Hormones (2021) 20:299–304
https://doi.org/10.1007/s42000-020-00240-8

ORIGINAL ARTICLE

A case series of bilateral inferior petrosal sinus sampling with desmopressin in evaluation of ACTH-dependent Cushing's syndrome in Iran

Fatemeh Rahmani[1] · Maryam Mahdavi[2] · Keyvan Edraki[3] · Majid Valizadeh[2]

Received: 22 June 2020 / Accepted: 26 August 2020 / Published online: 15 September 2020

Abstract

Background Differentiating the etiology of ACTH-dependent Cushing's syndrome (CS) has remained challenging due to the limited accuracy of noninvasive assays. Nowadays, bilateral inferior petrosal sinus sampling (BIPSS) with corticotropin-releasing hormone (CRH) is the gold standard method in the diagnostic work-up of complex CS. However, this method is as yet far from being widespread. The limited utility of this method could be due to many factors such as limited availability of an experienced interventionist, limited availability of CRH, and cost of the procedure. So far, very few studies have been conducted using desmopressin instead of CRH. In this study, we report the use of BIPSS with desmopressin as a diagnostic tool in a series of patients with suspected Cushing's disease (CD) and equivocal imaging in a tertiary referral center in Iran.

Methods A total of 13 patients with ACTH-dependent CS and no significant lesions in their pituitary MRI participated in this retrospective case series. All patients underwent BIPSS with desmopressin, and, following centralization of CS, transsphenoidal surgery (TSS) was carried out and diagnosis of CD was confirmed using standard methods.

Results Of the 13 patients with confirmed CD (by pathology or biochemical response after surgery), eight (61.5%) were female, with a median age of 32 years (IQR: 26–41). The median duration of disease was 24 months (IQR: 11–48). During BIPSS, all patients had a central-to-peripheral gradient greater than 2 under basal conditions. This central-to-peripheral gradient did not increase to > 3 after desmopressin administration in two of these patients. Based on the gradient after BIPSS, the sensitivity of this modality in the diagnosis of CD was 100%. Eight of the 13 patients had right lateralization in both BIPSS and TSS; therefore, the accuracy rate of lateralization by BIPSS was 61.5%. No complications occurred after BIPSS, the exception being the development of groin hematoma in one patient.

Conclusion No significant benefits of adding desmopressin to BIPSS were observed. The sensitivity of BIPSS in the diagnosis of CD was high, whereas it has moderate accuracy in tumor lateralization.

Keywords ACTH-dependent Cushing's syndrome · Cushing's disease · Bilateral inferior petrosal sinus sampling

Background

Differentiation between Cushing's disease (CD), an ACTH-producing pituitary adenoma, and an ectopic ACTH-producing tumor is challenging [1]. In some cases of Cushing's syndrome (CS), no endocrinological tests are able to differentiate between these two entities. Magnetic resonance imaging (MRI) is unable to find significant lesions in the pituitary gland in 40–50% of patients with CD; however, this does not include the pituitary incidentalomas seen in 10–20% of the normal population [2]. Due to the low sensitivity and specificity of noninvasive tests, using a precise and minimally invasive method such as bilateral inferior petrosal sinus sampling (BIPSS) to discriminate between a pituitary and an

✉ Majid Valizadeh
valizadeh@endocrine.ac.ir

[1] Prevention of Metabolic Disorders Research Center, Research Institute for Endocrine Sciences, Shahid Beheshti University of Medical Sciences, Tehran, Iran

[2] Obesity Research Center, Research Institute for Endocrine Science, Shahid Beheshti University of Medical Sciences, P.O. Box: 19395-4763, Tehran, Iran

[3] Neurosurgery Department of Sina Hospital, Tehran University of Medical Sciences, Tehran, Iran

ectopic source of ACTH secretion is essential [1]. In addition, BIPSS might be useful for lateralization of a pituitary adenoma based on the interpetrosal sinus gradient [3].

