Review

Lentigo Maligna: Contemporary Surgical Management and Outcome: A Review

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AIM: Lentigo maligna (LM) is the commonest melanoma *in situ* variant and frequently arises on chronically sun-exposed facial skin, where subclinical radial spread and background actinic melanocytic atypia complicate both surgical clearance and histological interpretation. The aim of this study is to appraise contemporary surgical options for LM and their oncological outcomes, focusing on conventional wide local excision (WLE), Mohs micrographic surgery (MMS), Paraffin embedded margin-controlled ("slow Mohs") techniques and staged excision (SE).
METHODS: A comprehensive search of PubMed and Web of Science (January 2015–January 2025) retrieved retrospective cohorts, systematic reviews and meta-analyses that detailed technique, margin policy and outcomes for LM or lentigo maligna melanoma (LMM). Forty-six studies met prespecified criteria and were synthesised qualitatively.
RESULTS: WLE remains the most widely performed procedure but showed the greatest heterogeneity in practice. Initial clinical margins of 5 mm often required histological extensions to 7–12 mm to secure clearance; under WLE, residual disease rates reached 16.7% and recurrences ranged from 5.7% to 27.3%. In contrast, MMS, especially when using immunohistochemistry, achieved recurrence rates between 0–3% with $\geq$5 years of follow-up. Slow Mohs and staged excision provided intermediate recurrence control (0–5.7%) while preserving tissue but were limited by procedural variability and delayed reconstruction. Although one retrospective study reported improved disease-specific survival with MMS, most studies showed no significant differences in melanoma-specific or overall survival across surgical techniques. Limited long-term follow-up and inconsistent statistical reporting (e.g., confidence intervals) were common.
CONCLUSIONS: Margin-controlled approaches (MMS, slow Mohs, SE) afford superior local control to WLE and are preferable for lesions on cosmetically or functionally critical sites. Because survival appears equivalent, the choice of technique should be guided by anatomical location, lesion size, available expertise, patient characteristics and preferences as well as cost-effectiveness and available resources. Well-designed prospective trials with standardised protocols are essential to refine margin recommendations and compare long-term outcomes.

Keywords: lentigo maligna; melanoma *in situ*; Mohs surgery; surgical treatment; staged excision

Introduction

Lentigo maligna (LM) is a melanoma *in situ* subtype, strongly associated with cumulative sun exposure [1, 2]. The terminology surrounding LM is controversial and varies widely in the literature. It has historically been referred to as Hutchinson's freckle, senile freckle and Dubreuilh's *melanosis circumscripta praecancerosa* [2]. More recently, alternative terms such as lentiginous melanoma *in situ*, and lentigo maligna melanoma *in situ* have been proposed to better define this entity [3]. Once LM progresses to an invasive phenotype the more commonly used designation is lentigo maligna melanoma (LMM). For consistency in this review, the term lentigo maligna (LM) will be used exclusively to refer to the in-situ stage of the disease and LMM to refer to the invasive counterpart [1].

LM is the second most common type of melanoma after superficial spreading melanoma and the most frequent form of melanoma *in situ* [4]. LM predominantly affects old individuals, likely due to cumulate lifetime UV exposure [4,5]. Clinically, LM presents as a slowly growing, irregular pigmented macule or patch, that arises in chronically sun-damaged skin [1]. From a histopathological perspective, LM is characterized by intraepidermal proliferation of atypical melanocytes, arranged irregularly in a lentiginous pattern with solar elastosis [1].

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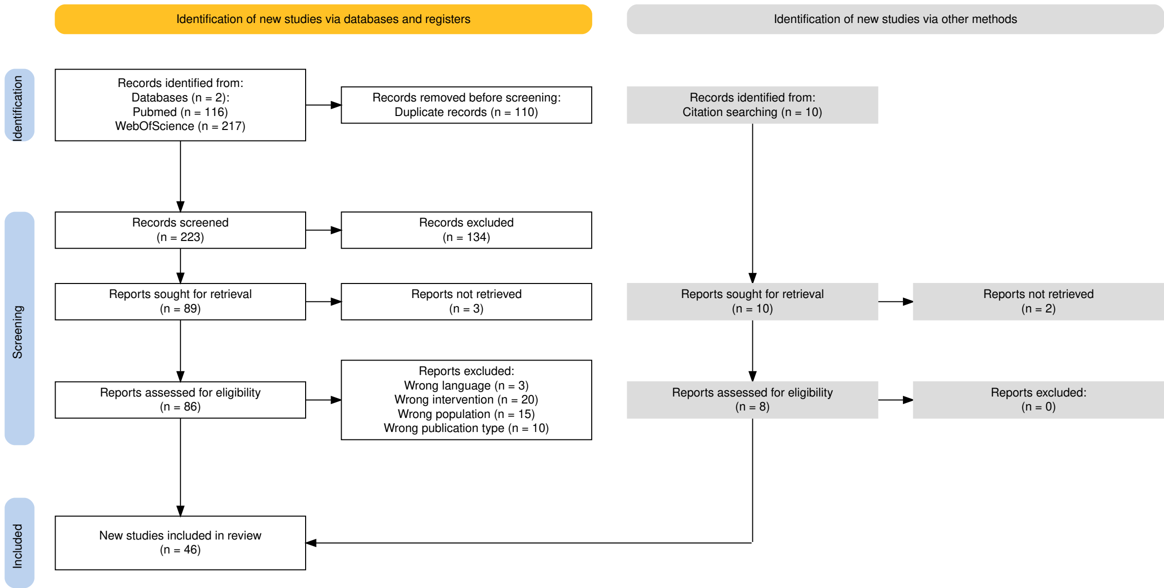

Fig. 1. PRISMA flow diagram illustrating the selection process for studies included in the review. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

Surgical excision remains the first-line treatment for LM, with options including conventional wide local excision (WLE), Mohs micrographic surgery (MMS), and staged excision (SE). These techniques aim to completely remove the lesion and prevent progression to invasive melanoma [6]. However, LM poses specific surgical challenges due to its frequent facial location and potential for subclinical extension [2,4,7]. Additionally, background melanocytic atypia in chronically sun-damaged skin makes histopathological margin assessment more difficult [8].

To date, no single surgical option has been universally recognized as superior, stressing the need for further investigation [4,7]. To address this issue, we conducted a narrative review evaluating the available surgical options for LM management. The present review summarizes findings from key studies on surgical approaches, technical variations, surgical outcomes and adherence to guidelines.

Methods

A comprehensive search was conducted in PubMed (MEDLINE) and Web of Science, covering all available publications from January 2015 to January 2025. Specific search strategies were applied to each database, integrating both MeSH terms and free-text keywords. The corresponding database search strategy is provided in the **Supplementary Material**.

Inclusion criteria encompassed: (1) Articles addressing surgical treatments for LM and LMM, describing different surgical techniques and their outcomes. (2) Retrospective observational studies, systematic reviews and meta-analysis. No restrictions were applied regarding previous or concomitant treatments. Exclusion criteria included: (1) Single case reports, (2) articles focusing only on non-excisional/destructive modalities (e.g., topical imiquimod, radiotherapy, laser or light-based therapies, cryotherapy, curettage/electrodesiccation), (3) manuscripts published in languages other than English or Spanish.

A three-stage selection process was conducted by CCS and LML. Articles were initially selected based on their titles, followed by abstract screening. Lastly, a full-text review of the selected articles was carried out, those that met the inclusion criteria were finally included. Additionally, a manual secondary search of reference lists from selected articles was also performed to identify further relevant studies. The key findings from the selected studies were qualitatively summarized. A Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)-style flow diagram (Fig. 1) illustrates the study selection process.

Results

Wide Local Excision (WLE)

WLE Technique Overview in Clinical Practice

In the included studies, WLE was primarily performed for LM/LMM in the head and neck region, though lesions on the trunk and extremities were also included [9–17]. Lesion sizes ranged widely, most of the cases reported a diameter around 1.5 cm and the smallest mean diameter reported was 0.7 cm [18]. Initial clinical margins of 0.5 cm were the most common across studies, although some authors reported margins up to 1.0 cm [8,11,12,15]. Three studies explicitly mentioned adherence to national or international guidelines when selecting surgical margin [8,11,16]. Additionally, the use of Wood's lamp for lesion delineation was noted in two studies [13,15]. Two studies reported the use of preoperative reflectance confocal microscopy [15,17] (Table 1, Ref. [8–19]).

Table 1. Studies reporting WLE included in the review.

