Sinus, and Skull Base Surgery, Head and Neck Institute, Cleveland Clinic, Cleveland, Ohio, United States

J Neurol Surg B 2018;79:593–598.

Abstract

Background T1-weighted magnetic resonance imaging (MRI) remains the standard pituitary imaging sequence. However, up to 50% of pituitary adenomas are missed with standard imaging in Cushing's disease (CD) patients. Utility of other imaging sequences needs be explored.

Objective To compare a T2-gradient echo sequence, constructive interference in steady state (CISS), with a contrast-enhanced (CE) T1-weighted sequence, volume-interpolated breath-hold examination (VIBE), in the detection of pituitary adenomas in CD patients.

Design Retrospective analysis of CD patients who underwent endoscopic transsphenoidal pituitary adenomectomy at our institution.

Patients and Measurement Twelve patients were included in the study. Two neuroradiologists, who were blinded to the patients' clinical and surgical findings, independently reviewed the CE-VIBE and CISS images. Localization of pituitary adenoma from imaging was compared with intraoperative localization.

Results The averaged sensitivity of detecting pituitary adenoma in CD patients was not significantly different between CE-VIBE sequence (63%) and CISS sequence (54%). The positive predictive value was 75% (Observer A) and 100% (Observer B) with CE-VIBE sequence, and 64% (Observer A) and 100% (Observer B) with CISS sequence. In two patients, pituitary adenoma was easily localized with CISS sequence but hard to detect with CE-VIBE sequence. In two other patients, the adenoma was much better delineated on CE-VIBE sequence.

Conclusion In our series, the addition of CISS sequence to T1-weighted MRI imaging protocols improved the detection of pituitary adenomas in CD patients. CISS sequence may be a useful adjunct to T1-weighted pituitary MRI protocols and an appropriate alternative for patients with gadolinium contraindications.

Keywords

- Cushing's syndrome
- hypercortisolism
- FIESTA
- endoscopic pituitary surgery
- transsphenoidal surgery
- imaging
- diagnosis

received
November 8, 2017
accepted after revision
March 3, 2018
published online
May 10, 2018

© 2018 Georg Thieme Verlag KG
Stuttgart · New York

DOI <https://doi.org/10.1055/s-0038-1642032>
ISSN 2193-6331.

Introduction

Cushing's disease (CD) is characterized by hypercortisolism produced by an adrenocorticotrophic hormone (ACTH)-producing pituitary adenoma. It is the most common cause of endogenous Cushing's syndrome, accounting for 60 to 80% of cases.¹

Due to the complex anatomical architecture of the sella turcica and the resolution limitations of two-dimensional spin-echo sequences, conventional T1-weighted images of pituitary adenomas often do not show satisfactory morphological and anatomical details.² Furthermore, up to 50% of pituitary ACTH-secreting adenomas are not detected via T1-weighted magnetic resonance imaging (MRI).^{3–5}

Constructive interference in steady state (CISS) is a high spatial-resolution fast gradient echo sequence that accentuates T2 values and emphasizes water content signal, making it useful for evaluating small structures or pathologic structures surrounded by cerebrospinal fluid (CSF). CISS images appear to be heavily T2 weighted but actually have some degree of mixed T2 and T1 weighting. The image contrast of CISS sequence is dependent on the T2 to T1 relaxation time ratio, making CSF signal intensity greater than the brain parenchyma. Based on these properties, previous studies have shown that CISS is superior to T1-weighted sequences at visualizing cranial nerves, cisternal spaces, and parasellar extension by pituitary macroadenomas.^{2,6–10} Furthermore, CISS sequence does not require the administration of contrast, and therefore, can be safely obtained in any patient able to undergo standard, nonenhanced imaging.

In this study, we compared the ability of CISS to a contrast-enhanced T1-weighted MRI sequence, volume interpolated breath-hold examination (VIBE) at detecting pituitary adenomas in CD patients.

Subjects and Methods

A retrospective study was performed on 12 patients (11 females and 1 male) who were diagnosed with CD. All patients underwent primary endoscopic transsphenoidal pituitary adenectomy by the senior author (PFR) between January 2014 and December 2015. In accordance to the Endocrine Society guidelines, patients were diagnosed with hypercortisolism/Cushing's syndrome by at least two of the three following tests: 24-hour urinary free cortisol, late night salivary cortisol, or low-dose dexamethasone suppression test.¹¹ ACTH levels were subsequently measured. When ACTH-dependent hypercortisolism was confirmed, a pituitary protocol MRI was obtained. Bilateral inferior petrosal sinus sampling (BIPSS) with corticotropin-releasing hormone (CRH) stimulation was performed in cases with unclear MRI results (no tumor or pituitary abnormality <6 mm). Histological staining of intraoperative biopsy samples was performed to confirm ACTH-secreting adenoma. The study was approved by Cleveland Clinic's Institutional Review Board.

