

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

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In the management of adrenocorticotrophic hormone (ACTH)-dependent Cushing's syndrome, inferior petrosal sinus sampling (IPSS) provides information for the endocrinologist, the neurosurgeon, and the neuroradiologist. To the endocrinologist who performs the etiological diagnosis, results of IPSS confirm or exclude the diagnosis of Cushing's disease with 80%–100% sensitivity and over 95% specificity. Baseline central-peripheral gradients have suboptimal accuracy, and stimulation with corticotropin-releasing hormone (CRH), possibly desmopressin, has to be performed. The rationale for the use of IPSS in this context depends on other diagnostic means, taking availability of CRH and reliability of dynamic testing and pituitary imaging into account. As regards the other specialists, the neuroradiologist may collate results of IPSS with findings at imaging, while IPSS may prove useful to the neurosurgeon to chart a surgical course. The present review illustrates the current standpoint of these 3 specialists on the role of IPSS.

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KEY WORDS inferior petrosal sinus sampling; Cushing's disease; Cushing's syndrome; diagnosis; pituitary adenoma; pituitary surgery; pituitary imaging

INFERIOR petrosal sinus sampling (IPSS) is an important procedure in the diagnostic work-up of Cushing's syndrome. Evidence accrued over the past 3 decades lays the foundation for its rational use in various clinical settings.

Evidence on the Use of Petrosal Sinus Sampling

Inferior petrosal sinus sampling entered the diagnostic work-up of Cushing's syndrome after the seminal National Institutes of Health (NIH) publication by Oldfield et al.⁴¹ in 1991, which followed upon a paper by Findling

et al.,¹⁴ published some 10 years earlier, pioneering petrosal venous sampling in Cushing's disease and ectopic adrenocorticotrophic hormone (ACTH) secretion. The NIH paper described results obtained in over 200 patients and asserted that the maximum ratio of ACTH concentrations in inferior petrosal sinus plasma to concentrations in peripheral-blood plasma (central/peripheral ratio), either at baseline sampling or after administration of corticotropin-releasing hormone (CRH), provided 100% diagnostic accuracy for both pituitary and ectopic ACTH-secreting tumors.⁴¹ Subsequent studies—including some from the NIH itself—showed, however, that the diagnostic accuracy is not absolute and both false-negatives (lack of a central/

ABBREVIATIONS ACTH = adrenocorticotrophic hormone, or corticotropin; CRH = corticotropin-releasing hormone; IPSS = inferior petrosal sinus sampling; NIH = National Institutes of Health.

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peripheral gradient in patients with Cushing’s disease), and false positives (presence of a central/peripheral gradient in patients with ectopic ACTH secretion) occur.

Table 1 describes publications reporting on the use of IPSS in at least 20 patients, and, as can be observed, false negatives may occur in 10%–15% of patients, with a higher prevalence on baseline, unstimulated ACTH levels. In detail, sensitivity of baseline central/peripheral gradients ranges from 54% to 96%, whereas CRH-stimulated gradients achieve 81%–100% sensitivity. These series represent data collected from centers in many areas of the world, thus false negatives are not a problem confined to single centers or areas. The main cause of absent ACTH gradient in patients harboring a pituitary ACTH-secreting tumor are unilateral or bilateral anatomical variants in the petrosal venous system. Shiu et al. originally classified 4 variants.⁵⁶ In Type I, the most common variant, the petrosal sinus drains directly into the internal jugular vein; in Type II, the petrosal sinus drains into the anterior condylar vein, thus into both the jugular vein and the vertebral venous plexus; in Type III, the petrosal sinus is plexiform, and a

network of small vessels drains into the internal jugular vein and the vertebral venous plexus; in Type IV, the petrosal sinus drains directly into the vertebral venous plexus via the condylar veins, without connection to the jugular vein. This classification was subsequently modified, and the most recent version describes 6 variants, with emphasis on the petrosal-jugular junction.³⁶ These variants also explain the less than 100% success rate of bilateral petrosal cannulation and sampling (Table 1). Sampling from jugular veins has been employed with some success²⁰ and appears a viable, fallback option if technical difficulties are encountered en route to the petrosal sinuses.^{2,28,54,67} On the other hand, cavernous sinus sampling does not appear to be superior to IPSS.³¹ False-negative results may also be due to the variability in the tumoral corticotrope secretory pattern,⁴⁷ and ACTH secretion by the adenoma into the petrosal sinuses in a given moment might not reach the expected 2- to 3-fold excess compared with peripheral concentrations. Ensuring clear hypercortisolism during sampling as well as using lower central/peripheral gradients^{20,54} may overcome this problem.