Year	Author	Study type	N (lesions)	Lesion site	Lesion size	Initial clinical margins	Technique specifications	Clearance rate with initial margins	Histological margins for total clearance	Surgical outcomes	Other
2024	Modin *et al*. [10]	Retrospective.	395 LM.	Head and neck 82%, trunk 8.4% and extremities 9.6%.	Median lesion diameter 11 mm (2–70 mm)	Mean clinical margin 0.48 cm (0.1–1 cm).	Bread-loafing technique. IHQ used in 40%, Melan-A (n = 95, 24.1%), SOX10 (n = 81, 20.5%), S100 (n = 46, 11.6%), HMB-45 (n = 14, 3.5%), and others (n = 6, 1.5%).	83.3%.	Mean margins in complete excision 4.8 mm (95% CI 4.7–4.9) ($p = 0.042$).	Residual disease rate for specifically LM: 16.7%.	Preoperative biopsies were performed in 64.6% of all cases (n = 255). Risk factors for incomplete excision: Head and neck location ($p = 0.0014$), clinical margins <5 mm ($p = 0.040$), and use of preoperative partial biopsies ($p = 0.023$). Clinical recommendation: LMs should be excised with ≥5 mm margins, particularly in the head and neck region.
2021	Crouch *et al*. [9]	Retrospective.	382 LM.	Head and neck.	Mean maximum diameter 10.52 ± 6.54.	0.5 cm.	Bread-loafing technique. IHQ: SOX10, *MiTF*.	91.6%.	Mean 4.0 ± 2.5 mm.	Local recurrence rate 9.9% for LM. Invasive component found in 2.3% of these. Median follow-up was 32 (range 12–223) months. Recurrence-free survival: 87.9% at 5 years (95% CI: 83.0–93.0%), 67.4% at 10 years (95% CI: 56.8–79.9%).	Margin requirements: A histological margin of 3.0 mm was needed, requiring a surgical margin of 6.5 mm, which exceeds the 5 mm recommended by some national guidelines.
2022	Jackett *et al*. [19]	Retrospective.	26 LM and 12 LMM out of 640 melanomas.	Head and neck, trunk and extremities.	Median diameter non residual melanoma: 9 mm (2–60 mm) and for residual melanoma 14 (4–25 mm). LM not individuated.	Initial 0.2 mm for CEB. WLE with 0.5–1.0 cm.	Bread loafing technique.	NA.	NA.	Residual disease rate (for all melanomas) 3.1%. 5/38 LM had residual disease.	LM is an independent risk factor for residual disease, regardless of clinical margins or prior complete excision OR 10.33 (2.84–37.54) $p = 0.0004$.
2016	Bolshinsky *et al*. [18]	Retrospective.	75 LM-LMM out of 807 melanomas.	Head, neck, trunk and extremities.	Mean diameter 0.7 cm.	0.5 cm for MIS.	Bread-loafing technique.	89.3% of all LM-LMM and 8.3% of all melanomas.	NA.	Residual disease rate: 4.2% (95% confidence interval [CI] 2.9–5.8). When individuated, LM represented 23.5%.	LM was not differentiated from LMM. Lesion site was not individuated for MIS subtypes. LM is an independent risk factor for residual disease.

Table 1. Continued.

Year	Author	Study type	N (lesions)	Lesion site	Lesion size	Initial clinical margins	Technique specifications	Clearance rate with initial margins	Histological margins for total clearance	Surgical outcomes	Other
2020	Moura *et al*. [11]	Retrospective.	134 LM out of 167 MIS.	Head and neck (83%) upper limb (8%), lower limbs and trunk 9%.	NA.	0.5–1.0 cm as AAD guideline recommended.	Bread-loafing technique. IHQ Melan A (MART-1).	97.8%.	NA.	Local recurrence rate 9% median follow-up 36 months.	No significant difference between LM (8%, 11/134) and non-LM MIS (12%, 4/33); p = 0.49. Recurrence by histological margin: 14% (13/103) for ≤3.0 mm vs. 3% (2/64) for >3.0 mm margins (p = 0.049).
2016	Dika *et al*. [12]	Retrospective.	25 LM.	Head and neck.	1.5 ± 0.4 cm^2 area.	0.5–1.0 cm.	Bread-loafing technique.	NA.	NA.	Recurrence 27.3% mean follow up 110.3 months.	Higher recurrence was observed with WLE compared to MMS guided by videoscopy and standard MMS.
2015	Hou *et al*. [13]	Retrospective.	269 LM.	Head and neck.	Maximum lesion dimension 1.81 ± 1.30 cm.	0.5 cm. Woods lamp.	Bread-loafing technique. IHQ.	NA.	NA.	Residual rate: 8.2% (22/269). Recurrence rate 6% no mean follow-up. Local recurrence-free survival (WLE): 96% at 5 years (95% CI: 94–98%; n = 202), 94% at 10 years (95% CI: 91–97%; n = 91), and 94% at 15 years (95% CI: 91–97%; n = 15).	No distinction between LM and the rest of MIS subtypes. Treatment preference: For well-defined LM on the trunk and extremities with feasible primary repair, WLE is favored.
2017	Nosrati *et al*. [14]	Retrospective.	385 MIS.	Head and neck 83.5%. Trunk and extremities 16.5%.	Diameter 1.8 ± 1.5 cm.	0.5 cm.	Bread-loafing technique.	NA.	NA.	Recurrence rate 5.7%. Median follow-up 8.6 (range, 0.2–37) years. Recurrence rates (WLE): 4.1% at 5 years (95% CI: 2.5–6.8%), 6.8% at 10 years (95% CI: 4.4–10.2%), 7.3% at 15 years (95% CI: 4.8–11.0%); p = 0.07. Melanoma specific death 0.7% in WLE.	Comparison between MMS and WLE.

Table 1. Continued.

Year	Author	Study type	N (lesions)	Lesion site	Lesion size	Initial clinical margins	Technique specifications	Clearance rate with initial margins	Histological margins for total clearance	Surgical outcomes	Other
2023	Elshot *et al*. [8]	Retrospective.	LM: 27. LMM: 48 out of 385.	Head and neck.	NA.	0.5–1.0 cm as ESMO guidelines recommended.	Bread-loafing technique. IHQ: Melan-A/MART-1, SOX10, or S100.	76%.	1.5 mm (IQR 1.0–3.0) for LM and 4.1 mm (IQR 1.0–10.0) for LMM.	Local recurrence for LM: 18.5%. No distant/regional recurrence. Local recurrence for LMM: 16.7% Regional recurrence for LLM: 14.6%, regional lymph node 6.3%, distant recurrence 10.4%. Median follow-up 64 months (IQR 49–78).	All invasive component was removed with a mean margin of 6.5 mm. Guidelines adherence did not modify survival outcomes. LMM was not shown to be an independent prognostic factor for RRFS, DRFS, or MSS in the multivariate analysis. Local recurrence was significantly associated with LM/LMM ($p < 0.001$).
2023	Elshot *et al*. [15]	Systematic review and meta-analysis.	1029 LM and 326 LMM.	Head and neck 92.7% trunk and extremities.	Mean diameter 14.7 ± 5.0 mm. Mean area: 1.4 cm^2.	0.5 cm LM and 1.0 cm for LMM. HH-RCM and woods lamp.	Bread-loafing technique.	83% for LM and 78% for LMM.	Weighted mean 7.7 ± 2.0 mm.	Local recurrence rate. WLE (13%; 95% CI: 7.2% –21.6%). Weighted mean follow-up was at least 57 months.	Both LM and LMM were analyzed. No other MIS subtypes were included. No separate recurrence analysis for LM and LMM were performed because of missing data. Selection bias is possible since WLE was used more widely in LMM than the rest of techniques.

Table 1. Continued.

Year	Author	Study type	N (lesions)	Lesion site	Lesion size	Initial clinical margins	Technique specifications	Clearance rate with initial margins	Histological margins for total clearance	Surgical outcomes	Other
2019	Demer *et al*. [16]	Retrospective.	97, 8 LM (8%) and 89 (92%) LMM.	Head and neck.		0.5 cm following NCCN guidelines.	Bread-loafing technique.	97%.	NA.	Residual rate disease: 6%. Local recurrence for LM 13%. Local recurrence for LMM (Breslow <0.8): 12%. Local recurrence for LMM (Breslow >0.8): 6%. No WLE patients developed metastatic disease or died secondary to melanoma. Mean follow-up: 25 months.	*In situ* melanomas were separately analyzed from invasive melanomas but LM was not individualized. WLE subgroup was largely composed of higher stage and risk tumors.
2023	Martinez-Molina *et al*. [17]	Retrospective.	53 LM.	Head and neck.	Mean lesion size 1.2 cm.	HH-RCM used in some cases prior to excision. 0.5 cm.	Bread-loafing technique.	96%.	NA.	Local recurrence rate: mean follow up 44 months. Local recurrence-free survival: 98% at 30 months, 95% at 60 months. Disease progression: No cases of progression to LMM, distant metastases, or melanoma-related death.	LMM were excluded. Comparative study between SE and WLE.

CEB, complete excision-biopsies; WLE, wide local excision; LM, lentigo maligna; LMM, lentigo maligna melanoma; RRFS, Regional Recurrence-Free Survival; DRFS, Distant Recurrence-Free Survival; MSS, Melanoma-Specific Survival; HH-RCM, handheld reflectance confocal microscopy; AAD, American Association of Dermatology; NCCN, National Comprehensive Cancer Network; ESMO, European Society for Medical Oncology; NA, not available; SE, staged excision; OR, odds ratio; IHQ, immunohistochemistry; MMS, Mohs micrographic surgery; MIS, melanoma *in situ*; *MiTF, melanocyte inducing transcription factor*; SOX10, SRY-related HMG-box transcription factor 10; HMB-45, Human Melanoma Black 45; Melan-A/MART-1, Melanoma Antigen Recognized by T cells 1.