Magnetic Resonance Imaging

Neuronavigation MRI protocol, with contrast-enhanced (CE)-VIBE and CISS sequences, was obtained in all patients after the

clinical diagnosis of CD and prior to endoscopic transsphenoidal surgery. Dynamic sequence was not included as part of the standard preoperative imaging protocol at our institution, and therefore was not acquired for the patients. These particular sequences were obtained as they can be reconstructed in three dimensions, allowing them to be used for neuronavigation by the surgeon to confirm anatomical structures on imaging intraoperatively. Thus, these images were not obtained for initial diagnostic purposes.

All MRI scans were performed in a 1.5 T scanner (Aera, Siemens, Erlangen, Germany). Two imaging techniques were included in the study: (1) axial and coronal CE-VIBE with repetition time/echo time of 9 ms/1.79 ms, 256 × 256 matrix, 200 mm field of view, 0.8 mm thick interleaved slices without gap, 9° flip angle, 20% distance factor, and ~4.9 minutes scan time; (2) axial and coronal CISS with repetition time/echo time of 5.84 ms/2.67ms, 256 × 256 matrix, 200 mm field of view, 0.7 mm thick interleaved slices without gap, 42° flip angle, 20% distance factor, and ~6.1 minutes scan time. Patients were administered 0.05 mmol/kg of gadolinium intravenous contrast for CE-VIBE, which is half the standard dose at most institutions.

Data Collection and Analysis

The images were reviewed by two neuroradiologists (Observer A, a neuroradiology fellow, and Observer B, a neuroradiology staff physician), who were blinded to the patients' clinical history and operative findings. Each independently reviewed the MRIs of two different sequences: CE-VIBE and CISS. Each reviewer was asked to evaluate the images for the presence of pituitary adenoma. Localization of pituitary adenomas from MRI results was compared with intraoperative surgical findings. Tumor size was measured only when the reported location of the tumor on MRI matched the intraoperative finding. The results of the two neuroradiologists were analyzed and listed independently. Tumor sizes were presented as mean ± standard deviation. The sensitivity of CE-VIBE and CISS was compared using McNemar's test.

Results

Tumor Identification

Observer A correctly identified a pituitary adenoma in 9 of 12 (75%) patients: seven cases of pituitary microadenoma, with an average size of 3.9 ± 2.2 mm, and two cases of macroadenoma, with an average size of 22.5 ± 17.7 mm. Observer B correctly identified a pituitary adenoma in 8 of 12 (67%) cases: six cases of microadenoma, with an average size of 6.5 ± 2.1 mm, and two cases of macroadenoma, with an average size of 24.5 ± 13.4 mm.

Imaging Outcomes

Pituitary adenomas exhibited decreased enhancement relative to surrounding pituitary parenchyma on CE-VIBE. In contrast, pituitary adenomas were hyperintense on CISS images. The imaging, BIPSS, and surgical localization of the 12 patients are listed independently in ►Table 1.

Table 1 Patient characteristics, imaging, BIPSS, and surgical results

Patient	Age	Gender	Observer A		Observer B		Micro- or macroadenoma	BIPSS	Surgical localization	Post-op adrenal insufficiency
			CE-VIBE	CISS	CE-VIBE	CISS				
1	63	F	R	R	R	–	Micro	*	R	Yes
2	63	F	L	L	L	–	Micro	L	L	Yes
3	37	F	R	–	–	–	Micro	*	R	Yes
4	49	F	Mid	Mid	–	–	Micro	L	L	Yes
5	42	F	R	R	–	R	Micro	R	R	Yes
6	38	F	L	L	R	R	Micro	L	R	Yes
7	33	F	Mid	Mid	–	–	Micro	L	L	Yes
8	57	F	R	R	–	R	Micro	*	R	Yes
9	47	F	Mid	R	Mid	Mid	Macro	*	Mid	No
10	36	F	R	R	R	R	Micro	*	R	Yes
11	50	M	L	L	–	–	Micro	R	L	Yes
12	52	F	Mid	Mid	Mid	Mid	Macro	*	Mid	No

Abbreviations: *, not performed; –, negative finding; BIPSS, bilateral inferior petrosal sinus sampling; CE-VIBE, contrast-enhanced volume interpolated breath-hold examination; CISS, constrictive interference in steady state; F, Female; L, tumor located on the left side of the pituitary; M, Male; Macro, macroadenoma; Micro, microadenoma; Mid, tumor located on the midline of the pituitary; R, tumor located on the right side of the pituitary.