TABLE 1. Summary of case series reporting on IPSS in at least 20 patients*

Authors & Year	Location	Cushing’s Disease†		Ectopic ACTH‡		Successful Cannulation
		Baseline	Post-CRH	Baseline	Post-CRH	
Oldfield et al., 1991	Bethesda	205/215 (95%)	203/203 (100%)	20/20	17/17	99%
Findling et al., 1991	Milwaukee	18/20 (90%)	17/18 (94%)	9/9	6/6	93%
Tabarin et al., 1991	Bordeaux	18/22 (82%)	22/22 (100%)	5/5	5/5	89%
López et al., 1996	Madrid	27/30 (90%)	22/25 (88%)			94%
Landolt et al., 1994	Zurich	33/38 (87%)	37/38 (95%)			—
Zarilli et al., 1995	Naples	12/22 (54%)	19/22 (86%)	4/4	4/4	85%
Booth et al., 1998	Toronto	24/26 (84%)				91%
Teramoto et al., 1998	Tokyo	27/35 (77%)		5/5		—
Kaltsas et al., 1999	London	50/68 (72%)	64/69 (93%)	6/6	6/6	73%
Invitti et al., 1999 ²³	Italy§	69/85 (81%)	65/76 (85%)	9/10	10/10	—
Bonelli et al., 2000	Mayo Clinic	48/54 (89%)	47/54 (87%)	9/9	8/9	87%
Wiggam et al., 2000	Belfast	36/44 (82%)		1/1		—
Lefournier et al., 2003	Grenoble	71/74 (96%)	74/74 (100%)	12/12	10/12	—
Liu et al., 2004	Cleveland	39/42 (93%)	21/22 (95%)	9/9	7/7	—
Ilias et al., 2004	Bethesda	58/65 (89%)	59/65 (91%)	13/13	13/13	92%
Kalgikar et al., 2005	Mumbai	23/34 (68%)		4/4		100%
Kaskarelis et al., 2006	Athens	57/63 (90%)		12/12	12/12	81%
Jehle et al., 2008	New York		103/105 (98%)			97%
Daousi et al., 2010	Liverpool	21/24 (87%)	21/24 (87%)	2/2	2/2	69%
Shi et al., 2011	Shanghai	57/64 (89%)		4/5		100%
Mulligan et al., 2011	Cleveland	33/35 (94%)	33/35 (94%)		1/1	—
Andereggen et al., 2012	Bern	17/20 (85%)	19/20 (95%)	2/3	2/3	96%
Sheth et al., 2012	Boston	194/296 (94%)		9/11		83%
Grant et al., 2012	London		67/83 (81%)		10/10	—
Wind et al., 2013	Bethesda	467/501 (93%)	487/500 (97%)			99%

* Some series from the same center might contain duplicate data. The most recent series from a given center is listed in case of multiple publications on the same patient database. Diagnostic criteria as defined by Oldfield et al.⁴¹ Cushing’s disease is defined as a central/peripheral baseline ACTH gradient ≥ 2 or post-CRH ≥ 3 ; ectopic ACTH secretion is defined as a central/peripheral baseline ACTH gradient < 2 or post-CRH < 3 .

† Number of true positives over total number of patients with Cushing’s disease tested (sensitivity).

‡ Number of true negatives over total number of patients with ectopic ACTH secretion tested.

§ Multicenter study.

In addition to false negatives, a small portion of patients bearing an extrapituitary ACTH-secreting tumor present an unexpected central/peripheral ACTH gradient. A scattering of cases have been reported in major case series (Table 1) as well as in individual case reports.^{9,30,42,58,62,69} Overall, although the paucity of reported cases allows only an approximate calculation, the specificity of IPSS may be estimated at 90%–95%. In a number of these cases, patients were subjected to transsphenoidal surgery, but the postoperative course suggested an ectopic source, and the causative lesion—in some cases already evident prior to pituitary surgery but deemed incidental at the time—was subsequently removed. Some tumors were documented to secrete both ACTH and CRH,^{30,69} a credible explanation for false-positive results, or were located close to the pituitary (e.g., esthesioneuroblastoma or sphenoidal sinus ectopic pituitary adenoma).^{21,62} It has been suggested that false positives could be due to intermittent hypercortisolism and sampling performed by chance in the eucortisolemic state;⁶⁸ this implies that normal corticotropes rapidly recover their secretory pattern as soon as cortisol levels decrease, which contrasts, however, with long-standing secondary adrenal insufficiency after curative surgery for Cushing's syndrome due to any cause. For the most part, the cause of false-positive IPSS results remained elusive in patients with proven ectopic ACTH-secreting tumors.

Altogether, given the different prevalence of the 2 etiologies of ACTH-dependent Cushing's syndrome, with pituitary outnumbering ectopic secretion by 4–5 to 1, it appears evident that any patient without a central/peripheral gradient is still more likely to harbor a pituitary rather than an extra-pituitary tumor. Indeed, this justified transsphenoidal surgery in all those patients in whom IPSS results were proven false by the success of pituitary surgery. In these patients, dynamic testing and/or pituitary imaging pointed toward a pituitary origin and no extra-pituitary lesion was evident, thus supporting pituitary exploration.