The BIPSS modality, initially described in 1977 by Corrigo [4], was upgraded by Landolf [5] in 1986 by adding corticotropin-releasing hormone (CRH) to BIPSS to improve the sensitivity of the test [6]. Nowadays, BIPSS is considered a gold standard technique for distinguishing between the two main subtypes of ACTH-dependent CS, with a diagnostic sensitivity rate of 95% and specificity of 90–95% [1]. Since 1995, desmopressin has replaced CRH in BIPSS due to the unavailability and high cost of CRH in many countries [7]. The sensitivity of desmopressin to induce stimulation of ACTH secretion during BIPSS and to lateralize the pituitary adenoma was found to be comparable with that of CRH in some studies [3, 8–10]. In two studies conducted to show the efficacy of desmopressin for differentiation of CD from ectopic CS, the sensitivity of BIPSS increased from 80 to > 90% after the addition of desmopressin.

Here we present an experience of a single tertiary care center using BIPSS with desmopressin in a series of 13 patients with ACTH-dependent CS and inconclusive pituitary MRI for localization of the lesion and lateralization of the intrapituitary origin of ACTH hypersecretion.

Methods

Between August 2015 and March 2019, 16 patients (including two children) with a diagnosis of ACTH-dependent CS and inconclusive imaging results for pituitary adenoma were referred to the Endocrinology Clinic of Taleghani Hospital, Tehran, Iran. Patients had elevated 24-h urine-free cortisol along with high ACTH levels (> 15 pg/ml), nonsuppressible cortisol after the low-dose dexamethasone suppression test (LDDST) [11], and > 50% suppression of serum or 24-h urine cortisol after a high-dose dexamethasone suppression test (HDDST) [12]. A dynamic pituitary MRI with and without gadolinium was performed in all patients. The MRI study was considered negative if the radiologist reported no adenomas or lesions smaller than 6 mm. All images were reviewed by an experienced radiologist. Based on the epicenter of the lesion on imaging, it was considered right-sided, left-sided, bilateral, or midline. Spiral chest and abdominopelvic computed tomography and octreoscan with technetium-99 were done to rule out ectopic CS, following which BIPSS with desmopressin was performed in all patients. After central localization of CS with BIPSS, TSS was performed in 15 patients, with one patient of the original 16 refusing surgery. Confirmation of CD was based on immunohistochemical staining (IHC) of surgical tissues or biochemical response after surgery. Informed consent was obtained from each participant, for whom identifying information has been included in this article. The proposal of our study was approved by the ethics committee of the Research Institute for Endocrine Sciences (RIES), Shahid Beheshti University of Medical Science, Tehran, Iran.

Catheterization procedures

BIPSS with desmopressin was performed in all patients in Taleghani Hospital, based on the standard algorithm of BIPSS [13]. After local anesthesia in an angiography unit, the procedure was conducted by an expert endovascular specialist, an endocrinologist, and three nurses aiding in the collection of labeled samples. Firstly, cannulation of the bilateral femoral vein was performed, and both petrosal sinuses were catheterized with anticoagulation. Blood samples from the right and left petrosal sinus and the peripheral vein (femoral) were simultaneously collected twice before and 3, 5, and 10 min after IV administration of 10 μg desmopressin in all patients [13], except one whose samples were taken once before and 5 and 10 min after desmopressin stimulation. Confirmation of catheter position and venous anatomy was performed by venography. Finally, all samples were immediately sent to the laboratory in ice bags, and ACTH levels were promptly measured using ECLIA methods (Cobas Immulite Chemiluminescene Immunoassay Kit). To corroborate suitable catheter placement, a post-procedure digital venogram was done. Due to the high rate of successful cannulation, the measurement of prolactin levels was not deemed cost-effective in our series.

IPSS interpretation and tumor lateralization

IPSS is considered an indicator of CD if the central-to-peripheral ratio of plasma ACTH concentration was ≥ 2 before or ≥ 3 after the administration of desmopressin [13]. Additionally, an interpetrosal gradient ratio of ≥ 1.4 at each time point (lateralization rate) was used to predict the site of the tumor [13].

