

Predicting Surgical Outcomes in Pituitary Adenomas: The Role of Radiological Classifications

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Abstract

Pituitary adenomas are common sellar tumours in which transsphenoidal surgery is often the main treatment. Surgical resection largely depends on extrasellar extension, especially cavernous sinus involvement, making radiological classifications important for operative planning and patient counselling. This review summarizes evidence on the Hardy-Wilson and Knosp classifications (including revised Knosp) for predicting extent of resection. Hardy-Wilson grading describes sellar changes and suprasellar extension but has limited value for assessing parasellar invasion on modern MRI. The Knosp classification, based on the tumour's relationship to the internal carotid artery, more directly estimates cavernous sinus invasion and correlates with gross total resection rates. Studies consistently show reduced resection and remission with higher Knosp grades, while the revised Knosp subdivision (3A/3B) improves its predictive value. Overall, revised Knosp is more reliable for outcome prediction in contemporary endoscopic practice.

DOI: <https://doi.org/10.47391/JPMA.26-22>

Introduction

Pituitary adenomas (PA), are common benign sellar tumours that may present with endocrine symptoms, mass effect, or apoplexy.¹ Studies suggest that PAs have a rising incidence and a substantial burden, partly due to wider availability of neuroimaging.² Progressive tumour expansion may cause visual field deficits (due to optic chiasm compression), headache, and variable degrees of hypopituitarism; functioning adenomas also present as endocrine syndromes.³ Most of the symptomatic PAs are macroadenomas (≥ 1 cm) and transsphenoidal surgery remains the primary treatment, with the goal ranging from decompression and tumour control to hormonal remission, depending on tumour subtype.⁴ Extent of resection is strongly influenced by tumour extension beyond the sella, particularly parasellar growth and

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cavernous sinus involvement. For this reason, radiological grading systems are widely used to describe tumour extension and guide operative planning regarding the likelihood of gross total resection (GTR). The two most commonly used classifications are the Hardy-Wilson classification; which evaluates sellar and extrasellar extension, while the Knosp classification estimates cavernous sinus invasion by assessing the tumour's relationship to the internal carotid artery (ICA) (Table 1,2 and Fig 1).⁵

This review summarizes and compares the studies reporting Hardy-Wilson and Knosp (including revised Knosp) with a focus on their relevance in modern pituitary adenoma surgery and predictive value for extent of resection.

Review of Literature

With transsphenoidal surgery as the standard approach for most pituitary adenomas, preoperative imaging remains central to surgical decision-making. Over time, radiological classification systems evolved from simply describing tumour size to estimate tumour extension and predict the resectability, particularly in areas like cavernous sinus where resection can be limited.^{6,7} These classifications translate preoperative images into clinically meaningful categories that could guide surgical planning and help counsel patients regarding expected surgical outcomes.

Hardy-Wilson classification is one of the earliest and most widely recognized systems used to classify PAs. It combines two key elements: sellar floor invasion (Grade 0-IV) and suprasellar extension (Stage A-E) (Table 1). Higher grades reflect increasing bone destruction, while higher stages describe progressive extrasellar extension.⁷ In practice, Hardy-Wilson remains useful particularly for characterizing suprasellar growth patterns, which may relate to optic chiasm compression and operative complexity. However, it was developed in an era before high-resolution MRI and was not specifically designed to assess parasellar anatomy or cavernous sinus invasion in detail. As a result, it may be less reliable when the key surgical question is whether the tumour has entered the cavernous sinus.⁸

In contrast, the Knosp classification was introduced to address cavernous sinus invasion using MRI-based

Table-1: Hardy-Wilson radiological classification of pituitary adenomas

Component	Grade/ Stage	Radiological description	Surgical relevance
Sellar floor invasion (Grade)	Grade 0	Normal sella; no sellar floor invasion	High likelihood of GTR
	Grade I	Focal enlargement of the sella	Usually resectable
	Grade II	Diffuse enlargement of the sella, but the floor is intact	May increase surgical complexity
	Grade III	Localized erosion/ destruction of the floor	Reduced likelihood of GTR
	Grade IV	Extensive destruction of the floor with skull base involvement	Often limits GTR
Suprasellar extension (Stage)	Stage A	Minimal suprasellar extension	Low risk of optic apparatus compression
	Stage B	Tumour reaches optic chiasm	Moderate surgical complexity
	Stage C	Significant suprasellar extension with chiasmal displacement	Increased risk of visual compromise
	Stage D	Asymmetric parasellar extension	High surgical complexity
	Stage E	Massive lateral extension into cavernous sinus	Low GTR rates

The Hardy-Wilson classification primarily describes sellar and suprasellar tumour extension, with higher stages (D & E) indicating lateral/ parasellar spread, and was developed before high-resolution MRI became standard. Abbreviations: GTR = gross total resection.

Table-2: Knosp and the revised Knosp classification of cavernous sinus invasion.

Knosp grade	Radiological relationship to ICA (Coronal MRI)	Cavernous sinus invasion	Expected surgical outcome
Grade 0	Tumour does not reach the medial ICA tangent	Absent	Very high likelihood of GTR
Grade 1	Tumour crosses the medial ICA tangent but does not cross the intercarotid line	Unlikely	High likelihood of GTR
Grade 2	Tumour crosses the intercarotid line but does not cross the lateral ICA tangent	Possible	Moderately reduced GTR rates
Grade 3A	Tumour crosses the lateral ICA tangent and extends to the superior cavernous sinus compartment	Likely	Intermediate GTR rates
Grade 3B	Tumour crosses the lateral ICA tangent and extends to the inferior cavernous sinus compartment	Highly likely	Low GTR rates
Grade 4	Complete encasement of intracavernous ICA	Definite	GTR rarely achievable

The revised Knosp classification subdivides Grade 3 into 3A (superior) and 3B (inferior) parasellar extension, which are associated with significantly different rates of cavernous sinus invasion and surgical resectability. Abbreviations: ICA = internal carotid artery, MRI = Magnetic resonance imaging, GTR = gross total resection.