Note: All studies identified as retrospective are observational in nature, unless otherwise stated. "N" refers to patients with LM unless otherwise specified.

Table 2. MMS studies included in the review.

Year	Author	Study	N (lesions)	Site	Size	Initial margins from de lesion	Additional instrument	Surgical technique specifications	IHQ	Debulk	Margins clearance	% clearance at stage 1	Number of stages	Recurrence rate	Other data
2019	Foxton *et al*. [20]	Prospective.	62.	89% head and neck, 11% trunk and extremities	Mean diameter 2.01 cm.	0.6 cm.	Naked eye.	Traditional 45° technique.	MART-1 on frozen.	On excision. Paraffin embedded bread-loafing technique.	6.7 mm median.	66%.	Maximum 3.	0% (0–30 months follow up).	No deaths. LM invasive component in 13% (Breslow 0.5 mm).
2016	Stigall *et al*. [26]	Retrospective.	882 MIS.	Trunk and proximal extremities	Mean diameter 1.78 cm.	0.6 cm.	NA.	Traditional 45° technique.	MART-1 on frozen.	On excision. Paraffin embedded bread-loafing technique.	12 mm 100% clearance.	83%	NA.	0.1% mean follow-up 60.2 months; median 45 months (range 1–340 months).	Surgical margins of 0.9 should be considered. Only 23% (n = 203) were classified as LM.
2024	Tate *et al*. [24]	Retrospective.	846 MIS.	Head and neck	Mean area 2.2 cm^2 (0.04–36 cm^2).	0.5 cm.	Woods lamp.	NA.	MART-1 on frozen.	On excision. Paraffin embedded bread-loafing technique.	Mean 6.94 mm ± 3.27. 15 mm 97% clearance.	62.37%.	Average 1.37 ± 0.70.	NA.	Lesions on the cheek and eyelid, as well as those with larger preoperative sizes, required margins greater than 5 mm for clearance of all MIS only 3% n = 22 LM.
2017	Nosrati *et al*. [14]	Retrospective.	277 MIS.	Head and neck 83.5% Trunk and extremities 16.5%.	Mean diameter 1.8 ± 1.5 cm.	0.5 cm.	Woods lamp.	NA.	Not used.	On excision. Paraffin embedded bread-loafing technique.	NA.	NA.	NA.	1.8% no median follow-up.	No significant differences were found in the recurrence rate, overall survival, or melanoma-specific survival of patients with MIS treated with MMS compared with WLE.

Table 2. Continued.

Year	Author	Study	N (lesions)	Site	Size	Initial margins from de lesion	Additional instrument	Surgical technique specifications	IHQ	Debulk	Margins clearance	% clearance at stage 1	Number of stages	Recurrence rate	Other data
2021	Sharma *et al*. [27]	Systematic review.	3033 LM in 27 studies.	NA.	NA.	NA.	Woods lamp on half of large series studies.	NA.	HMB-45 (3 studies, 18% of all studies), S100 (3, 18%), Mel-5 (2, 12%), MART-1 (2, 12%).	On excision. Paraffin embedded bread-loafing technique.	NA.	NA.	NA.	1.35% mean follow up ranging from 3 months to 5 years.	No RCTs included.
2019	Kunishige *et al*. [21]	Prospective.	1506 LM.	Head and neck (73.1%). Trunk and extremity (26.9%).	NA.	0.6 cm.	NA.	NA.	HMB-45 and MART-1 frozen.	On excision. Paraffin embedded bread-loafing technique.	12-mm margin on the head and neck for 100% clearance and a 9-mm margin on the trunk and extremities.	79%.	NA.	5-year recurrence rate 0.27% 10-year recurrence rate 0.33%.	The use of MART-1 made it more likely to perform a second stage of Mohs, but not additional stages.
2015	Hou *et al*. [13]	Retrospective.	154 MIS.	Head and neck 71%, trunk and extremities 29%.	2.51 cm^2 (mean area).	0.1–0.2 cm.	Woods lamp.	NA.	37% of the lesions with IHQ MART-1.	On excision. Paraffin embedded bread-loafing technique.	NA.	NA.	1.7 ± 0.9.	1.9%, 5 years mean follow up	No distinction between LM and MIS. This study group prefers MMS for larger ill-defined LM at a complex anatomic site.
2019	Demer *et al*. [16]	Retrospective	221 MIS treated with MMS.	Head and neck 100%.	NA.	0.2–0.3 cm.	Woods lamp.	NA.	MEL-5 frozen.	On excision. Paraffin embedded bread-loafing technique.	NA.	NA.	Mean 1.4 (maximum 3).	0.9%, median time to recurrence 44.31 months.	MMS was preferred in MIS. No distinction between LM and MIS was made.

Table 2. Continued.

Year	Author	Study	N (lesions)	Site	Size	Initial margins from de lesion	Additional instrument	Surgical technique specifications	IHQ	Debulk	Margins clearance	% clearance at stage 1	Number of stages	Recurrence rate	Other data
2016	Felton *et al*. [25]	Retrospective	343 MIS.	Head and neck 100%.	1.73 cm^2.	0.5 cm.	Woods lamp.	NA.	MART-1 frozen.	On excision. Paraffin embedded bread-loafing technique.	Mean 6.9 ± 3.2 cm.	65%.	Mean 1.3 ± 0.6 cm.	NA.	No distinction of LM from MIS. 1.5% showed invasive component.
2016	Valentín-Nogueras *et al*. [23]	Retrospective	863.	Head and neck, trunk and extremities.	Mean diameter 1.66 cm ± 0.96.	0.6 cm.	NA.	NA.	MART-1 frozen.	On excision. Paraffin embedded bread-loafing technique.	7.2 mm (± 3.3 mm).	76%.	NA.	Mean follow-up 3.73 years, local recurrence 0.56 ± 0.40, disease-specific survival 100%.	No distinction of LM from the rest of MIS.
2020	Heath *et al*. [22]	Retrospective	529	Head and neck 93.6%, trunk and extremities 6.7%.	1.61 (± 1.09) cm (diameter).	0.3–0.5 cm.	Naked eye/woods lamp.	Modified Mohs: If frozen section margins were considered clear by the Mohs surgeon, then an mMMS margin of 1–2 mm was taken and sent for *En face* formalin-fixed, Paraffin embedded analysis.	MART-1 frozen.	On excision. Paraffin embedded bread-loafing technique.	0.77 ± 0.44 cm.	NA.	Mean 1.6, maximum 7.	Mean follow-up 5.18 years, local recurrence 1.98%.	MIS pooled from IM but LM was not distinguished from the rest of MIS subtypes. The correlation between negative frozen section margin interpretation and mMMS permanent margin was 83.3% (547/657).

Table 2. Continued.

Year	Author	Study	N (lesions)	Site	Size	Initial margins from de lesion	Additional instrument	Surgical technique specifications	IHQ	Debulk	Margins clearance	% clearance at stage 1	Number of stages	Recurrence rate	Other data
2016	Dika *et al*. [12]	Retrospective	29 LM	Head and neck.	1.2 ± 0.5 cm^2 for LM treated with MMS. 1.5 ± 0.2 LM treated with VDS-MMS.	0.3–0.4 mm.	VDS on 7 LM.	Traditional 45° technique. VDS-MMS: After the first MMS step, videodermoscopy (×40 magnification) was used to assess the specimen perimeter (360° control).	No IHQ used.	On excision. Paraffin embedded bread-loafing technique.	NA.	NA.	NA.	Local recurrence for classical MMS: 4.5% re (1/22), mean follow-up 82.6 months; VDS-MMS local recurrence: 0%, mean follow-up 62.5 months.	Significant difference in stages and procedure duration between MMS and VDS-MMS.
2023	Elshot *et al*. [15]	Systematic review and meta-analysis.	2300.	Head and neck 81.8%, trunk and extremities 15.1%, unknown 3.1%.	MMS classic 17.0 mm mean diameter. MMS, IHQ 25.0 mean diameter.	NA.	Woods lamp, naked eye and HH-RCM.	Classic MMS n = 380.	Frozen IHQ n = 1920.	On excision. Paraffin embedded bread-loafing technique.	NA.	NA.	NA.	Local recurrence for classic MMS.7% (10/373) mean follow up 27 months. Local recurrence for MMS with IHQ 0.6 (11/1916). Mean follow up 63.3 months. Death rate 0.5%.	High heterogeneity. Results selection bias. HH-RCM could be useful.

VDS, videodermoscopy; mMMS, modified MMS; RCT, randomized controlled trial.

Note: All studies identified as retrospective are observational in nature, unless otherwise stated. "N" refers to patients with LM unless otherwise specified.

