

Review Article

Snowman Sign in Pituitary Macroadenoma — A Contemporary Review

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Abstract: The “snowman sign” (also described as a “figure-of-eight” or “dumbbell” configuration) is a classic neuroradiologic appearance encountered with many suprasellar-extending pituitary macroadenomas. It results when a soft, expanding Sellar mass protrudes through the Sellar diaphragm and becomes bilaterally indented by the diaphragma sellae, producing a constricted waist and two lobulated compartments on coronal or sagittal imaging. Although not pathognomonic, recognition of the snowman configuration is clinically useful: it suggests an intra- and suprasellar origin, favors pituitary adenoma over many other Sellar/suprasellar masses, guides preoperative planning (including endoscopic transsphenoidal approaches), and helps predict relationships with the optic apparatus, cavernous sinuses, and diaphragmatic attachment. This review summarizes the anatomic basis of the sign, imaging appearances across modalities (MRI and CT), differential diagnoses and discriminating imaging features, clinical and surgical implications, limitations of the sign, and areas for future work. Representative contemporary case reports and pictorial reviews are used to illustrate the sign and its utility in modern practice.

Keywords: snowman sign, pituitary macroadenoma, diaphragma sellae, figure-of-eight sign, pituitary MRI

1. INTRODUCTION

Pituitary macroadenomas — conventionally defined as pituitary adenomas measuring 10 mm or greater in maximum diameter — are the most frequent cause of Sellar and suprasellar mass effect in adults and a leading indication for transsphenoidal surgery [1]. These tumors produce clinical morbidity through a combination of endocrine dysfunction (hypersecretion or hypopituitarism) and mass effect on adjacent structures, most notably the optic apparatus. Magnetic resonance imaging (MRI) is the modality of choice for anatomic delineation, characterization of tumor extent, and presurgical planning; standard MRI descriptors (size, suprasellar and para Sellar extension, cavernous sinus invasion, presence of cystic change or hemorrhage) guide both prognostication and operative strategy [2,3]. Contemporary imaging classifications such as the SIPAP system (which records extension in superior, inferior, anterior, posterior and para Sellar directions) and other MRI-based grading schemes remain widely used to standardize reporting and surgical decision-making. Among the classic structural appearances taught in neuroimaging is the so-called “snowman” (or “dumbbell”/ “figure-of-eight”) configuration of a pituitary macroadenoma with suprasellar extension. This configuration results from bilateral indentation of the superior margin of a soft, expanding pituitary lesion by the diaphragma sellae as the tumor herniates through the dural aperture into the suprasellar cistern, producing a waist-like constriction between two bulbous compartments [4,5,6]. The snowman sign has enduring teaching value because it not only suggests pituitary origin of a Sellar/suprasellar mass but also conveys information about diaphragmatic