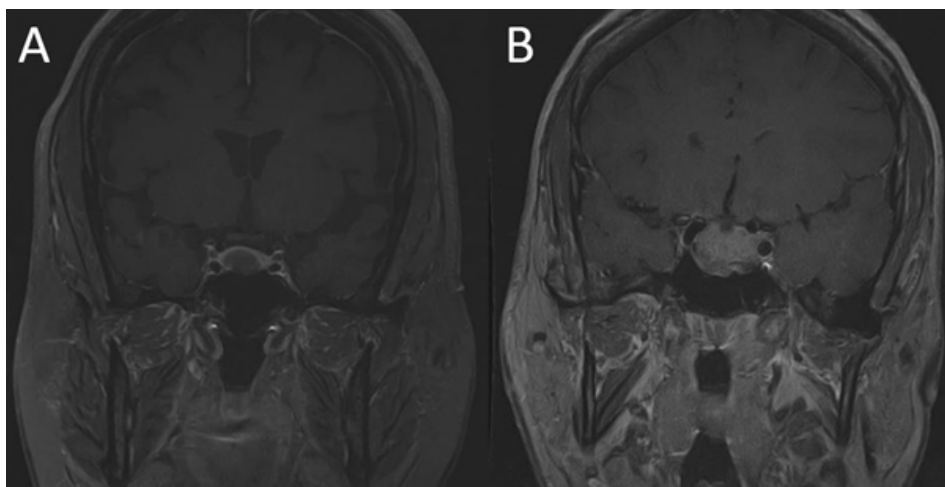


Figure: Representative coronal contrast-enhanced T1-weighted MRI images of pituitary adenomas with corresponding Hardy-Wilson and Knosp classifications. Figure 1A: Pituitary adenoma confined to the sella with minimal suprasellar extension and no radiological evidence of cavernous sinus invasion, consistent with Hardy-Wilson stage A and Knosp grade 1. Figure 1B: Pituitary macroadenoma with suprasellar and parasellar extension, consistent with Hardy-Wilson stage D and Knosp grade 3A.

parasellar landmarks.⁸ This classification grades tumour extension relative to the ICA, ranging from Grade 0 (no cavernous sinus extension) to Grade 4 (complete ICA encasement) (Table 2). This classification has become a widely adopted tool because it is directly aligned with cavernous sinus involvement - one of the most important predictors of the resection.⁵ In 2015, Micko et al., refined this classification subdividing Grade 3 into 3A (predominantly superior compartment) and 3B (predominantly inferior compartment). They also reported substantially higher invasion rates in Grade 3B

tumours and lower GTR rates compared with Grade 3A, supporting that the direction of parasellar extension reflects surgically different behaviour.⁹

Representative coronal MRI images illustrating commonly encountered Hardy-Wilson and Knosp grades are shown in Figure 1.

In contemporary endoscopic practice, Hardy-Wilson grading can still be applied on MRI, but studies reassessing its use found that overall inter-rater reliability could be acceptable, but agreement was weak in intermediate grades/categories.¹⁰ This limits its reliability as a predictive tool when surgeons need consistent estimates of invasiveness and expected extent of resection. The Knosp grading, on the other hand, is built around parasellar MRI anatomy, making it better suited to modern endoscopic approaches where cavernous sinus extension is the key determinant of whether complete resection is feasible.

In a prospective study by Rouf et al., patients diagnosed with non-functioning pituitary adenoma were evaluated using both the Knosp and revised Knosp classifications. Patients with higher Knosp grades (>2) experienced more pronounced clinical symptoms and were less likely to achieve surgical remission ($P = 0.008$), whereas the revised Knosp system (3A/3B distinction) demonstrated superior predictive value for remission.¹¹ Expanding on this, Micko et al., analyzed 106 high-grade pituitary adenomas (Grades 3A–4) and found that the invasion varied significantly with the parasellar extension pattern. Grade 3A tumours which are limited to the superior cavernous sinus compartment achieved significantly higher rates of remission and gross total resection (64%) than Grades 3B–4.⁹ This study confirmed that distinguishing between 3A and 3B subtypes is clinically meaningful for predicting surgical outcomes. It also demonstrated that higher Knosp grades (3–4) are significantly associated with reduced rates of GTR, validating the prognostic value of this classification.

The only study directly comparing Knosp, revised Knosp, and Hardy–Wilson classifications for predicting outcomes following endoscopic endonasal transsphenoidal (EET) surgery showed that Knosp classification provided the highest diagnostic accuracy (AUC 0.820) for predicting surgical cure, compared with the lower utility of the Hardy-Wilson classification for this purpose (AUC 0.654)⁵

Conclusion

Hardy-Wilson is useful for describing overall tumour configuration, especially suprasellar extension and sellar

changes, while revised Knosp grading more directly informs the likelihood of GTR by estimating cavernous sinus invasion. Despite their usefulness, radiological grading systems are not perfect predictors of surgical outcome. Surgical results are influenced by factors beyond anatomy, including tumour consistency, volume, primary versus revision surgery, and surgeon's expertise. Therefore, grading systems should be viewed as tools for risk stratification and counselling rather than absolute determinants of resectability.

Disclaimer: None.

Conflict of Interest: None.

Source of Funding: None.

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