Histological assessment was performed using the bread-loafing technique in all cases. Immunohistochemistry was variably employed [9–11,13,15], with Melanoma Antigen Recognized by T cells 1 (Melan-A/MART-1) and SRY-related HMG-box transcription factor 10 (SOX10) being the most used markers. Histological margins needed for clearance varied. Modin *et al*. [10] reported a mean histological clearance margin of 4.8 mm. Crouch *et al*. [9] indicated that a 3.0 mm histological margin corresponded to a 6.5 mm surgical excision, Elshot *et al*. [8] observed that margins necessary were 5 mm (IQR 1.0–3.0) for LM, and the meta-analysis by the same authors reported a weighted mean of 7.7 mm [15].

Additional findings included a significant association between head and neck location, clinical margins <5 mm, and incomplete excision [10]. WLE was more frequently used in higher-stage tumours and in well-defined LM/LMM on the trunk and extremities [13,16].

Surgical and Clinical Outcomes of WLE

Residual disease rates varied among cohorts. Modin *et al*. [10] reported the highest with 16.7% for LM. Jackett *et al*. [19] observed residual disease in 5 of 38 LM cases. Bolshinsky *et al*. [18] described a 4.2% overall residual disease rate, with LM/LMM accounting for 23.5%. LM/LMM was identified as an independent risk factor for residual disease in some studies [18,19].

Recurrence rates, including recurrence-free survival data, showed marked variability. A study reported recurrence rates above 5%, with the lowest reported being 5.7% [14]. Dika *et al*. [12] reported the highest recurrence at 27.3%. A systematic review reported a recurrence rate of 13% for LM with a weighted follow up of 57 months, noting WLE was used more frequently for LMM. Most of the studies reported a recurrence-free survival rate over 85% at 5 years [9,14,17].

Fewer studies reported survival outcomes. Nosrati *et al*. [14] indicated a melanoma-specific mortality rate of 0.7%. Demer *et al*. [16] and Martinez-Molina *et al*. [17] reported no melanoma-related deaths or distant metastases. Elshot *et al*. [15] observed no distant or regional recurrences for LM and noted that survival outcomes were not influenced by adherence to guideline-recommended margins.

Mohs Micrographic Surgery (MMS)

MMS in Clinical Practice and Technical Overview

In the current work, across the studies reviewed, lesions excised with MMS predominantly involved the head and neck region, as reported by Foxton *et al*. [20] (89%), Kunishige *et al*. [21] (73.1%), and Heath *et al*. [22] (93.6%). A smaller proportion of lesions were located on the trunk and extremities ranging from 6.7% to 26.9% [8,13,21–23]. Lesion sizes varied widely (Table 2, Ref. [12–16,20–27]). The use of woods lamp for lesion delineation was reported in several studies [13–16,24,25]. Elshot *et al*. [15] uniquely mentioned the use of handheld reflectance confocal microscopy (HH-RCM) in MMS. Dika *et al*. [12] used video-dermoscopy after the first Mohs stage and observed significant reduction of the number of stages required as well as overall procedure duration.

Initial surgical margins generally ranged between 0.2 cm and 0.6 cm regardless of whether they used Wood’s lamp or not.

Debulking was performed during the initial excision in most studies, with all specimens evaluated using a Paraffin embedded bread-loafing technique.

The traditional 45° angled Mohs was explicitly described in some studies [12,20,26], whereas other studies did not specify incision angles. The 90° modified Mohs approach was not reported in any of the included studies. Variation in MMS technique was, however, observed, e.g., Heath *et al*. [22] performed a modified MMS (mMMS). If frozen section margins were clear, they excised an additional 1–2 mm strip and sent it for paraffin fixation and H-E study. The correlation between negative frozen section margin interpretation and mMMS permanent margin was 83.3%.

The application of immunohistochemistry (IHC) during Mohs surgery also varied among studies. The most employed markers included MART-1, Human Melanoma Black 45 (HMB-45), S100, and MEL-5, with MART-1 frozen sections being the most frequently cited. Sharma *et al*. [27] reported immunostaining across studies as: HMB-45 and S100 (each in 18% of studies), MEL-5 (12%), and MART-1 (12%).

Outcomes Following Mohs Micrographic Surgery

The number of Mohs stages required for complete excision mean range varied from a minimum of 1.3 to 1.7, with the maximum stages reported up to 7 [22]. The percentage of lesions cleared in a single stage was inconsistently reported, when assessed it ranged from 62.37% [24] to 83% [26].

Surgical margins for histological clearance margins typically ranged from approximately 6 to 12 mm, with larger margins needed for head and neck locations or larger lesions. For example, Kunishige *et al*. [21] observed that margins of 12 mm on the head and neck and 9 mm on the trunk and extremities ensured 100% clearance. Larger margins were needed for lesions on the cheek and eyelid or larger preoperative sizes [24]. Recurrence rates were consistently low across all studies. Foxton *et al*. [20] and Kunishige *et al*. [21] reported 0% and 0.27–0.33% recurrence, respectively, over 5–10 years of follow-up. Two systematic reviews reported local recurrence rates of 1.35% and 2.7% respectively [15,27]. Heath *et al*. [22] observed a recurrence rate of 1.98% for mMMS over a mean follow-up of 5.18 years. Elshot *et al*. [15] found lower recurrence rates when using HH-RCM.

Survival outcomes were largely favourable. Valentín-Nogueras *et al*. [23] reported 100% disease-specific survi-

Table 3. Studies reporting outcomes and technical specifications of slow Mohs micrographic surgery for lentigo maligna.

Year	Author	Study type	N (lesions)	Area	Lesion size	Paraffin embedded technique	Initial margins and assessment	Technique specifications	Margins processing.	Median margins	Clear margins at 1 Mohs layer	N° of Mohs layers for clearance	Recurrence rate	Other data
2023	Elshot *et al*. [15]	Systematic review.	229.	Head and neck (96.5%) trunk and extremities (3.5%).	Mean 17 mm diameter.	Slow MMS.	NA.	NA.	NA.	NA.	NA.	NA.	7.9% mean follow up 33.7 months.	No melanoma specific deaths.
2021	Gao *et al*. [28]	Retrospective.	47 LM.	Head and neck.	NA.	Slow MMS.	RCM in 21 studies.	NA.	NA.	NA.	62% for not mapped LM and 81% for mapped LM.	Mean 1.54 ± 0.81 for not mapped LM vs 1.29 ± 0.64 for mapped LM.	NA.	Mean days to repair were 27 ± 30 for not mapped LM (n = 26) and 14.6 ± 9.6 for mapped LM (n = 21). Not difference in the number of Mohs layers required using RCM mapping.
2021	Sharma *et al*. [27]	Systematic review.	566 LM and LMM.	Head and neck, trunk and extremities.	NA.	Slow MMS.	Woods lamp in some studies	IHC used in 2 studies (HMB-45 and S100).	NA.	NA.	NA.	NA.	Recurrence 2.4% follow up 22.0 months.	NA.

RCM, reflectance confocal microscopy; IHC, immunohistochemistry.

Note: All studies identified as retrospective are observational in nature, unless otherwise stated. "N" refers to patients with LM unless otherwise specified.

Table 4. Studies for staged excision technique and its multiple variants.

Year	Author	Study type	N (lesions)	Area	Lesion size	Paraffin embedded technique	Initial margins and assessment	Technique specifications	Margins and debulk piece processing	Margins for clearance	Clear margins at 1 Mohs layer	Mohs layer for clearance	Recurrence rate	Other data
2021	Liu *et al*. [29]	Retrospective.	102	Head and neck.	Mean 71 mm.	SE. Spaghetti width 2 mm.	0.5 cm. Woods lamp.	Moat defect sutured directly. Debulking once clear margins are obtained. Delayed reconstruction, flap preferred.	Margins: *En face*. Debulk piece: Bread-loafing.	0.5 cm (range 0.3–3.0 cm).	1 SE: 78.4%.	Range 1 to 6.	3.9% recurrence median follow-up time 1410.5 (IQR 260–1756) days.	Infection rate 0.06%. One patient upstaged to invasive melanoma. SE repeated every 5–6 days.
2022	de Wet *et al*. [37]	Retrospective.	62	Head and neck.	Mean 22.5 mm.	SE. Spaghetti width 3 mm.	0.3 cm.	Debulking on initial excision, temporary suture. Delayed reconstruction, flap preferred.	Margins: *En face*. Debulk piece: Bread-loafing.	6 mm 60% patients obtained clearance, 21 mm 100% patients.	1 SE: 60.94%.	Range 1 to 5.	0% mean follow up 23.5 months.	Initial biopsy consisted mainly in incisional ones. Recurrent tumors had wider surgical margins. 6.5% initial LM were upstaged as LMM.
2016	de Vries *et al*. [38]	Retrospective.	100 LM. 17 LMM.	Head and neck.	Mean diameter 20.1 mm for LM. 23.75 mm mean diameter for LMM.	SE. Spaghetti width 3 mm.	0.3 cm.	Debulking on initial excision, temporary coverage. Delayed reconstruction.	Margins: *En face*. Debulk piece: Bread-loafing.	3 mm obtained clearance in 49%. 18 mm obtained clearance in 100%.	1 SE 49%.	LM: range 1–4. LMM: 1.9 mean (range 1–5).	4% mean follow up 5 years for LM and 0% mean follow up 4.8 years for LMM.	Infection rate: 0.09%. Patients' satisfaction 7.8/10. 5% initial LM were upstaged as LMM.
2024	Samaniego González *et al*. [30]	Retrospective.	33.	Head and neck.	Mean area 3.2 cm^2 (0.5–25).	SE. Spaghetti width 3 mm.	0.3–0.5 cm. Woods lamp.	Moat defect sutured directly. Debulking once clear margins are obtained. Delayed reconstruction using grafts or flaps.	Margins: Whole ring assessment in micro-carrier. Horizontal sectioning. Debulk: Conventional bread-loafing.	NA.	68.6%.	Range 1–2.	2.9% mean follow up 41 months.	LMM found in 2/33 cases.