competence and likely tumor relationships to the optic chiasm and suprasellar cistern. Radiologic case series and pictorial reviews continue to document the sign across a spectrum of pituitary pathologies, and acute events such as tumor hemorrhage (pituitary apoplexy) may transiently alter this morphology while often preserving the underlying topographic clue. Anatomically, the diaphragma sellae is a dural fold that forms the roof of the Sella turcica and is pierced centrally by an aperture for the pituitary stalk. The size and elasticity of this aperture vary between individuals and can determine the path of least resistance for expanding pituitary lesions. When the diaphragm is relatively competent and its aperture narrow, suprasellar tumor growth tends to be channeled through the dural opening, producing the characteristic hourglass contour. By contrast, an incompetent diaphragm or a wider aperture may permit more uniform suprasellar expansion without a pronounced waist [7]. Morphometric MRI studies and cadaveric/anatomical investigations have demonstrated measurable variation in diaphragmatic geometry that correlates with patterns of tumor protrusion, Sella remodeling, and the likelihood of cerebrospinal fluid (CSF) fistula at surgery — findings that underscore the anatomic basis for imaging morphology and have practical implications for operative planning. The final structural appearance of a macroadenoma on MRI is, however, not solely a function of diaphragmatic anatomy. Tumor-intrinsic properties — including cellular consistency (soft/gelatinous vs. fibrous), growth velocity, internal cystic degeneration or necrosis, and prior intra tumoral hemorrhage — influence how the lesion deforms under dural constraints. Slow, indolent growth commonly produces more lobulated margins and allows the diaphragm to gradually indent the mass, whereas rapid expansion or apoplexy may create irregular contours and heterogeneous signal characteristics that transiently obscure classic external contours [8]. Moreover, asymmetric adhesions to the diaphragm, invasion into the cavernous sinus, or preferential lateral growth may produce departures from the symmetric “snowman” shape and complicate preoperative inference of surgical corridors and risk. These nuances explain why structural descriptors must be interpreted in the context of signal characteristics on T1/T2 and contrast-enhanced sequences, and (where available) advanced imaging biomarkers. Accurate radiologic differentiation between pituitary adenomas and other Sellar-suprasellar lesions is clinically important because management strategies differ substantially. The snowman configuration is useful but not pathognomonic: certain meningiomas, craniopharyngiomas, and Rathke cleft cysts can mimic a rounded suprasellar mass, and heterogeneous enhancement after contrast may reflect cystic components or hemorrhage rather than neoplastic heterogeneity. Large series that analyzed imaging features across Sellar pathologies have found that combinations of morphology (including a waist-like constriction), enhancement homogeneity, relation to the pituitary gland and stalk, and presence of calcification or cystic contents improve discrimination [9]. Consequently, radiology reports that explicitly comment on diaphragmatic indentation, stalk displacement, optic chiasm position, and signs of cavernous sinus invasion provide actionable detail to neurosurgical and endocrinologic teams. The implications of diaphragmatic morphology and suprasellar configuration extend into contemporary surgical practice. Endoscopic endonasal transsphenoidal approaches have evolved to address a wide range of pituitary and suprasellar lesions; surgical planning requires anticipation of whether the suprasellar component lies extradurally beneath an intact diaphragm or has breached into the subarachnoid/intradural space, whether the diaphragm is draped tightly over the tumor dome, and whether reconstruction of the skull base may be required to prevent postoperative CSF leak. Recent surgical series and comparative outcome studies have emphasized the importance of preoperative MRI in predicting resect ability, risk of hypothalamic or optic apparatus injury, and postoperative endocrine outcomes; standardized radiologic grading of suprasellar extension correlates with these clinical endpoints and informs the choice between a purely endonasal route and combined or transcranial strategies for giant or complex lesions. Finally, imaging research in pituitary adenomas is rapidly incorporating quantitative techniques that may augment or supersede purely structural signs. Radiomics and texture analysis applied to pituitary MRI aim to extract subvisual features that predict

hormonal activity, tumor consistency (which can affect the ease of surgical debulking), propensity for cavernous sinus invasion, and likelihood of recurrence. While initial studies show promise, systematic reviews highlight methodological heterogeneity, single-center biases, and limited external validation — indicating that integration of radiomics into routine clinical workflows will require larger multicenter prospective validation studies and harmonized imaging protocols [10]. Meanwhile, MRI-based classifications such as SIPAP remain pragmatic tools for multidisciplinary communication and case stratification in both clinical practice and research. In summary, the “snowman” configuration of suprasellar pituitary macroadenomas encapsulates an interplay between tumor biology and diaphragmatic anatomy that has persisted as a practical imaging indicator despite advances in MRI resolution and surgical technique. Recognition of this morphology — together with a structured assessment of diaphragmatic competence, optic chiasm relationship, cavernous sinus involvement and intra tumoral characteristics — refines differential diagnosis, guides surgical planning, and frames contemporary investigational efforts aimed at prognostic imaging biomarkers. This manuscript seeks to (1) synthesize contemporary radiologic and surgical literature on diaphragmatic interactions in pituitary macroadenomas, (2) examine how structural descriptors correlate with surgical exposure and outcomes, and (3) explore emerging imaging techniques that could improve preoperative risk stratification and individualized management.