Surgery, pathology, and biochemical confirmation

Based on the significant central-to-peripheral gradient observed in BIPSS that indicated CD in all patients, TSS was carried out in all subjects except one. Total pituitary exploration was performed if no tumor was observed. CD was ultimately confirmed by positive ACTH immunohistological staining of the pituitary adenoma or biochemical remission 6 months after TSS. Biochemical response was defined as morning cortisol < 5 μg/dl or UFC < 190 μg/24 h (less than the upper limit of normal) or 1 mg overnight dexamethasone suppression test < 1.8 μg/dl 6 months after surgery [14].

Statistical analysis

Continuous variables are expressed as median (IQR) and categorical variables as numbers (percentage). The diagnostic value for BIPSS was interpreted by sensitivity. Lateralization efficacy was assessed by the concordance rate between lateralization by BIPSS and surgery. All results were performed using the SPSS statistical software package (SPSS for Windows; SPSS Inc., Chicago, IL, USA; version 20.00).

Results

Of the 16 patients who underwent BIPSS, one refused TSS, and we had no information on the IHC of the lesion or serum cortisol level after surgery in two patients; hence, in 13 patients, CD was confirmed, four of whom had histological evidence of ACTH-producing pituitary adenomas and nine had a biochemical response. Of the 13 patients, eight were female (61.5%) with a median age of 32 years (IQR: 26–41). The median duration of disease was 24 months (IQR: 11–48); the median ACTH level was 42 pg/ml (IQR: 29.5–69.4); and the median 24 h UFC level was 600.5 μg/day (IQR: 345.3–1080.7). Table 1 illustrates the baseline characteristics of the patients. The maximum ACTH level of basal petrosal/peripheral in all 13 patients was > 2, and a central gradient was observed in all patients at baseline. After desmopressin injection, 11 of the 13 patients had a petrosal/peripheral ratio > 3. No adverse events occurred during or after BIPSS, except for one patient, who had a groin hematoma that was reabsorbed 3 days after BIPSS without further management.

Based on positive BIPSS findings in favor of a central gradient in all 13 patients with a confirmed diagnosis of CD, the sensitivity of BIPSS was 100%. Due to the absence of ectopic CS cases, we were unable to determine the specificity. During surgery, we found localization of the tumor in all patients; in ten of these (76.9%), the lesion was on the right side of the pituitary gland, in two (15.3%), the tumor had spread to both sides, and in one (7.6%), it was in the midline. Concordance of intrasellar localization of the tumor by BIPSS and surgery is shown in Table 2. Of the 13 patients, nine had right lateralization by BIPSS, eight of which were confirmed by surgery, two had left lateralization by BIPSS that were bilateral or midline in surgery, and two had no intrasellar gradient on BIPSS, both of which were right in surgery; thus, the accordance rate of BIPSS and actual tumor lateralization was 61.5% (Tables 2 and 3).

Location of the lesion was determined by MRI in eight of the 13 patients (61.5%); four lesions were located on the left side and four on the right side of the pituitary gland. Consistency of left localization by MRI was not found with surgery, but in two patients with right localization in MRI, compatibility was established during surgery. Moreover, two patients had midline lesions in pituitary MRI, one of which was found to be in line with lateralization during surgery.