Table 4. Continued.

Year	Author	Study type	N (lesions)	Area	Lesion size	Paraffin embedded technique	Initial margins and assessment	Technique specifications	Margins and debulk piece processing	Margins for clearance	Clear margins at 1 Mohs layer	Mohs layer for clearance	Recurrence rate	Other data
2025	Le May *et al.* [33]	Retrospective	70.	Head and neck.	NA.	SE. Spaghetti width 2 mm.	0.27 cm (0–0.5). HH-RCM.	Moat defect sutured directly. Debulking once clear margins are obtained. Delayed reconstruction.	*En face.*	0.27 cm.	NA.	NA.	5.7% mean follow up 6.6 years.	Non-specific death disease. Acknowledges the importance of long-term follow up, 3 out of 4 recurrences occurred more than 5 years after the procedure.
2016	Wilson *et al.* [40]	Retrospective	61 LM. 10 LMM.	Head and neck 72%, trunk and extremities 28%.	Mean area 1.5 ± 0.2 cm^2.	SE. Spaghetti width 2–3 mm.	0.5–1 cm.	No available data for debulking. Delayed reconstruction	Margins: >3 mm wide: Bread-loafing. <3 mm wide: *En face.* No data for debulk piece.	7.0 ± 0.5 mm	50%.	Mean: 1.8 ± 0.2 Range 1–6.	5.6%, mean follow up 133.2 ± 63.0 months.	LM of the cheek required higher margins and number of stages $p < 0.04$.
2018	Beveridge *et al.* [31]	Retrospective	24.	Head and neck.	Mean area 12.1 cm^2.	SE. Spaghetti width 2 mm.	0.6 mm. Woods lamp.	Moat defect sutured directly. Debulking once clear margins are obtained. Delayed reconstruction, local flap preferred.	*En face.*	Minimum 6 mm. Mean 9 mm.	NA.	2.1 mean (range 1–4).	0% mean follow up 18 months.	Infection rate 8.3%.
2017	Glazer *et al.* [32]	Retrospective	127 MIS. LM 92/127.	Head and neck.	NA.	SE. Spaghetti width 2–3 mm.	0.5 cm. Woods lamp.	Moat defect sutured directly. Debulking once clear margins are obtained. Delayed reconstruction, skin grafts preferred.	Margins: *En face* .	NA.	1 SE: 77.2%.	Range 1–4.	2.4% mean follow up 5.4 months.	4.7 patients did not achieve clear margins. Increased recurrence was correlated to the number of procedures (Cox proportional hazard ratio 3 = 0, p = 0.039).

Table 4. Continued.

Year	Author	Study type	N (lesions)	Area	Lesion size	Paraffin embedded technique	Initial margins and assessment	Technique specifications	Margins and debulk piece processing	Margins for clearance	Clear margins at 1 Mohs layer	Mohs layer for clearance	Recurrence rate	Other data
2017	Garcia *et al*. [36]	Retrospective	29 MIS. LM 8/29 lesions.	Head and neck 93.1% trunk and extremities 6.8%.	Mean size 13.6 mm.	Simple disk-shaped excision. No width specified.	0.5 cm.	Debulking on initial excision. Temporary coverage. Delayed reconstruction.	Margins: Rush permanent section, bread-loafing along the vertical axis.	NA.	1 SE: 53%.	Range 1–3.	0% mean follow up 31.5 months.	Larger surgical margin with increasing preoperative lesion size.
2023	Martinez-Molina *et al*. [17]	Retrospective	26.	Head and neck.	Mean lesion size 2.2 cm.	SE. Spaghetti width 2 mm.	0.2–0.3 mm RCM used in some cases, not specified.	Moat defect sutured directly. Debulking once clear margins are obtained. Delayed reconstruction.	Margins: *En face*. Debulk: Bread-loafing.	NA.	1 SE: 0%	Range 1–3.	0% mean follow-up 44 months.	Direct and significant correlation between the number of stages needed and the recurrence rate.
2018	Couty *et al*. [34]	Retrospective	59 LM. 11 LMM.	Head and neck.	30 mm ± 17 mean diameter.	SE. Spaghetti width 2 mm. Use of double bladded scalpel.	Surgical margins varied, all identified with RCM.	Moat defect sutured. Debulking once clear margins are obtained. Delayed reconstruction.	Margins: *En face*. No data for debulk piece.	NA.	NA	Mean 1.13 Range 1–3.	0% mean follow-up 44 months.	Lower average of SE because of RCM.
2023	Himeless *et al*. [39]	Retrospective	126 MIS.	Head and neck 78.5%, trunk and extremities 21.5%.	15 × 11 mm.	SE.	0.5 cm.	On initial excision, temporary coverage. Delayed reconstruction with complex repairs.	Bread-loafing for debulk and re-excision pieces.	0.8 cm.	NA.	Mean 1.23. Range: 1–4.	0% mean follow up 19.5.	Preoperative size was associated with larger surgical margin, greater number of excisions, positive margins and upstaging.

Table 4. Continued.

Year	Author	Study type	N (lesions)	Area	Lesion size	Paraffin embedded technique	Initial margins and assessment	Technique specifications	Margins and debulk piece processing	Margins for clearance	Clear margins at 1 Mohs layer	Mohs layer for clearance	Recurrence rate	Other data
2020	Reynolds *et al*. [35]	Retrospective	342 MIS.	Head and neck 50.1% trunk and extremities 49.1%.	NA.	SE, square procedure. Strip 5 mm.	0.5 cm.	Moat defect sutured. Squared. Debulking once clear margins are obtained. Delayed reconstruction.	Margins: *En face*. Debulk piece: Bread-loafing.	NA.	1 SE: 81.1%.	Mean 1.26.	0.9% no mean follow-up specified.	Head and neck cases had lower clear margin rates with 5 mm ($p < 0.001$); patients >70 yrs needed more SEs (mean 1.37). 3 cases were found to be LMM.
2023	Elshot *et al*. [8]	Systematic review.	2442 LM.	Head and neck, trunk and extremities.	SE partial margin mean diameter: 12.6 ± 3.2. SE total margin mean diameter: 23.2 ± 5.0.	SE partial margin 1115. SE total margin 1327. Spaghetti.	0.5 cm. RCM.	NA.	SE partial margin: Radial-bread loafing technique. SE total margin: *En face*.	NA.	1 SE partial margin 71%. 1 SE total margin 55%.	Mean 1.7 ± 0.1.	Local recurrence: 2.3% minimum follow up 57 months.	No melanoma specific deaths. HH-RCM reduced number of stages.

Note: All studies identified as retrospective are observational in nature, unless otherwise stated. "N" refers to patients with LM unless otherwise specified.

Table 5. Comparative studies between surgical techniques included in the review.

Year	Author	Study type	MMS	WLE	Paraffin embedded SE	Area	Item	Outcome	Other
2017	Nosrati *et al*. [14]	Retrospective.	277	385.	NA.	Head and neck 83.5%. Trunk and extremities 16.5%.	Recurrence rate, overall survival and melanoma-specific survival.	No significant differences were found in the recurrence rate, overall survival, or melanoma-specific survival of patients with MIS treated with MMS compared with WLE.	LM was not analyzed separately from other melanoma *in situ* subtypes.
2015	Hou *et al*. [13]	Retrospective.	154.	269.	NA.	Head and neck 71%. Trunk and extremities 29%.	Recurrence rate.	No direct comparisons between both techniques can be made. Lower recurrence rates were observed in the MMS group with no statistical significance. MMS may be suitable for MMIS-LM with high-risk characteristics.	LM was not analyzed separately from other melanoma *in situ* subtypes.
2019	Phan and Loya. [46]	Retrospective.	2580.	5353.	NA.	Head and neck.	Overall survival and melanoma-specific survival.	No significant difference in cancer-specific survival (HR: 0.902, 95% CI: 0.539–1.511, p = 0.695) and overall-survival (HR: 0.943, 0.813–1.093, p = 0.435) between MMS and WLE.	LM was not analyzed separately from other melanoma *in situ* subtypes. SEER database.
2018	Trofymenko *et al*. [47]	Retrospective.	6237.	12,102.	NA.	Face.	5 years overall survival and melanoma-specific survival.	No statistically significant difference in melanoma-specific mortality was found between different surgical methods on multivariate analysis.	Outcomes for LM were not analyzed separately from MIS and invasive melanoma. MMS was used mainly for LM (74.64%). Results were adjusted for patient demographics, residence socioeconomic factors, and tumor characteristics. SEER database.
2024	Puyana *et al*. [45]	Retrospective.	9263.	13,589.	NA.	Head and neck, trunk and extremities.	Survival outcomes.	There were no significant differences in disease-specific survival comparing WLE to MMS. *In situ* cases treated with MMS were 6.8% less likely to die from any cause compared to WLE (p = 0.0413).	Only lentigo LM and LMM data was analyzed. SEER database.