The sensitivities were calculated by comparing the imaging results to surgical findings. The sensitivities for detecting pituitary adenoma using CE-VIBE and CISS MR images were 75 and 58%, respectively, for Observer A; 50 and 50%, for Observer B (►Table 2). The averaged sensitivities for CE-VIBE and CISS were 63 and 54%, respectively (►Fig. 1). There was no significant difference between the sensitivity of CE-VIBE and CISS sequences ($p = 0.48$ for Observer A; $p = 0.62$ for Observer B). For Observer B, the sensitivity increased to 67% if CE-VIBE and CISS results were used in conjunction. Twenty-five percent (3 of 12 cases) and thirty-six percent (4 of 11 cases) of CE-VIBE and CISS findings from Observer A were false positives; meaning the pituitary adenoma localization from MRI findings did not match that of the surgical

findings. Observer B did not have any false positives using CE-VIBE or CISS imaging.

In two patients (*patient 5 and 8*), the pituitary adenoma was much better delineated on CISS images than on CE-VIBE images (►Fig. 2). Adenoma localization of these two patients using CISS matched the intraoperative localization. Conversely, in two other patients, CE-VIBE sequence provided much better visualization of pituitary adenoma than CISS sequence (►Fig. 3). When pituitary adenoma was observable on both CE-VIBE and CISS images, the laterality concordance rate between the two sequences were 91 and 100% for Observer A and Observer B, respectively.

Bilateral Inferior Petrosal Sinus Sampling

BIPSS with CRH stimulation was performed in 6 of the 12 CD patients and confirmed a central source for ACTH

Table 2 Detection of pituitary adenoma in Cushing's disease patients by Observer A and Observer B

Observer A	Number of patients			Sensitivity (%)
	True positives	False positives	False negatives	
CE-VIBE	9	3	0	75
CISS	7	4	1	58
Observer B	Number of patients			Sensitivity (%)
	True positives	False positives	False negatives	
CE-VIBE	6	0	6	50
CISS	6	0	6	50

Abbreviations: CE-VIBE, contrast-enhanced volume interpolated breath-hold examination; CISS, constructive interference in steady state.

Fig. 1 Averaged sensitivity of magnetic resonance imaging (MRI) sequences from Observer A and Observer B's results. Abbreviations: CE-VIBE, contrast-enhanced volume interpolated breath-hold examination; CISS, constructive interference in steady state.

Fig. 2 Pituitary imaging of *patient 5*. The adenoma (arrow) was difficult to delineate on axial (A) and coronal (B) CE-VIBE sequence, but was easily identified on axial (C) and coronal (D) CISS sequence. The localization of the tumor was confirmed by surgery to be on the right side. Abbreviations: CE-VIBE, contrast-enhanced volume interpolated breath-hold examination; CISS, constructive interference in steady state.

hypersecretion in all cases (sensitivity of 100%). Petrosal venous sinus to peripheral ACTH ratio was calculated to determine adenoma laterality. The accuracy at predicting laterality was 67% (4 of 6 patients) (► **Table 1**).

Histological Findings and Surgical Outcome

Histopathology confirmed ACTH secreting pituitary adenoma in 11 of the 12 CD patients. Ten of the 12 patients developed adrenal insufficiency (cortisol < 2 µg/dL) postoperatively (► **Table 1**). The two patients with pituitary

macroadenoma did not exhibit adrenal insufficiency and showed minimal decrease in serum cortisol level. One patient with negative histopathology did develop adrenal insufficiency postoperatively.

Discussion

In the present study, we compared the utility CISS MRI sequence to a contrast-enhanced T1-weighted MRI sequence at detecting pituitary adenomas in CD patients. We found

Fig. 3 Pituitary imaging of *patient 1*. The adenoma (arrow) was much better delineated on axial (A) and coronal (B) CE-VIBE sequence than on axial (C) and coronal (D) CISS sequence. The localization of the tumor was confirmed by surgery to be on the right side. Abbreviations: CE-VIBE, contrast-enhanced volume interpolated breath-hold examination; CISS, constructive interference in steady state.

that the sensitivity for pituitary adenoma detection was similar between the two sequences, but the detection rate increased when the two sequences were used in conjunction. To the best of our knowledge, this is the first study to assess the usefulness of CISS sequence for preoperative evaluation of pituitary adenomas in CD patients.