The data reported so far rest on measurement of ACTH in the petrosal sinus, the most rational approach to confirming the presence of a corticotrope tumor; however, the tumor might secrete additional pituitary-derived peptides, such as growth hormone, prolactin, thyroid-stimulating hormone, alpha subunit, alternative proopiomelanocortin breakdown products (e.g., β -endorphin),⁵⁰ or non-pituitary-derived factors (e.g., atrial natriuretic factor, interleukin-1 receptor antagonist, tumor necrosis factor alpha, or parathyroid hormone-related protein).^{34,65} Of these, only prolactin has proven of some use to attest to successful catheterization.¹⁵ Furthermore, in some patients without a central/peripheral gradient, normalizing the ACTH ratio by prolactin pointed toward a pituitary origin,^{18,53} thus reversing a false-negative result. However, proposed cut-offs for pituitary or ectopic secretion vary, and an area of uncertainty remains.⁵² The prolactin inter-sinus ratio has been used to predict tumor localization within the pituitary, as it is known that the ACTH inter-sinus ratio is correct in less than 70% of cases.⁶⁷ However, even with the prolactin-adjusted ACTH ratio, tumor site prediction is by no means absolute.³⁹ Altogether, the measurement of prolactin proved useful in selected cases, mostly with negative gradients, but whether it provides meaningful,

adjunctive information and should be assessed routinely remains to be established.

As regards baseline versus stimulated ACTH gradients, as mentioned above, most series report greater sensitivity after CRH stimulation, thus supporting its use during IPSS to maximize diagnostic accuracy. Nevertheless, CRH is not readily available worldwide, and desmopressin, an alternative stimulant for tumoral ACTH secretion,^{37,49} has been employed. Approximately 150 patients with Cushing's disease tested with desmopressin have been reported on so far,^{4,10,33} with the results showing sensitivity comparable to that of CRH stimulation (i.e., 90%–97%). Stimulation with desmopressin and CRH together, performed to amplify corticotrope responses, identified a central/peripheral ACTH gradient in 46 of 47 patients with Cushing's disease.⁶³ The use of desmopressin however might mandate additional precautions during the sampling procedure, as this agent is a known hemostatic and causes release of von Willebrand factor as well as other factors of the coagulatory cascade in patients with Cushing's disease.⁴⁶

In this context, it is worth recalling that IPSS is an invasive maneuver that requires specific expertise to achieve successful bilateral cannulation and accurate and coordinated blood sampling and minimize untoward effects. Minor complaints during or after petrosal sampling have included tinnitus or otalgia (1%–2%) and groin swelling or hematoma (2%–3%). More serious complications—both neurological (nerve palsy [1%], subarachnoid hemorrhage, brainstem infarction, or contrast extravasation) and peripheral (e.g., pulmonary and deep vein thromboembolism)—have been reported but appear extremely rare.^{35,61} Developments in endovascular materials, such as smaller, hydrophilic catheters and microcatheters and pressurized sacks for continuous catheter flushing, may minimize the risks of thromboembolic and hemorrhagic events. Unilateral femoral vein puncture using 9-Fr sheaths may reduce groin complications in obese patients.⁴³

Rationale for the Use of Petrosal Sinus Sampling

Petrosal sinus sampling can yield 2 different types of evidence: 1) it can differentiate between pituitary and ectopic tumoral ACTH secretion, and 2) it can provide clues as to the site of a patient's pituitary adenoma (i.e., midline or right or left of midline). The endocrinologist is obviously interested in achieving the correct differential diagnosis, whereas the neurosurgeon also benefits from any information as to the location of the adenoma.

Series reporting on the use of IPSS have adopted different strategies—for example, performing the procedure in any patient with ACTH-dependent Cushing's syndrome, only in patients with ACTH-dependent Cushing's syndrome and equivocal responses to dynamic testing (CRH stimulation and/or high-dose dexamethasone suppression), or only in patients in whom pituitary imaging failed to visualize an adenoma, regardless of results of dynamic testing. In patients with clear-cut responses to CRH and/or 8-mg dexamethasone and some evidence of a pituitary adenoma, IPSS is usually not performed.