Table 5. Continued.

Year	Author	Study type	MMS	WLE	Paraffin embedded SE	Area	Item	Outcome	Other
2021	Theunissen *et al*. [42]	Systematic review.	4374.	1154.	2100.	Head and neck.	Recurrence rate risk.	MMS demonstrated the lowest pooled local recurrence rate for early-stage melanomas at 0.8% (95% CI: 0.4–1.1), compared to 2.5% for staged excision (95% CI: 1.5–3.4) and 8.7% for wide local excision (95% CI: 5.1–12.2) ($p <$ 0.001).	LM was not analyzed separately from other melanoma *in situ* subtypes. The authors acknowledged considerable heterogeneity in surgical techniques, reporting standards, and methodologies across the included studies.
2023	Elshot *et al*. [15]	Systematic review and meta-analysis.	2200.	1355.	2442 (SE total and partial). 229 slow Mohs.	Head and neck, trunk and extremities.	Local recurrence rate and survival outcomes.	The local recurrence rate was lowest for patients treated by MMS-IHC (1%; 95% CI: 0.3%–1.9%), and highest for WLE (13%; 95% CI: 7.2%–21.6%). Survival impact could not be assessed due to selection bias, heterogeneity, and limited advanced-stage data.	Both LM and LMM were analyzed. No other MIS subtypes were included. No separate recurrence analysis for LM and LMM were performed because of missing data. Use of HH-RCM was associated with fewer incomplete excisions and local recurrences, even with WLE.
2021	Bittar *et al*. [43]	Systematic review and meta-analysis.	4826 (34.5%).	7138 (51.0%).	2034 (14.5%).	Head and neck.	Local recurrence rate.	Local recurrence rates were lowest for MMS (0.61%; 95% CI: 0.1%–1.4%), followed by staged excision (1.8%; 95% CI: 1.0%–2.9%) and WLE (7.8%; 95% CI: 6.4%–9.3%). IHQ MMS had the lowest recurrence rate.	The definitions of local recurrence were inconsistent across studies. The surgical approaches differed, involving various proportions of invasive melanoma cases. There was notable heterogeneity among the studies.
2019	Demer *et al*. [16]	Retrospective.	291.	97.	NA.	Head and neck.	Local recurrence rate and median time to recurrence.	Subgroup analysis indicated that patients with melanoma *in situ* or thin invasive tumors ($<$0.8 mm) treated with MMS experienced lower local recurrences (p = 0.0049), MMS was linked to a significantly longer interval before local recurrence in *in situ* cases (HR = 31.8; p = 0.0148).	MIS were separately analyzed from invasive melanomas but LM was not individualized.

Table 5. Continued.

Year	Author	Study type	MMS	WLE	Paraffin embedded SE	Area	Item	Outcome	Other
2019	Cheraglhou *et al*. [49]	Retrospective.	3234 (13.5% LMM after propensity score matching).	67,085 (13.6% LMM after propensity score matching).	NA.	Head and neck, trunk and extremities.	Overall survival.	MMS linked to modest OS improvement vs WLE (HR 0.86; 95% CI: 0.76–0.97). Propensity-matched analysis confirmed benefit (HR 0.82; 95% CI: 0.68–0.98). MMS more used in academic vs. non-academic centers (OR 2.03; 95% CI: 1.88–2.18).	MIS were excluded. LMM was not evaluated separately from the rest of melanomas subtypes for OS analysis. Multivariable analysis showed no significant association with OS (HR 1.00; 95% CI: 0.91–1.10; $p > 0.99$). Nacional cancer database.
2025	Taylor *et al*. [48]	Retrospective.	2262.	3636.	NA.	Head and neck, trunk and extremities.	Overall survival.	WLE was associated with higher disease-specific mortality vs MMS (HR 1.82; 95% CI: 1.18–2.81; p = 0.007). MMS showed better 5- and 10-year disease-specific survival, regardless of Breslow depth or margin size.	Included only invasive LMM; excluded LMM and distant disease cases. Results were adjusted for age, sex, race/ethnicity, stage, Breslow depth, and tumor site. SEER database.
2022	Pride *et al*. [44]	Systematic review and meta-analysis.	7967.	5711.	2897.	Head and neck, trunk and extremities.	Local recurrence rates.	Increased recurrence after WLE compared with MMS or staged excision (OR, 2.5; 95% CI: 1.4–4.6) and compared with MMS alone (OR, 3.3; 95% CI: 1.8–5.9)	Statistical heterogeneity was high.
2023	Martinez-Molina *et al*. [17]	Retrospective.	NA.	53.	26.	Head and neck.	Local recurrence.	No significant difference in the frequency of local recurrence between WLE and SE.	RCM guidance contributed to the low number of stages.

SEER, Surveillance, Epidemiology, and End Results; HR, hazard ratio; OS, overall survival.

Note: All studies identified as retrospective are observational in nature, unless otherwise stated. "N" refers to patients with LM unless otherwise specified.

val, and Foxton *et al*. [20] noted no deaths. Elshot *et al*. [15] reported a death rate of 0.5% in LM treated with MMS.

Paraffin Embedded Margin Controlled Surgery

Slow Mohs, MMS With "Rush Sections"

Slow Mohs in Clinical Practice and Technique Overview. In the current review, only three studies reported using of slow Mohs micrographic surgery (slow MMS). Two were systematic reviews [15,27], which included seven and four earlier studies conducted prior to the current review period. A third study reported 47 LM cases; all located on the head and neck. RCM was used in 21 cases for pre-surgical mapping of the lesion [28]. Technique specifics, such as data on margins or number of Mohs stages, were not detailed in any of these studies (Table 3, Ref. [15,27,28]).

Outcomes Following Slow Mohs Micrographic Surgery. Sharma *et al*. [27] reported a recurrence rate of 2.4%. Elshot *et al*. [15] documented a mean recurrence rate of 7.9% over 33.7 months of follow-up, with no melanoma-specific deaths. Gao *et al*. [28] found higher rates of clear margins after one stage in RCM-mapped cases (81%) compared to non-mapped LM/LMM cases (62%).

Staged Excision

Staged Excision in Clinical Practice and Surgical Overview. In this review, most lesions treated with SE were located on the head and neck, as consistently reported across studies. Initial margins typically ranged from 0.2 to 1 cm, with most common values being 0.3–0.5 cm (Table 4, Ref. [8,17,29–40]).

Woods lamp was used as a clinical tool to delineate lesion borders in several studies [29–32]. RCM or its handheld variant was specified in the protocols by some authors [17, 33,34,41].

The "spaghetti" technique was the predominant method used for SE, employed in nearly all studies. The width of the excised strips generally ranged from 2 to 3 mm. However, square-SE and simple disk-shaped excision were also described [35,36]. Most studies reported *En face* analysis for margin evaluation. Samaniego González *et al*. [30] described a specific practice involving horizontal sectioning on a macrocarrier. Most authors performed debulking only after obtaining clear margins. In 4 studies debulking was performed during the initial excision [36–39]. All studies that reported the histologic processing of the debulked central specimen used the bread-loafing technique. Delayed reconstruction was universal across all studies. Where specified, reconstructions were described as complex and often employed flaps or grafts.

Outcomes Following Staged Excision. Margins required to achieve histological clearance varied across studies. Reported clearance margins ranged from 0.27 cm [33] up to 3.0 cm [29] Some authors provided stratified clearance rates according to margin size [40]; de Vries *et al*. [38] reported a 100% clearance rate at 18 mm and de Wet *et al*. [37] achieved 100% clearance at 21 mm.

Clear margins were obtained after the first SE in a wide range of cases: the lowest reported rate was 0% [36] while the highest was 81.1% [35]. The number of SE stages necessary to obtain clearance ranged from 1 to 6, with mean values commonly around 1.2 to 2.

Several studies reported 0% recurrence rates [31,34,36–39], although follow up periods were limited. The highest reported recurrence was 5.7% in the study by Le May *et al*. [33]. No melanoma specific deaths were reported. Some studies reported the upstaging of LM to LMM [29,38]. Moreover, infection rates were reported in a few studies: 0.06% [29] 0.09% [38], and 8.3% [31].