Discussion

The use of BIPSS for diagnosis of CD varies between centers. Most centers prefer to perform this modality in selected patients with inconclusive biochemical and imaging results [15]

Table 1 Baseline characteristics of 13 patients with Cushing's disease

	Sex	Age(y)	Duration of disease(m)	Mean UFC (μg /24 h)	ACTH (pg/ml)	LDDST (μg/24 h)	HDDST (μg/24 h)	HDDST suppression%
1	M	44	12	600.50	60.00	170	44.6	92
2	F	45	24	357.00	78.80	76	38.2	89
3	F	35	46	1219.50	31.80	N/A	436	64
4	M	28	24	333.70	46.70	N/A	38.3	88
5	F	38	12	657.00	83.00	107	56.3	91
6	M	24	6	420.00	36.00	N/A	42	90
7	F	32	48	669.00	27.20	187	93	86
8	F	31	10	237.50	26.10	29	35	85
9	M	31	24	1687.00	55.30	N/A	682	59
10	F	14	6	147.00	39.00	168	38	74
11	M	14	12	942.00	19.80	N/A	12.7	98
12	F	58	48	408.00	42.00	N/A	58	85
13	F	38	48	1665.50	85.20	N/A	163.5	90

UFC, urine free cortisol; *HDDST*, high-dose dexamethasone suppression test; *LDDST*, low-dose dexamethasone suppression test

Table 2 Cross tabulation demonstrating tumor lateralization by BIPSS compared with lateralization by surgery

		Total	*Lat.BIPSS*		
			Right	Left	Inconclusive
Lat.surgery	*Right*	*10*	*8*	*0*	*2*
	Left	*0*	*0*	*0*	*0*
	Bilateral	*2*	*1*	*1*	*0*
	Midline	*1*	*0*	*1*	*0*
Total		*13*	*9*	*2*	*2*

BIPSS, bilateral inferior petrosal sinus sampling

Table 4 BIPSS data of the non-respondents to desmopressin

		ACTH(pg/ml)				
		− 5	*0*	*3*	*5*	*10*
Case 2	*Rt.petrosal*	-	*985.5*	-	*95.5*	*125.2*
	Lt.petrosal	-	*63.8*	-	*95.5*	*90.1*
	Peripheral	-	*67.8*	-	*91*	*93*
Case 9	*Rt.petrosal*	*70.8*	*200.5*	*72.5*	*71.5*	*65.3*
	Lt.petrosal	*60.5*	*113.9*	*65.9*	*66.9*	*65*
	Peripheral	*52.7*	*52.4*	*62.3*	*67.1*	*62.2*

BIPSS, bilateral inferior petrosal sinus samplings

due to its invasiveness, limited availability, and high cost. Based on our findings, BIPSS had a sensitivity of 100% in the diagnosis of ACTH-producing pituitary adenoma, despite the fact that several previous investigations reported a sensitivity rate of 92.1 to 95% [1, 5, 7, 9, 16, 17]. This difference may be due to the limited number of patients in our series. We found that following the administration of desmopressin, a central gradient was observed in all but two patients, in whom no such gradient could be found following desmopressin stimulation (Table 4). Therefore, using desmopressin did not increase the sensitivity of BIPSS in centralizing CS in our series. Desmopressin, a synthetic analog of human vasopressin, is used instead of CRH in the BIPSS procedure. Theoretically, the overexpression of V2 desmopressin receptors in corticotropin adenoma cells permits desmopressin to stimulate ACTH secretion through its binding to pituitary vasopressin receptors. So far, a few recent studies [17, 18] have shown the expression of V2 and V3 receptors in some cases of ectopic CS. In two case series previously published, the use of desmopressin increased the sensitivity of BIPSS from 80 to 90% [3, 16]. We failed to observe increased sensitivity of BIPSS following desmopressin stimulation in our series. This might be attributed to the lower numbers of AVP receptors in some corticotroph adenomas. Another possible explanation is catheter displacement, technical errors, or mislabeling during BIPSS, emphasizing the need for retrograde venography at the end of the procedure. However, considering our protocols for BIPSS, the last hypotheses are improbable.

In our results, BIPSS with desmopressin showed an accuracy of 92.5% for the diagnosis of CD. The diagnostic accuracy of BIPSS reported in previous series was between 90 and 100% [13, 19, 20], findings that are consistent with those of our series.