Surgery is the mainstay of treatment for CD. If left untreated, the estimated 5-year survival rate is ~50%.^{12,13} In comparison, 5- and 10-year survival rates after successful surgical resection have been reported to be 99 and 93%, respectively.¹⁴ However, 20 to 30% of CD patients who undergo surgery do not achieve hormonal remission due to diagnostic errors, small tumors, or tumor invasion into adjacent tissues.^{15,16} Studies have reported improved remission rates when the tumor can be localized through preoperative MRI.^{17,18} It has also been suggested that surgical complications such as CSF leak are less prevalent when preoperative tumor localization is possible.¹⁹ Being able to localize on imaging allows for better surgical planning and decreases the risk of pituitary damage due to unnecessary exploration.²⁰

Conventional T1-weighted MRI has a reported sensitivity of 50 to 60% for detecting pituitary adenomas in CD.^{16,21} In a more recent study of 57 CD patients, the sensitivity was only 37.5%.²² To improve detection, other imaging modalities such as dynamic MRI and CE-VIBE have been explored. Dynamic MRI allows imaging of the pituitary during the early phases of contrast enhancement. While dynamic MRI did increase the detection of microadenomas in CD patients, the false-positive rate was higher than conventional T1-weighted MRI.^{4,23,24} CE-VIBE was also found to be superior to conventional T1-weighted MRI for detecting pituitary adenoma in CD patients, with a reported sensitivity of 75 to 80%.²⁵ Thin sections, fast acquisition time that minimizes motion artifacts, and good soft tissue contrast make CE-VIBE particularly useful at detecting pituitary microadenomas in CD.²⁵ In our cohort, however, the averaged sensitivity between two observers was 63% using CE-VIBE imaging. This difference may be due to the small number of patients in our cohort and the different stringency used for adenoma identification across studies. Nevertheless, our findings support the use of CE-VIBE for localization of pituitary adenomas in CD patients.

CISS sequence, also known as FIESTA (Fast Imaging Employing Steady-state Acquisition Cycled Phases) on GE (General Electric, Milwaukee, Wisconsin, United States), has been shown to be useful in investigating a variety of pathologies involving the pituitary stalk, skull-base tumors, cranial nerve disorders, neurocysticercosis, and diseases of the spine and spinal cord.⁶ Its high signal-to-noise ratio and insensitivity to motion make it a useful imaging tool. Furthermore, CISS obtained at submillimetric thickness can provide more detailed visualization of the suprasellar compartment due to good contrast between CSF and the surrounding structures.²⁶ While CISS imaging has been shown to be effective at predicting pituitary macroadenoma consistently, its ability to detect pituitary adenoma in CD patients has never been reported.^{10,27}

In our patient cohort, we found that CISS sequence had a similar, albeit slightly lower, sensitivity to CE-VIBE at detecting

pituitary adenoma in CD patients (►Fig. 1). Interestingly, 2 out of the 12 CD patients in our study had pituitary adenomas that were isointense and difficult to visualize on CE-VIBE, but were easily localized on CISS images (►Fig. 2). The opposite was true for two other patients (►Fig. 3). This suggests that CE-VIBE and CISS may be good complementary sequences. Furthermore, the sensitivity of detecting pituitary adenoma for Observer B improved by 17% when CISS sequence results were used in conjunction with CE-VIBE results. Accurate localization of the adenomas in all cases was helpful in establishing the surgical approach and preoperative planning. We think CISS may be of value as an adjunct sequence to CE-VIBE for the workup of CD. Furthermore, CISS sequence does not require contrast enhancement. Therefore, it may even be an appropriate alternative to T1-weighted sequences in patients with gadolinium contraindications, such as those with renal dysfunction or chronic renal failure.^{28–30} Interestingly, we found no correlation between the histopathology, the location, or adenoma size and which sequence the adenoma was better visualized with. This remains an interesting topic for future studies with a more robust sample size.