Studies Comparing Surgical Outcomes Between Techniques

Comparative Studies on Local Recurrence

Local recurrence was addressed in several comparative studies. Four systematic reviews and meta-analyses [15, 42–44] reported lower recurrence rates with MMS, followed by SE, and higher rates with WLE. Recurrence definitions and included populations varied. Demer *et al*. [16] described lower local recurrence and longer intervals to recurrence in *in situ* cases treated with MMS. Other retrospective studies reported no significant differences in local recurrence between surgical approaches [13,14,17] (Table 5, Ref. [13–17,42–49]).

Survival Outcomes in Comparative Studies of Surgical Techniques

Survival outcomes were described in retrospective studies, including four based on the Surveillance, Epidemiology, and End Results (SEER) database [45–48]. Two of them [46,47] found no significant differences in overall or melanoma-specific survival between MMS and WLE. Puyana *et al*. [45] reported no differences in disease-specific survival but noted a lower all-cause mortality in patients treated with MMS. Taylor *et al*. [48] reported improved disease-specific survival with MMS compared to WLE. Cheraghlou *et al*. [49] used the National Cancer Database and found a modest survival benefit with MMS in some analyses. Other studies, such as Nosrati *et al*. [14], Puyana *et al*. [45], Phan and Loya [46] and Trofymenko *et al*. [47], did not observe survival differences. Elshot *et al*. [15] included survival outcomes in a systematic review but did not assess them due to heterogeneity and limited data.

Discussion

Surgical excision has been the gold standard for LM treatment, as referred to by major international guidelines, including the National Comprehensive Cancer Network (NCCN), American Association of Dermatology (AAD), European Society for Medical Oncology (ESMO), and EADO [6,50–52]. These works recommend clinical margins of 5 to 10 mm; however, such margins are based on low-level evidence and expert opinion rather than high-quality prospective data [53]. Our review, composed mainly of retrospective studies and systematic reviews, highlights the limitations of current evidence and the need for more rigorous comparative research.

WLE remains the most performed surgical technique for LM/LMM, consistent with international guidelines recommending 5–10 mm clinical margins. However, evidence from our review underscores important limitations in its accuracy. Several studies directly addressed the issue of residual disease, reinforcing concerns about the adequacy of standard clinical margins and the limited sensitivity of the bread-loafing technique for detecting peripheral margin involvement [10,13,19]. Furthermore, histologic margin analysis revealed that achieving clear margins often required surgical excisions wider than the standard 5 mm recommended by current guidelines [8–10].

Local recurrence rates varied substantially across studies, ranging from 5.7% [14] to as high as 27.3% [12]. Some studies identified correlations between narrower margins and higher recurrence rates, or between recurrence and incomplete excision [10,11] although others found no significant differences [19]. More importantly, the LM subtype itself was significantly associated with residual disease and local recurrence, particularly when located on the head and neck. This is not unexpected, as LM typically develops in chronically sun-exposed areas and is characterized by subclinical extension beyond the clinically apparent margins [2,54]. Another relevant finding from this review is that many authors reported selecting WLE specifically for cases of LMM, suggesting a potential selection bias that complicates direct comparison between surgical techniques [8,15,16].

On the other hand, MMS has emerged as a valuable alternative for the treatment of LM, offering the notable advantage of complete peripheral margin control. In MMS, following central tumour debulking, a circumferential, bowl-shaped layer is excised, allowing for intraoperative margin assessment of both peripheral and deep margins through horizontal frozen sections. This process is repeated until histological margins are obtained [2,55,56]. The traditional technique employs a 45-degree beveled incision, which facilitates optimal tissue orientation during processing. Nevertheless, this bevel may distort the true depth of invasion when present, prompting some authors to describe a 90-degree modified approach that facilitates more accurate assessment of lateral margin, the primary focus in LM management using MMS [2,27,55]. In our review, not all studies consistently reported the angle of bevelling, and none utilized the 90-degree modified Mohs technique. Permanent section analysis of the central debulking specimen is recommended to detect and appropriately stage invasive melanoma [27]. In all the studies reviewed that specified the technique, permanent sections were used for this purpose.

In our analysis, MMS appeared to be the most methodologically consistent among the complete margin assessment techniques, showing minimal variability in execution and reporting across the included studies, in contrast to what was reported by Krausz *et al*. [57]. A notable exception was the protocol by Heath *et al*. [22], who performed an additional final stage for Paraffin embedded histology after obtaining clear margins. This approach has been controversial [56,57], as it may undermine the defining principle of MMS, real-time margin assessment.

In fact, one of the main strengths of MMS lies in the ability to achieve histologically verified tumour-free margins during surgery, enabling same-day reconstruction; given LM subclinical extension this is particularly relevant. MMS also allows for maximal tissue preservation and functional conservation, thus enhancing aesthetic outcomes. For example, Heath *et al*. [22] reported a patient satisfaction score of 8.2 out of 10, illustrating the procedure's favourable acceptance.

Additionally, MMS provides excellent local recurrence control. In the literature reviewed, recurrence rates after MMS ranged from 0% to 4.5%, with most studies reporting rates below 2%, consistent with earlier findings [58,59]. Two included systematic reviews found a recurrence rate of 1.35% and 2.7% respectively for MMS and LM/LMM [15,27]. These outcomes are lower than reported for WLE.

Despite these advantages, MMS presents important challenges. It is time and resource-consuming, requires specialized training. Furthermore, it depends on accurate histopathological interpretation of melanocytic lesions in frozen sections, a controversial issue. Differentiating between background melanocytic hyperplasia and malignant melanocytes is difficult in frozen specimens, due to the loss of cellular morphology and freezing artefacts [2,60,61]. To improve diagnostic accuracy "fast" IHC has been increasily used on frozen sections [61].

Several studies in our review [16,20–26] incorporated IHC in MMS protocols and consistently documented lower recurrence rates. For example, Bittar *et al*. [43], in a systematic review, found that local recurrence decreased from 3.37% in MMS without IHC to 0.49% when IHC was incorporated, highlighting its clinical utility. Concordance between IHC in frozen and Paraffin embedded histologic assessment was reported at 83.3% by one of the included studies [22], a finding supported by other works in literature [61–63]. This high correlation may further support the potential utility of IHC in improving margin assessment. MART-1/Melan-A was the most frequently used marker across the included studies, as has been reported in other works [57,62], although nuclear stains such as *melanocyte inducing transcription factor (MiTF)* and SOX10, shown in other series to offer superior specificity and sensitivity

[2,27,63,64] were also employed. Despite the potential for increased operative time and cost, incorporating IHC into MMS for lentigo maligna appears to enhance diagnostic accuracy and may improve local control. However, because most studies did not stratify outcomes by the specific IHC protocol used, the individual impact of each marker on recurrence remains uncertain and warrants further investigation.

Another area of ongoing debate is the initial margin used in MMS for LM. Whilst current guidelines recommend 5–10 mm margins, they also emphasize the need for individualization based on anatomical location [6,45,50,52]. MMS is most applied in areas where tissue conservation is critical, making subcentimeter initial margins more common. Most studies in our review reported using 5 mm margins, or even smaller ones in sensitive areas such as the periocular region. Despite this, none of the studies that reported margin clearance achieved 100% tumour clearance on the first stage. Final clear margins typically ranged between 7 mm and 15 mm [20–26], like the WLE included studies conclude.

A further point of concern is whether MMS provides adequate treatment in cases of incidental LMM. MMS typically employs subcentimeter margins, raising concerns about adherence to the 1–2 cm excision guidelines for invasive melanoma. Some theoretical models suggest that narrower margins may lead to increased in-transit or nodal metastasis and poorer survival outcomes. However, these concerns are not substantiated by current data [56,65,66]. Furthermore, the role of wider margins in invasive melanoma, regardless of surgical method, for reducing in-transit metastasis remains under active investigation [56]. Still, some authors advocate for additional excision in cases of upstaged LMM, though guidelines remain unclear [55]. Among the MMS cohorts studied in our review, only Felton *et al.* [25] reported cases of upstaging (1.5%), all of which had a Breslow thickness below 0.5 mm. This is consistent with other reports in which upstaging did not lead to changes in clinical management [67]. Importantly, the rate of LM progressing to LMM is relatively low [7] and frequently reaches considerable size before becoming invasive [2] which further supports the rationale for using MMS.

To address the limitations of MMS, alternative techniques have been developed that allow for Paraffin embedded histological analysis, which is considered the gold standard according to current guidelines.

Slow Mohs seeks to combine the histological reliability of permanent sections with the margin control of MMS. This technique is performed similarly to MMS; however, unlike Mohs, reconstruction is performed in a delayed fashion, once the pathologist confirms clear margins, typically within 48 hours. This approach is often referred to as 'rush paraffin sections'. Most studies on slow Mohs precede the time frame of our current review. Recurrence rates were low across these reports; however, we were unable to retrieve consistent data regarding technical variability or other procedural details [15,27,28].