These strategies all have pros and cons. The abridged

strategy for IPSS in any patient with Cushing's syndrome, detectable ACTH levels, and normal or equivocal findings on pituitary imaging is based on an epidemiological premise—that is, that Cushing's disease is by far the more likely diagnosis and that dynamic testing does not add to (and may even detract from) this a priori probability. Arguing against this approach is the risk of false negatives at IPSS, which—in the absence of supportive results from dynamic testing—may divert the patient from appropriate surgery. Furthermore, IPSS may prove inconclusive due to failure to correctly cannulate the petrosal sinuses (see Table 1); indeed, a large series detailing unsuccessful IPSS showed that a pituitary source was detected at surgery in over 85% of cases.⁵⁴ Of note, this strategy has even led to petrosal sampling in patients with adrenal Cushing's syndrome and unsuppressed plasma ACTH concentrations.^{28,54}

In other series, IPSS was performed in patients with equivocal responses to dynamic testing, usually to confirm the diagnosis of Cushing's disease.^{22,60} CRH stimulation has proven the most accurate, non-invasive approach to differentiate between pituitary and ectopic tumors,^{45,48} but CRH is expensive and not widely available. In contrast, high-dose dexamethasone suppression can be easily performed but is less accurate. Indeed, to obtain certainty of pituitary disease, the criterion for cortisol suppression needs to be set at 80%–90% of pretest concentrations, and this, in turn, increases the number of non-suppressors among patients with Cushing's disease.^{12,17,23} On the other hand, the likelihood of false-positive responses to both the CRH test and the 8-mg dexamethasone test in patients with ectopic ACTH secretion using appropriate response criteria appears very low.^{1,21,40,64} Of note, false-positive IPSS results have been reported in patients with false-positive responses to these tests.^{58,62,69}

Lastly, IPSS has been used in patients with ACTH-dependent Cushing's syndrome who did not present a clear pituitary lesion, even though testing was indicative of a pituitary lesion. This approach is burdened by the low prevalence of visible pituitary tumors in patients with Cushing's disease; indeed, even the most sensitive pituitary imaging techniques proved negative in 20%–50% of patients in whom an ACTH-secreting adenoma was confirmed by surgery.⁴⁴ Furthermore, incidental pituitary lesions have been described in the general population,¹⁹ in patients with ectopic ACTH secretion,^{1,3,21} and in patients with Cushing's disease.⁸ With respect to this latter group, this observation is supported by the fact that concordance between adenoma site prediction at imaging and location at pituitary surgery is by no means absolute (i.e., has been reported to be as low as 50%).⁸ Reported data refer to imaging performed mostly prior to the advent of newer, more sensitive MRI equipment (1.5-, 3-, and in the future even 7-T units), and findings could therefore change over the next few years. Whether the increased sensitivity for these small adenomas is offset by an increased detection rate of pituitary incidentalomas remains to be seen.

On the other hand, in patients with a high likelihood of Cushing's disease and without visible evidence of a pituitary adenoma, IPSS may provide adjuvant information to the neurosurgeon rather than be required to complete the diagnostic work-up. The main challenge in these pa-

tients is in fact careful exploration of the pituitary gland in search of a microadenoma. Most authors agree that IPSS should, at most, suggest the side of the gland to be explored first; however, a thorough exploration is usually recommended even after an initial finding because contralateral ACTH-secreting pituitary adenomas have been described.¹³ As to technical issues, pituitary gland exploration requires specific training: one possible, quite common pitfall is to interpret small seepage due to pituitary tissue manipulation or squeezing as a microadenoma.⁵¹ Color and consistency of the tumor are easily recognized by the experienced neurosurgeon, as ACTH-secreting adenomas are usually whitish and soft. Further, care should be taken during tumor collection to avoid inadvertent tumor specimen aspiration. Filters in the suction system may be of use to collect aspirated surgical specimens, but these are often too small for pathology, thus definite proof of tumor removal is not obtained. No study has yet evaluated whether more extensive pituitary exploration due to misleading or absent lateralization at IPSS is linked to postsurgical hypopituitarism, but this is not an unreasonable assumption. This argument may prove particularly significant in children with Cushing's disease, in whom pituitary imaging is often inconclusive.²⁵

As regards the influence of IPSS on remission rates, both older⁵ and more recent²⁴ studies have shown that outcome of pituitary surgery is comparable in patients who have or have not undergone IPSS prior to surgery. Moreover, detection of the pituitary adenoma and remission were also extensively proven in patients with negative central/peripheral ratios (see Table 1); indeed, proof of Cushing's disease by either was a prerequisite to assert a false-negative result. Thus, negative IPSS does not appear to affect likelihood of remission.

Conclusions

The endocrinologist, neuroradiologist, and neurosurgeon have different but overlapping expectations from IPSS. The endocrinologist might need to confirm the diagnosis, the neuroradiologist to locate the adenoma, and the neurosurgeon to direct pituitary surgery. Altogether, these requirements establish the framework for the role of IPSS in Cushing's syndrome, as discussed by members of the Italian Society for Endocrinology (SIE), Italian Society for Neurosurgery (SINCh), and Italian Society for Neuroradiology (AINR) during the meeting “Altogether to Beat Cushing's Syndrome.”

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