Inter-rater discrepancy of MRI reporting was noted in our study. The more experienced of the two neuroradiologists (Observer B) had greater accuracy at pituitary adenoma localization, with no false positives with CE-VIBE or CISS sequences (►Table 2). This was not surprising as the additional years of experience likely contributed to the more conservative but also more accurate calls. Moreover, inter-rater differences are not uncommon when assessing pituitary pathologies through imaging.^{31,32}

A limitation of our study is the cohort size. A larger patient cohort is necessary to better compare the sensitivities of CE-VIBE and CISS sequences to detect pituitary adenomas in CD patients.

Conclusion

CISS sequence and the T1-weighted VIBE sequence had comparable sensitivity at detecting pituitary adenoma in CD patients and the addition of CISS sequence to T1-weighted MRI imaging protocols improved the detection of pituitary adenomas in CD patients in our series. CISS sequence may be a useful adjunct to T1-weighted pituitary MRI protocols and an appropriate alternative for patients with gadolinium contraindications.

Funding

None.

Conflict of Interest

The authors report no conflicts of interest in this work.

Disclosures

Pablo F. Recinos is on the scientific advisory board of Acera, Inc.

Varun R. Kshetry was a recent consultant for Medprin.

Acknowledgments

None.

References

- Sulentic P, Morris DG, Grossman A. Cushing's disease. In: De Groot LJ, Beck-Peccoz P, Chrousos G, Dungan K, Grossman A, Hershan JM, Koch C, McLachlan R, New M, Rebar R, Singer F, Vinik A, Weickert MO, eds. *Endotext*. South Dartmouth, MA: MDText.com, Inc.; 2000
- Tong T, Yue W, Zhong Y, Zhenwei Y, Yong H, Xiaoyuan F. Comparison of contrast-enhanced SPACE and CISS in evaluating cavernous sinus invasion by pituitary macroadenomas on 3-T magnetic resonance. *J Comput Assist Tomogr* 2015;39(02):222–227
- Newell-Price J, Bertagna X, Grossman AB, Nieman LK. Cushing's syndrome. *Lancet* 2006;367(9522):1605–1617
- Tabarin A, Laurent F, Catargi B, et al. Comparative evaluation of conventional and dynamic magnetic resonance imaging of the pituitary gland for the diagnosis of Cushing's disease. *Clin Endocrinol (Oxf)* 1998;49(03):293–300
- Johnston PC, Kennedy L, Hamrahian AH, et al. Surgical outcomes in patients with Cushing's disease: the Cleveland clinic experience. *Pituitary* 2017;20(04):430–440
- Hingwala D, Chatterjee S, Kesavadas C, Thomas B, Kapilamoorthy TR. Applications of 3D CISS sequence for problem solving in neuroimaging. *Indian J Radiol Imaging* 2011;21(02):90–97
- Yagi A, Sato N, Taketomi A, et al. Normal cranial nerves in the cavernous sinuses: contrast-enhanced three-dimensional constructive interference in the steady state MR imaging. *AJNR Am J Neuroradiol* 2005;26(04):946–950
- Yoshino N, Akimoto H, Yamada I, et al. Trigeminal neuralgia: evaluation of neuralgic manifestation and site of neurovascular compression with 3D CISS MR imaging and MR angiography. *Radiology* 2003;228(02):539–545
- Naraghi R, Tanrikulu L, Troescher-Weber R, et al. Classification of neurovascular compression in typical hemifacial spasm: three-dimensional visualization of the facial and the vestibulocochlear nerves. *J Neurosurg* 2007;107(06):1154–1163
- Lang M, Silva D, Dai L, Kshetry VR, Woodard TD, Sindwani R, Recinos PF. Superiority of constructive interference in steady-state MRI sequencing over T1-weighted MRI sequencing for evaluating cavernous sinus invasion by pituitary macroadenomas. *J Neurosurg* 2018. Doi: 10.3171/2017.9
- Nieman LK, Biller BM, Findling JW, et al. The diagnosis of Cushing's syndrome: an Endocrine Society Clinical Practice Guideline. *J Clin Endocrinol Metab* 2008;93(05):1526–1540
- Plotz CM, Knowlton AI, Ragan C. The natural history of Cushing's syndrome. *Am J Med* 1952;13(05):597–614
- Lambert JK, Goldberg L, Fayngold S, Kostadinov J, Post KD, Geer EB. Predictors of mortality and long-term outcomes in treated Cushing's disease: a study of 346 patients. *J Clin Endocrinol Metab* 2013;98(03):1022–1030