2. Imaging Appearances and Modalities

Pituitary macroadenomas—classically defined as pituitary tumors with a maximum diameter ≥ 10 mm—are among the most frequent Sellar and suprasellar masses encountered in adult neuroendocrine practice. They produce morbidity both by hormone hypersecretion or hypopituitarism and by mass effect on adjacent structures, especially the optic apparatus, cavernous sinus, and hypothalamus. Precise preoperative imaging therefore underpins diagnostic differentiation, prognostication and surgical planning. Magnetic resonance imaging (MRI) is the imaging modality of choice for pituitary lesions: high-resolution T1-weighted sequences before and after gadolinium, supplemented with thin-slab coronal reconstructions and dynamic contrast-enhanced series, best define tumor extent, internal composition and relationships to the diaphragma sellae, optic chiasm, and cavernous sinuses [3]. Recent technical advances—such as submillimeter thin-slice protocols and deep learning–based reconstruction—have significantly improved delineation of small residual gland, tumor margins, and parameters relevant to cavernous sinus assessment, thereby enhancing preoperative risk stratification. A widely taught imaging indicator in pituitary radiology is the “snowman” or hourglass configuration, produced when an expanding, soft pituitary macroadenoma herniates superiorly through the diaphragmatic aperture into the suprasellar cistern and is symmetrically indented by the diaphragma sellae to create a constricted “waist” between two rounded lobes [6]. This sign is most conspicuous on coronal T1-weighted gadolinium-enhanced sequences but may also be appreciated on sagittal cuts; dynamic contrast sequences and thin-slice coronal reconstructions typically afford the clearest depiction of diaphragmatic indentation. The snowman appearance remains clinically useful because it suggests a pituitary (Pit NET) origin rather than an extra-axial (e.g., meningeal) or primary suprasellar lesion, and it implies a particular diaphragmatic geometry that has practical relevance for endoscopic exposure and skull-base reconstruction. Despite the educational clarity of the snowman sign, macroadenoma morphology on MRI is modulated by multiple interacting factors. Tumor signal intensity is often isointense to gray matter on both T1- and T2-weighted images, and many macroadenomas show moderate, and sometimes relatively homogeneous, contrast enhancement compared with meningiomas or sinonasal extra-axial lesions. Nevertheless, internal heterogeneity frequently arises from cystic degeneration, necrosis, or prior hemorrhage (pituitary apoplexy), each of which can alter T1/T2 signals and transiently obscure the classic lobulated outline [2]. Apoplexy in particular produces heterogeneous, often blood-product–dependent signal patterns that complicate structural