BIPSS can be used to predict the lateralization of pituitary adenoma in patients with negative imaging. We were able to accurately lateralize the lesion in 61.5% of cases using BIPSS. Previous reviews reported ranges of 54–78% [1, 7, 8], in line

Table 3 Details of BIPSS lateralization, pituitary imaging, surgical findings, and histological confirmation

	IPSS lateralization	MRI lateralization	Surgery lateralization	IPS/P before stimulation	IPS/P after stimulation	Histological confirmation
1	Left	Right	Bilateral	15.8	20.2	N/A
2	Right	NA	Right	14.5	**1.3**	Positive
3	Inconclusive	Right	Right	35.8	22	Neg
4	Right	Left	Right	7	16	N/A
5	Right	Left	Right	40.5	32.7	Positive
6	Right	Right	Right	10.2	11.3	N/A
7	Right	Right	Bilateral	4.2	16.1	N/A
8	Left	Midline	Midline	10.1	52.2	Neg
9	Right	Left	Right	3.8	1.05	N/A
10	Right	Left	Right	5.9	10.5	N/A
11	Right	NA	Right	7.2	30.07	Positive
12	Inconclusive	Midline	Right	13.2	19.08	Positive
13	Right	NA	Right	16.2	18.2	Neg

IPS inferior petrosal sampling/peripheral; *BIPSS*, bilateral inferior petrosal sinus sampling

with our results. Also, variable consequences in some other series are notable [21]. Correct lateralization rates of CD were 73.5%, 91%, and 93% reported by Fritsch et al. [22], Teramoto et al. [23], and Fujimori et al. [24], respectively. Numerous factors can influence the accuracy rate of correct lateralization in different studies, including asymmetry or hypoplastic petrosal sinus anatomy, intercavernous venous mixing and catheter position, and, very importantly, the skill and experience of the interventional team. In our series, relative lateralization accuracy was observed with right lateralization in BIPSS and surgery, in accordance with the report by Deipolyi et al. [10]. Anatomical abnormalities resulting in asymmetrical venous drainage of bilateral inferior petrosal sinus might explain these results. This is an important reason why physicians must pay attention to the limitation of BIPSS results in lateralization.

Even though BIPSS was able to centralize CS in the two children who participated in our study, limited research has been done on the application of BIPSS as a diagnostic tool in cases of child and adolescent CS. This is due to the low prevalence of CD in the pediatric age group and difficulty in catheterization even in the most experienced hands. Shei Chen et al. [25] revealed low sensitivity of BIPSS for the diagnosis of CD in children (64.7%). Batista et al. [26] and Magiakou et al. [27] reported a sensitivity of over 90% in children.

Conclusion

In situations in which noninvasive assays yield equivocal results, BIPSS can be a crucial diagnostic approach for differentiation of pituitary from ectopic ACTH-driven Cushing's syndrome. This minimally invasive and safe procedure could improve the pituitary adenoma detection rate in the setting of specialized BIPSS intervention radiology techniques.

Acknowledgments The authors wish to acknowledge Prof. Farzad Hadaegh and Dr. Zahra Piri for their assistance in the preparation of the article and Mrs. Niloofar Shiva for critical editing of the English grammar and syntax of the manuscript.

Authors' contributions FR, MV, and KE conceptualized and designed the study, drafted the initial manuscript, and approved the final manuscript as submitted. FR and MM carried out the analysis, reviewed, and revised the manuscript, and approved the final manuscript as submitted. KE and MV designed the case series, coordinated and supervised the data collection, critically reviewed the manuscript, and approved the final manuscript as submitted. Finally, all authors have read and approved the manuscript as presented.

Availability of data and materials The datasets generated and analyzed during the current study are not publicly available due to the privacy statement in the patients' informed consent form. However, they are available from the corresponding author on reasonable request.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval and consent to participate The research and ethics committee of Shahid Beheshti University of Medical Sciences provided us with ethical clearance to publish this case series. Written informed consent was obtained from the patients for publication of this case series. For those who were under 16 years old, informed consent was provided by their parents or guardians. Documentation of the written consent will be provided to the journal upon request.