Staged excision technique also provides margin-controlled excision using permanent sections, representing an intermediate approach between WLE and MMS. In SE, the tumor is first outlined, and peripheral tissue is removed in a staged and mapped fashion, usually preserving the central portion until histologic clearance of the margins is confirmed. One of the main advantages of SE is its use of Paraffin embedded sections, which are considered the gold standard by both the NCCN and AAD. This method also allows for selective re-excision only around involved margins, helping to spare healthy tissue. Moreover, because histologic analysis is performed on permanent sections, there is no need to dismantle reconstructions if invasive melanoma or a positive margin is later found, unlike with other techniques [55,68]. Several studies included in our review reported the presence of invasive melanoma in SE specimens [17,29,30,35,37]. In most cases, the Breslow thickness was low, and therefore the same considerations discussed for LMM and MMS also apply to SE.

A major limitation of SE is that the procedure is carried out over multiple sessions, often spaced several days apart. This can be particularly inconvenient for patients with persistently positive margins, as it delays definitive treatment and reconstruction. Despite these limitations, most studies reported a mean number of fewer than two SE stages per patient, even when first-stage clearance ranged between 49% and 78.4%. Some authors have also raised concerns regarding the use of temporary sutures between stages, as these may interfere with subsequent histopathologic assessment [2]. In our study, whereas the majority of studies reported using temporary closure, others [36–38] chose to leave the wound open between stages to avoid histologic artifacts. Notably, de Wet *et al.* [37] and de Vries *et al.* [38] reported recurrence rates of 0% in LM and LMM. Among the three studies that reported infection rates [29,31,38], only one involved open wound management [38] suggesting that with proper wound care and dressings, infection risk does not necessarily increase.

Unlike MMS, we observed marked heterogeneity in SE protocols across the studies included in this review. Variations were noted in several aspects, including initial margin width, the method of histologic evaluation (radial vs. *En face*), the use of adjunctive tools such as Wood's lamp or RCM, and, most notably, in how surgical defects were managed between stages. This lack of standardization, also highlighted by other authors such as Abrantes *et al.* [55], reflects a broader variability in technique and individual surgeon preference, which may influence outcomes and limit comparability between studies [35,55].

In fact, several SE variations have been described in literature being the most known as the "Square technique" and the "Spaghetti technique", which differ in the shape of the margin contour. In our review, most authors favored the spaghetti technique, while only one [35] employed the square approach. Although square-shaped margins may facilitate histologic evaluation, they can result in defects that are more difficult to close and may lead to less natural cosmetic outcomes, but this potential drawback was not addressed in this case.

Reported recurrence rates following SE ranged from 0% to 5.7%, generally lower than those seen with WLE but higher than those reported for MMS. It is important to note, however, that many of these studies had relatively short follow-up periods. Since LM is known to recur late, often between 57- and 71-months post-treatment [2] current recurrence rates are likely underestimated. For example, Collgros *et al*. [3] reported that nearly half of LM and LMM recurrences occurred more than four years after surgery. Similarly, in our review, Le May *et al*. [33] noted that three out of four recurrences took place after the fourth year of follow-up.

Moreover, several studies identified clinical factors associated with increased risk of local recurrence, such as the number of SE stages required to achieve clear margins [32,35] lesion location, particularly on the cheek [35,40] and preoperative tumor size [36,37,39] mirroring patterns also observed in MMS-treated cohorts.

Taken together, these findings suggest that SE is a viable and accessible option in daily clinical practice, particularly in centers where MMS is not readily available. However, its variable application and relatively limited long-term follow-up data underscore the need for greater standardization and more robust prospective studies. In addition, the lack of confidence intervals and inconsistent reporting of follow-up durations in many studies further limits the comparability and interpretability of recurrence outcomes.

Given the challenges in accurately delineating subclinical extension in LM, RCM has emerged as a valuable tool in both SE and MMS. As demonstrated in several studies included in our review, its preoperative application may reduce the number of surgical stages while preserving healthy tissue. Within SE, three studies in our review [17,33,34] reported using RCM for preoperative margin delineation. These studies observed a reduction in the number of surgical stages required and no recurrences on long-term follow-up. Elshot *et al*. [15] further supported these findings, demonstrating that HH-RCM significantly reduced both the number of stages and the rate of incomplete excisions. Although less frequently employed in MMS, RCM has also been used for preoperative mapping in this context [24,41]. The accuracy of RCM in predicting histologic margins in cases of LM and melanoma *in situ* (MIS) has been widely reported in literature [41,69–71]. Nevertheless, the maximum imaging depth of RCM is limited to the upper reticular dermis, making it unsuitable for assessing invasive melanoma. Despite its promising utility, RCM is not yet routinely integrated into surgical protocols, with its broader adoption constrained by high costs, limited availability, and the need for specialized training.

As part of our review, we specifically examined comparative studies that assessed not only local recurrence but also long-term oncologic outcomes such as overall and melanoma-specific survival (Table 5).

The majority of both comparative and individual studies on local recurrence show lower recurrence rates with MMS, followed by SE, and higher rates with WLE. However, several comparative studies, including systematic reviews [42–44], failed to demonstrate statistically significant differences between techniques and highlighted considerable heterogeneity across study designs, thereby, the current evidence should be interpreted with caution.

Notably, the collective findings from the literature do not indicate significant differences in either overall or melanoma-specific survival between MMS, WLE, and SE [15,42–47]. These results likely reflect the typically indolent biological behavior of LM and support the idea that treatment decisions should prioritize recurrence risk, anatomical location, and tissue preservation rather than any presumed impact on survival.

Furthermore, LM predominantly affects individuals over the age of 65 [1,2], who may present with comorbidities and reduced functional status. In elderly individuals, treatment decisions must carefully balance oncologic control with overall health status, surgical risk, and patient preferences, particularly when considering multi-stage or resource-intensive procedures.

Finally, non-surgical alternatives, such as topical imiquimod and radiotherapy, are increasingly considered in selected patients, particularly those who are poor surgical candidates or in whom surgery is not feasible due to anatomical or functional constraints. While not the primary focus of this review, existing literature supports the use of imiquimod as a neoadjuvant treatment to reduce surgical defect size or as a standalone therapy in inoperable cases [72–74]. Radiotherapy has also demonstrated effectiveness in achieving local control and may be preferred in elderly patients or those with contraindications to surgery [7,74,75]. Both modalities remain off-label and should be considered on a case-by-case basis, with careful monitoring due to limited long-term data on recurrence and progression [74,76,77].

This narrative review has several limitations. First, there is considerable variability among the included studies in how LM, recurrence, and surgical procedures, particularly staged excision, are defined and carried out. Second, the studies come from a range of clinical settings and involve heterogeneous patient populations, often without methodology or reporting standards. Data from pre-operative size, invasive status, primary lesions are often inconsistently reported, furthermore many studies did not individuate LM from the rest of MIS subtypes, or even between LM and LMM. When LM-specific data were available, they were extracted and analysed separately; however, in many cases, results were reported for MIS as a group, and LM proportions were only identifiable through the sample description. This heterogeneity in diagnostic classification across studies further limits the possibility of conducting a fully stratified outcome analysis between LM and LMM, despite their distinct biological behavior and prognostic implications. Third, the absence of randomized controlled trials makes it difficult to directly compare surgical approaches. Fourth, access to surgical options such as MMS may also depend on socioeconomic factors, which can influence treatment decisions and outcomes. Fifth, most studies did not report patient-reported outcomes such as quality of life or cosmetic satisfaction, limiting assessment of the patient-centered impact of each technique. Sixth the literature search was restricted to two databases (PubMed and Web of Science) and a 10-year time frame. While this strategy enhances focus on contemporary surgical practice, it may have excluded relevant older studies or records indexed in other databases.

These elements together limit how broadly the findings can be applied.

Conclusions

LM surgical management continues to be a challenge. Although WLE remains the most used approach, it is limited by higher recurrence rates and less precise margin control. MMS with IHC offers the most favourable recurrence outcomes and logistical advantages; SE and slow Mohs, especially when combined with RCM and permanent histology, represent strong alternatives in appropriate settings. While no approach has shown superiority in survival endpoints, the choice of surgical technique should be guided by lesion characteristics, anatomical considerations, patient characteristics (e.g., age and comorbilities) and resource availability. Access to surgical technologies such as MMS, RCM, or IHC remains uneven across institutions, and this variability should be considered when applying evidence to real-world clinical settings. Future research should focus on standardizing surgical protocols and conducting prospective comparative trials to refine treatment strategies for LM.

Availability of Data and Materials

Not applicable.

Author Contributions

CCS conceived the review, designed the search strategy, extracted and analysed the data, and drafted the manuscript. LML analysed the data and critically reviewed successive drafts, providing methodological guidance and editorial feedback. MDSyR conceived and designed the study and reviewed. AB conceived and designed the study and assisted with data management and verification of extracted variables. ÁF conceived and designed the study, and provided supervision throughout the project. All authors have been involved in revising it critically for important intellectual content. All authors gave final approval of the version to be published. All authors have participated sufficiently in the work to take public responsibility for appropriate portions of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to its accuracy or integrity.

Ethics Approval and Consent to Participate

Not applicable.

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Conflict of Interest

The authors declare no conflict of interest.

Supplementary Material

Supplementary material associated with this article can be found, in the online version, at https://doi.org/10.62713/aic.4228.

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