interpretation and may demand urgent clinical attention. Consequently, accurate interpretation of external tumor contour requires correlation with intra tumoral signal characteristics and, when available, dynamic enhancement kinetics. Anatomic variability of the diaphragma sellae and the size of its central aperture are additional determinants of suprasellar configuration. A relatively narrow or elastic diaphragmatic aperture tends to channel upward growth into a constricted neck with prominent suprasellar bulging, producing the archetypal snowman or dumbbell shape; conversely, a wide or lax diaphragm allows smoother, less constricted expansion [1]. Cadaveric and morphometric MRI studies have documented interindividual variation in diaphragmatic geometry that correlates with patterns of tumor protrusion, degree of Sella remodeling, and potential for cerebrospinal fluid (CSF) communication at surgery — considerations that inform both approach selection and skull-base reconstruction strategies. Ultimately, the external contour seen on imaging is the phenotypic product of diaphragmatic anatomy combined with tumor consistency, growth rate, and any asymmetric adhesions or para Sellar invasion. Cavernous sinus invasion is a pivotal factor affecting operative planning and the extent of safe resection. The Knosp grading system—widely adopted in clinical practice and incorporated into many imaging reports—uses para Sellar relationships on coronal sequences to predict the likelihood of cavernous sinus invasion and thereby inform surgical strategy. Meta-analytic studies demonstrate reasonable pooled performance of Knosp grading for predicting intraoperative cavernous sinus involvement, but they also highlight heterogeneity across series and the potential incremental value of thin-slice high-resolution MRI for more accurate assessment [4]. Advanced imaging protocols that increase spatial resolution or incorporate vessel-sparing reconstructions improve visualization of carotid encasement and may influence the decision between purely endoscopic endonasal resection, staged approaches, or adjunctive radiosurgery. Computed tomography (CT) retains a complementary role when MRI is contraindicated or when assessment of osseous anatomy or calcification is required. CT more sensitively reveals Sellar and clival bony remodeling, erosion of the sphenoid sinus and anterior skull base, and chondroid or calcified components (for example, craniopharyngioma), while contrast-enhanced CT may occasionally reproduce the snowman silhouette in sufficiently large suprasellar masses. For preoperative planning—especially when extensive bony work or odontoid-like remodeling is anticipated—CT and bone-window imaging remain helpful adjuncts to MRI [3]. Beyond structural assessment, contemporary research increasingly seeks quantitative imaging biomarkers to predict biologic behavior and surgical characteristics. Radiomic texture analyses, diffusion and perfusion metrics, and machine-learning approaches have shown preliminary associations with hormonal activity, tumor consistency (important for predicting ease of suction/curettage), and recurrence risk; however, the field is nascent and limited by single-center datasets and methodological heterogeneity [5]. Until robust, externally validated imaging biomarkers are available, structured MRI reporting that emphasizes diaphragmatic indentation, stalk displacement, optic chiasm relationship, cavernous sinus grading and intra tumoral heterogeneity remains the most practical foundation for multidisciplinary decision-making. In this context, the snowman configuration functions as both a teaching image and a concise surrogate for a constellation of anatomic and tumor-specific variables that shape management. Recognition of the sign—when interpreted alongside thin-slice, contrast-enhanced coronal and sagittal MRI sequences, dynamic enhancement patterns and careful assessment for hemorrhage or cystic change—helps narrow the differential diagnosis, forecast operative exposure and potential reconstruction needs, and prioritize multidisciplinary planning between neurosurgery and endocrinology. This paper aimed to synthesize contemporary imaging and surgical literature regarding diaphragmatic interactions in pituitary macroadenomas, to quantify how structural descriptors (including the snowman sign) correlate with cavernous sinus invasion and surgical outcomes, and to evaluate emerging high-resolution and quantitative MRI techniques that may refine preoperative prediction of tumor behavior.

3. DIFFERENTIAL DIAGNOSIS AND DISTINGUISHING FEATURES

Pituitary macroadenomas—tumors with a maximal diameter ≥ 10 mm—are a leading cause of Sellar and suprasellar masses in adults. They produce clinical morbidity by endocrine dysfunction (either hormone hypersecretion or hypopituitarism) and by mass effect on neighboring structures, most critically the optic apparatus, cavernous sinuses, and hypothalamus [7]. High-quality preoperative imaging therefore underpins accurate diagnosis, differential consideration, surgical planning, and prognosis. Magnetic resonance imaging (MRI) is the modality of choice for pituitary lesions: contrast-enhanced T1-weighted sequences with thin coronal slices, dynamic contrast runs, and dedicated sagittal planes offer optimal anatomic and tissue characterization, while high-resolution protocols improve delineation of diaphragmatic relationships, stalk displacement, and cavernous sinus involvement. Computed tomography (CT) remains complementary when MRI is contraindicated or when assessment of calcification and bony remodeling is required. A classic, widely taught structural sign of suprasellar extension is the “snowman” (or dumbbell/figure-of-eight) configuration. On coronal and sagittal contrast-enhanced T1-weighted MRI, a macroadenoma that has herniated through the diaphragmatic aperture may present as two rounded lobes separated by a narrowed waist at the level of the diaphragma sellae. This hourglass silhouette arises when the tumor’s soft, expansile tissue is symmetrically indented by the dural fold as it is pushed upward into the suprasellar cistern [8]. The snowman sign is most conspicuous on coronal gadolinium-enhanced images and is best appreciated on thin-slice coronal reconstructions and dynamic enhancement sequences that accentuate the diaphragmatic indentation. Because the sign simultaneously indicates pituitary origin and a particular diaphragmatic geometry, it conveys useful information about likely relationships to the optic chiasm, the stalk, and the suprasellar cistern—details that meaningfully influence endoscopic exposure and skull-base reconstruction strategies. Despite its teaching value, the snowman configuration is not absolutely specific for pituitary adenoma. The structural phenotype seen on neuroimaging is the net result of several interacting variables: diaphragma sellae anatomy (aperture size and elasticity), tumor consistency (soft/gelatinous versus fibrous), growth velocity, presence of cystic degeneration or hemorrhage, asymmetric adhesions, and para Sellar invasion such as cavernous sinus encroachment [9]. Slow-growing adenomas more commonly permit gradual diaphragmatic indentation and classic lobulated outlines, whereas rapid expansion or pituitary apoplexy (intra tumoral hemorrhage) often produces heterogeneous signal patterns that can transiently obscure familiar contours. Many macroadenomas are isointense to gray matter on T1 and T2 and enhance variably—some relatively homogeneously compared with extra-axial meningeal lesions—so interpretation of external contour should always be correlated with internal signal characteristics and enhancement dynamics [10]. Distinguishing pituitary macroadenomas from other Sellar/suprasellar pathologies is critical because management and prognosis differ substantially. Important differentials include:

- Craniopharyngioma — Tend to show mixed cystic and solid components and frequently contain calcification that is readily seen on CT. Cyst fluid may be T1-hyperintense (proteinaceous or oily contents), and the bimodal age distribution (children and older adults) together with CT evidence of calcification are valuable distinguishing clues.
- Rathke’s cleft cyst — Typically a midline cystic lesion within the pituitary, often with variable T1 signal depending on cyst contents, and usually demonstrating minimal or no internal enhancement. A thin, non-enhancing epithelial rim and midline location help separate Rathke’s cleft cysts from enhancing adenomatous tissue.
- Suprasellar/planum sphenoidale meningioma — Classically extra-axial and dural-based, meningiomas usually show strong homogeneous enhancement and often preserve a distinct normal pituitary gland.

They may have a dural tail and cause hyperostosis of adjacent bone; true diaphragmatic indentation producing a symmetric snowman waist is less characteristic of meningioma.

- Hypothalamic/chiasmatic glioma — More common in children and often associated with pilocytic histology; these lesions tend to be intrinsic to the optic pathway or hypothalamus and lack the well-defined Sellar origin typical of pituitary adenomas.
- Lymphocytic hypo physitis — May present with symmetric pituitary enlargement and stalk thickening, commonly in a postpartum or autoimmune context; contrast enhancement and clinical history (e.g., recent pregnancy, autoimmune disease) are helpful discriminators.

When the snowman configuration is combined with other imaging markers—contrast-enhancement pattern, presence or absence of calcification, patient age, hormone profile, and careful assessment for cavernous sinus invasion—radiologists can often favor an adenoma diagnosis while acknowledging residual diagnostic uncertainty. Retrospective imaging series indicate that combining structural signs such as diaphragmatic waisting with contrast dynamics and anatomic markers (stalk displacement, optic chiasm relationship) increases diagnostic specificity. Cavernous sinus invasion, typically graded by the Knosp system on coronal MRI, is a pivotal determinant of achievable resection and operative risk. High-resolution thin-slice imaging improves detection of carotid encasement and para Sellar invasion and thus refines preoperative counseling and selection of surgical approach [11]. The endoscopic endonasal corridor has expanded indications for managing many macroadenomas with predominant midline and suprasellar components, but accurate preoperative assessment of diaphragmatic competence (e.g., whether the tumor is intradural beneath an intact diaphragma or has breached the subarachnoid space), cavernous sinus involvement, and optic apparatus displacement remains essential for selecting between purely endonasal, combined, or transcranial strategies and for anticipating the need for robust skull-base reconstruction to prevent cerebrospinal fluid leak. Beyond conventional structural descriptors, contemporary research increasingly explores quantitative MRI biomarkers to predict biologic behavior and surgical characteristics. Radiomic texture analysis, diffusion metrics, perfusion imaging, and machine-learning classifiers have shown preliminary associations with hormonal activity, tumor consistency (which correlates with intraoperative ease of debulking), and recurrence risk [12]. These techniques are promising but remain constrained by single-center datasets, protocol heterogeneity, and limited external validation. For the present, structured MRI reporting that emphasizes diaphragmatic indentation (the presence or absence of a constricted waist), stalk displacement, optic chiasm relationship, Knosp grading, and intra tumoral heterogeneity offers the most pragmatic and reproducible basis for multidisciplinary decision-making. In sum, the snowman configuration is a useful imaging indicator that encapsulates the interplay between diaphragmatic anatomy and tumor biology, but it must be interpreted within a broader diagnostic and surgical context [13]. Accurate recognition of this morphology—when integrated with thin-slice contrast-enhanced MRI, dynamic contrast sequences, CT where indicated, and clinical-hormonal data—helps narrow the differential diagnosis, forecast operative exposure, and prioritize perioperative planning between neurosurgery and endocrinology [14,15]. This paper reviews contemporary radiologic and surgical literature on diaphragmatic–tumor interactions in pituitary macroadenomas, evaluates how structural descriptors (including the snowman sign) correlate with cavernous sinus invasion and surgical outcomes, and examines emerging imaging techniques that may refine preoperative prediction and individualized management.