Abbreviations **CS**, Cushing's syndrome; CD, Cushing's disease; BIPSS, bilateral inferior petrosal sinus sampling; CRH, corticotropin-releasing hormone; TSS, transsphenoidal surgery; MRI, magnetic resonance imaging; LDDST, low-dose dexamethasone suppression test; HDDST, high-dose dexamethasone suppression test; IHC, immunohistochemical staining

References

1. Giraldi FP, Cavallo LM, Tortora F, Pivonello R, Colao A, Cappabianca P, Mantero F (2015) The role of inferior petrosal sinus sampling in ACTH-dependent Cushing's syndrome: review and joint opinion statement by members of the Italian Society for Endocrinology, Italian Society for Neurosurgery, and Italian Society for Neuroradiology. Neurosurg Focus 38(2):E5
2. Boscaro M, Arnaldi G (2009) Approach to the patient with possible Cushing's syndrome. J Clin Endocrinol Metab 94(9):3121–3131
3. Machado MC, De Sa SV, Domenice S, Fragoso MCBV, Puglia P Jr, Pereira MAA, De Mendonça BB, Salgado LR (2007) The role of desmopressin in bilateral and simultaneous inferior petrosal sinus sampling for differential diagnosis of ACTH-dependent Cushing's syndrome. Clin Endocrinol 66(1):136–142
4. Corrigan DF, Schaaf M, Whaley RA, Czerwinski CL, Earll JM (1977) Selective venous sampling to differentiate ectopic ACTH secretion from pituitary Cushing's syndrome. N Engl J Med 296(15):861–862
5. Landolt A, Valavanis A, Girard J, Eberle A (1986) Corticotrophin-releasing factor-test used with bilateral, simultaneous inferior petrosal sinus blood-sampling for the diagonosis of pituitary-dependent Cushing's disease. Clin Endocrinol 25(6):687–696
6. Deipolyi A, Oklu R (2015) Bilateral inferior petrosal sinus sampling in the diagnosis of Cushing disease. J Vasc Diagn 3:1–7
7. Malerbi DA, Mendonça BB, Liberman B, Toledo SP, Corradini MCM, Cunha-Neto MB, Fragoso MCB, Leo Wajchenberg B (1993) The desmopressin stimulation test in the differential diagnosis of Cushing's syndrome. Clin Endocrinol 38(5):463–472
8. Castinetti F, Morange I, Dufour H, Jaquet P, Conte-Devolx B, Girard N, Brue T (2007) Desmopressin test during petrosal sinus sampling: a valuable tool to discriminate pituitary or ectopic ACTH-dependent Cushing's syndrome. Eur J Endocrinol 157(3): 271–277
9. Belli S, Oneto A, Mendaro E (2007) Bilateral inferior petrosal sinus sampling in the differential diagnosis of ACTH-dependent Cushing's syndrome. Rev Med Chil 135(9):1095–1102
10. Deipolyi AR, Alexander B, Rho J, Hirsch JA, Oklu R (2015) Bilateral inferior petrosal sinus sampling using desmopressin or corticotropic-releasing hormone: a single-center experience. J Neurointervent Surg 7(9):690–693
11. Nieman LK, Biller BM, Findling JW, Newell-Price J, Savage MO, Stewart PM, Montori VM (2008) The diagnosis of Cushing's