- Swearingen B, Biller BM, Barker FG II, et al. Long-term mortality after transsphenoidal surgery for Cushing disease. *Ann Intern Med* 1999;130(10):821–824
- Bochicchio D, Losa M, Buchfelder M. Factors influencing the immediate and late outcome of Cushing's disease treated by transsphenoidal surgery: a retrospective study by the European Cushing's Disease Survey Group. *J Clin Endocrinol Metab* 1995;80(11):3114–3120
- Invitti C, Pecori Giraldo F, de Martin M, Cavagnini F; Study Group of the Italian Society of Endocrinology on the Pathophysiology of the Hypothalamic-Pituitary-Adrenal Axis. Diagnosis and management of Cushing's syndrome: results of an Italian multicentre study. *J Clin Endocrinol Metab* 1999;84(02):440–448
- Yamada S, Fukuhara N, Nishioka H, et al. Surgical management and outcomes in patients with Cushing disease with negative pituitary magnetic resonance imaging. *World Neurosurg* 2012;77(3-4):525–532
- Lonser RR, Wind JJ, Nieman LK, Weil RJ, DeVroom HL, Oldfield EH. Outcome of surgical treatment of 200 children with Cushing's disease. *J Clin Endocrinol Metab* 2013;98(03):892–901
- Watson JC, Shawker TH, Nieman LK, DeVroom HL, Doppman JL, Oldfield EH. Localization of pituitary adenomas by using intraoperative ultrasound in patients with Cushing's disease and no demonstrable pituitary tumor on magnetic resonance imaging. *J Neurosurg* 1998;89(06):927–932
- Batista D, Courkoutsakis NA, Oldfield EH, et al. Detection of adrenocorticotropin-secreting pituitary adenomas by magnetic resonance imaging in children and adolescents with Cushing disease. *J Clin Endocrinol Metab* 2005;90(09):5134–5140
- Lüdecke DK, Flitsch J, Knappe UJ, Saeger W. Cushing's disease: a surgical view. *J Neurooncol* 2001;54(02):151–166
- Grober Y, Grober H, Wintermark M, Jane JA Jr, Oldfield EH. Comparison of MRI techniques for detecting microadenomas in Cushing's disease. *J Neurosurg* 2017;•••:1–7
- Moshang T Jr. Cushing's disease, 70 years later, and the beat goes on. *J Clin Endocrinol Metab* 2003;88(01):31–33
- Potts MB, Shah JK, Molinaro AM, et al. Cavernous and inferior petrosal sinus sampling and dynamic magnetic resonance imaging in the preoperative evaluation of Cushing's disease. *J Neurooncol* 2014;116(03):593–600
- Patronas N, Bulakbasi N, Stratakis CA, et al. Spoiled gradient recalled acquisition in the steady state technique is superior to conventional postcontrast spin echo technique for magnetic resonance imaging detection of adrenocorticotropin-secreting pituitary tumors. *J Clin Endocrinol Metab* 2003;88(04):1565–1569
- Kulkarni C, Moorthy S, Pullara SK, Rajeshkannan R, Unnikrishnan AG. Pituitary stalk transection syndrome: Comparison of clinicoradiological features in adults and children with review of literature. *Indian J Radiol Imaging* 2012;22(03):182–185
- Yamamoto J, Kakeda S, Shimajiri S, et al. Tumor consistency of pituitary macroadenomas: predictive analysis on the basis of imaging features with contrast-enhanced 3D FIESTA at 3T. *AJNR Am J Neuroradiol* 2014;35(02):297–303
- Zada G. Diagnosis and multimodality management of Cushing's disease: a practical review. *Int J Endocrinol* 2013;2013:893781
- Perazella MA. Gadolinium-contrast toxicity in patients with kidney disease: nephrotoxicity and nephrogenic systemic fibrosis. *Curr Drug Saf* 2008;3(01):67–75
- Abbassy M, Kshetry VR, Hamrahian AH, et al. Surgical management of recurrent Cushing's disease in pregnancy: a case report. *Surg Neurol Int* 2015;6(Suppl 25):S640–S645
- Mooney MA, Hardesty DA, Sheehy JP, et al. Interrater and intrarater reliability of the Knosp scale for pituitary adenoma grading. *J Neurosurg* 2017;126(05):1714–1719
- Bahurel-Barrera H, Assie G, Silvera S, Bertagna X, Coste J, Legmann P. Inter- and intra-observer variability in detection and progression assessment with MRI of microadenoma in Cushing's disease patients followed up after bilateral adrenalectomy. *Pituitary* 2008;11(03):263–269