4. CLINICAL AND SURGICAL IMPLICATIONS

Recognition of the snowman sign carries immediate and actionable clinical implications. Radiologic identification of a bilobed intra- and suprasellar lesion should promptly trigger targeted endocrine

evaluation — at minimum serum prolactin, GH and IGF-1, morning cortisol/ACTH (and dynamic testing as indicated), and TSH/free T4 — because tumor subtype directs both medical and surgical management [15]. Concurrent formal ophthalmologic assessment (visual acuity, formal perimetry) is essential whenever suprasellar extension approaches or displaces the optic chiasm, since even subtle visual field defects may change the urgency and scope of intervention. For the neurosurgeon, the snowman morphology conveys important anatomic and technical clues that influence approach selection and intraoperative strategy. A largely midline, soft, bilobed adenoma that demonstrates a constricted diaphragmatic waist often permits descent of the suprasellar component into the endonasal transsphenoidal corridor after debulking of the intrasellar portion, facilitating a more complete resection while minimizing brain retraction [16]. By contrast, features that predict surgical complexity — firm or fibrotic tumor consistency, marked lateral para Sellar extension with Knosp-grade cavernous sinus invasion, or asymmetric diaphragmatic adhesions — favor extended endonasal or combined transcranial approaches and raise the likelihood of subtotal resection with adjuvant radiosurgery [17,20]. Preoperative anticipation of diaphragmatic attachments also informs the reconstruction plan (e.g., need for vascularized flap or multilayer closure) to mitigate postoperative CSF leak risk. Finally, clinicians must interpret the snowman sign in clinical and temporal context. Acute intra tumoral hemorrhage (pituitary apoplexy) or rapid cystic change can transiently alter tumor contours and enhancement patterns, producing pseudo-lobulations that may mimic or obscure a true diaphragmatic waist [18,21]. Integrating symptom chronology, hormone trends, and repeat or advanced imaging (dynamic sequences, high-resolution coronal slices) when necessary, helps avoid misclassification and ensures that biochemical, visual, and surgical decisions are made on the most accurate anatomic and functional information available [19,22].

5. LIMITATIONS AND PITFALLS

The snowman sign should not be used in isolation to make management decisions because its sensitivity and specificity are imperfect: other Sellar/suprasellar lesions can produce similar hourglass silhouettes and small suprasellar recesses or minimal diaphragmatic indentation may fail to generate a conspicuous waist. Acute intra tumoral hemorrhage (pituitary apoplexy) or rapid cystic change frequently alters signal and contour, sometimes producing pseudo-lobulations that obscure the classic morphology; likewise, rare ectopic pituitary adenomas or large para Sellar masses may distort diaphragmatic anatomy and confound interpretation. For these reasons a full multimodal assessment is mandatory — high-resolution MRI with thin coronal and sagittal T1 pre/post-gadolinium and dynamic sequences remains the cornerstone for structural and relationship assessment, CT is useful when calcification or bony remodeling must be assessed, and formal endocrine and ophthalmologic evaluation (including targeted hormonal assays and visual field testing) must be integrated into decision-making. Structured reporting that documents diaphragmatic indentation (presence/absence of a constricted waist), stalk displacement, Knosp grading for cavernous sinus invasion, and intra tumoral heterogeneity improves communication with surgical colleagues and reduces misclassification. When imaging and clinical data remain discordant or equivocal, short-interval repeat MRI, advanced sequences, or multidisciplinary case review (neurosurgery, endocrinology, neuroradiology, ophthalmology) help avoid inappropriate or premature interventions.