syndrome: an endocrine society clinical practice guideline. J Clin Endocrinol Metab 93(5):1526–1540
12. Flack MR, Oldfield EH, Cutler GB, Zweig MH, Malley JD, Chrousos GP, Loriaux DL, Nieman LK (1992) Urine free cortisol in the high-dose dexamethasone suppression test for the differential diagnosis of the Cushing syndrome. Ann Intern Med 116(3):211–217
13. Oldfield EH, Doppman JL, Nieman LK, Chrousos GP, Miller DL, Katz DA, Cutler GB Jr, Loriaux DL (1991) Petrosal sinus sampling with and without corticotropin-releasing hormone for the differential diagnosis of Cushing's syndrome. N Engl J Med 325(13):897–905
14. Czepielewski MA, Rollin GA, Casagrande A, Ferreira NP (2007) Criteria of cure and remission in Cushing's disease: an update. Arq Bras Endocrinol Metabol 51(8):1362–1372
15. Jehle S, Walsh JE, Freda PU, Post KD (2008) Selective use of bilateral inferior petrosal sinus sampling in patients with adrenocorticotropin-dependent Cushing's syndrome prior to transsphenoidal surgery. J Clin Endocrinol Metab 93(12):4624–4632
16. Tsagarakis S, Kaskarelis I, Kokkoris P, Malagari C, Thalassinos N (2000) The application of a combined stimulation with CRH and desmopressin during bilateral inferior petrosal sinus sampling in patients with Cushing's syndrome. Clin Endocrinol 52(3):355–361
17. De Keyzer Y, Rene P, Beldjord C, Lenne F, Bertagna X (1998) Overexpression of vasopressin (V3) and corticotrophin-releasing hormone receptor genes in corticotroph tumours. Clin Endocrinol 49(4):475–482
18. Antoni FA (1984) Novel ligand specificity of pituitary vasopressin receptors in the rat. Neuroendocrinology 39(2):186–188
19. Wind JJ, Lonser RR, Nieman LK, DeVroom HL, Chang R, Oldfield EH (2013) The lateralization accuracy of inferior petrosal sinus sampling in 501 patients with Cushing's disease. J Clin Endocrinol Metab 98(6):2285–2293
20. Kaltsas G, Giannulis M, Newell-Price J, Dacie J, Thakkar C, Afshar F, Monson J, Grossman A, Besser G, Trainer P (1999) A critical analysis of the value of simultaneous inferior petrosal sinus sampling in Cushing's disease and the occult ectopic adrenocorticotropin syndrome. J Clin Endocrinol Metab 84(2):487–492
21. Gazioglu N, Ulu MO, Ozlen F, Albayram S, Islak C, Kocer N, Oz B, Tanriover N, Yetkin DO, Gundogdu S (2008) Management of Cushing's disease using cavernous sinus sampling: effectiveness in tumor lateralization. Clin Neurol Neurosurg 110(4):333–338
22. Flitsch J, Lüdecke D, Knappe U, Grzyska U (2002) Cavernous sinus sampling in selected cases of Cushing's disease. Exp Clin Endocrinol Diabetes 110(07):329–335
23. Teramoto A, Yoshida Y, Sanno N, Nemoto S (1998) Cavernous sinus sampling in patients with adrenocorticotrophic hormone—dependent Cushing's syndrome with emphasis on inter-and intracavernous adrenocorticotrophic hormone gradients. J Neurosurg 89(5):762–768
24. Fujimura M, Ikeda H, Takahashi A, Ezura M, Yoshimoto T, Tominaga T (2005) Diagnostic value of super-selective bilateral cavernous sinus sampling with hypothalamic stimulating hormone loading in patients with ACTH-producing pituitary adenoma. Neurol Res 27(1):11–15
25. Chen S, Chen K, Lu L, Zhang X, Tong A, Pan H, Zhu H, Lu Z (2019) The effects of sampling lateralization on bilateral inferior petrosal sinus sampling and desmopressin stimulation test for pediatric Cushing's disease. Endocrine 63(3):582–591
26. Batista D, Gennari M, Riar J, Chang R, Keil MF, Oldfield EH, Stratakis CA (2006) An assessment of petrosal sinus sampling for localization of pituitary microadenomas in children with Cushing disease. J Clin Endocrinol Metab 91(1):221–224
27. Magiakou MA, Mastorakos G, Oldfield EH, Gomez MT, Doppman JL, Cutler GB Jr, Nieman LK, Chrousos GP (1994) Cushing's syndrome in children and adolescents–presentation, diagnosis, and therapy. N Engl J Med 331(10):629–636