6. CONCLUSION

The snowman sign remains a compact, visually intuitive neuroradiologic cue that often accompanies pituitary macroadenomas with suprasellar extension. Its mechanistic basis — symmetric indentation of an expanding intrasellar mass by the diaphragma sellae — explains why the sign favors an intrasellar origin and why it frequently signals a soft, lobulated tumor that may descend into the endonasal corridor after intrasellar debulking. Clinically, recognition of the sign prompts focused endocrine assays

and formal ophthalmologic assessment, and it contributes practical, preoperative information about diaphragmatic geometry and the likely relationship of tumor lobes to the optic chiasm. At the same time, the snowman appearance is not pathognomonic: a range of other Sellar/suprasellar entities and transient processes (apoplexy, cystic fluctuation) can mimic or obscure it. Accordingly, the sign must be interpreted within a full multimodal assessment that includes high-resolution MRI (thin-slice coronal/sagittal T1 ± gadolinium and dynamic sequences), CT when calcification or bone detail is needed, endocrine testing, and clinical context.

To move beyond teaching value and toward evidence-based integration into clinical pathways, several research priorities are clear:

- Systematic diagnostic performance studies — Prospectively collected, multi-center imaging cohorts should be used to quantify the snowman sign’s sensitivity, specificity, positive and negative predictive values, and likelihood ratios across contemporary MRI protocols and patient demographics (including children, young adults, and older adults). These studies should predefine imaging criteria for “snowman” morphology and compare imaging reads from blinded neuroradiologists to reference standards (surgical diagnosis, histopathology, or multidisciplinary consensus).
- Correlation with intraoperative and outcome metrics — Prospective registries linking preoperative morphology to intraoperative findings (tumor consistency, degree of diaphragmatic attachment, unexpected CSF communication), extent of resection, complication rates (CSF leak, visual deterioration), and functional outcomes (endocrine recovery or deficit, tumor recurrence) would clarify how much clinical weight the sign should carry in selecting endoscopic versus extended or transcranial approaches.
- Standardized imaging and reporting frameworks — Harmonized MRI acquisition parameters and a structured reporting template that systematically documents diaphragmatic indentation (presence/absence; degree), stalk displacement, optic chiasm position, Knosp grade, and intra tumoral heterogeneity would improve inter reader reliability and facilitate pooled analyses. A simple graded scale for diaphragmatic waisting (e.g., none/minimal/moderate/severe) could be tested for prognostic utility.
- Quantitative and computational approaches — Radiomics and deep-learning models offer two complementary paths: (1) radiomic texture features or diffusion/perfusion metrics might predict tumor consistency, invasiveness, or hormonal subtype; (2) convolutional neural networks could be trained to detect diaphragmatic indentation automatically and to provide probabilistic outputs (e.g., probability of pituitary origin, likelihood of cavernous sinus invasion). Any model should be developed on large, heterogeneous datasets, employ rigorous cross-validation, and be externally validated before clinical deployment.
- Implementation and decision-support studies — Once validated, imaging-assisted tools (automated flagging of snowman morphology, integration with endocrine panels and visual field results) should be evaluated in prospective clinical workflows to determine whether they improve time to diagnosis, operative planning accuracy, patient counseling, or resource utilization.

In practical terms, adopting these research priorities will require interdisciplinary collaboration among neuroradiology, neurosurgery, endocrinology, ophthalmology, and data science teams; standardized data collection; and attention to imaging harmonization and open data sharing where appropriate. By quantifying the diagnostic performance of the snowman sign, correlating it with surgical and functional outcomes, and integrating it into validated automated pipelines, the community can convert a long-standing visual indicator into a reproducible, evidence-based element of pituitary care. Until then, the

snowman sign should remain a valuable but nondefinitive clue—one piece of the diagnostic mosaic that must be weighed alongside multimodal imaging, biochemical profiling, and clinical judgment.

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