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Transitioning to endoscopic Type 1 tympanoplasty: a single-centre retrospective analysis of competence, outcomes, and operative delegation to guide departmental adoption

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Abstract

Background: Departments adopting endoscopic ear surgery need realistic expectations of how competence develops, how long it takes, whether outcomes hold, and how operative responsibility is shared safely, for both training and service planning. Single-surgeon data describing this transition as a staged process are scarce, particularly for surgeons already proficient with the microscope. Using one consultant's adoption of endoscopic Type 1 tympanoplasty, we characterised competence, outcomes, and the graduated delegation of operative responsibility, benchmarked against the same surgeon's microscopic practice.

Methods: We performed a single-centre, retrospective cohort study of 124 Type 1 tympanoplasties (106 endoscopic, 18 microscopic) performed by one surgeon between 2018 and 2025, reported in accordance with STROBE. Endoscopic cases were ordered chronologically into prespecified early, mid, and late phases. Competence acquisition was further characterised using exploratory post hoc cumulative sum (CUSUM) analysis and binary logistic regression of graft (eardrum closure) success against case number. Operative time, air-bone gap closure, complications, and second-surgeon involvement were compared across phases and between approaches.

Results: The prespecified three-phase comparison of closure rate was not statistically significant (p=0.215); however, exploratory CUSUM analysis localised a rise from 58% to 88% around the 24th case, supported by logistic regression (odds ratio 1.20 per 10 cases, 95% confidence interval 0.99 to 1.45). Operative time did not shorten across phases (p=0.144). Hearing gains (approximately 6 to 9 dB) and the complication rate (8.5%) were maintained. Second-surgeon involvement rose from 2.8% to a peak of 60% as competence consolidated, without compromising closure rate (p=0.284) or hearing (p=0.875). Endoscopic outcomes matched the microscopic benchmark (closure rate 81% versus 94%, p=0.30; operative time p=0.26), with the difference concentrated in the early learning phase, after which the endoscopic closure rate was 88%.

Conclusions: For an experienced microscopic surgeon, competence in endoscopic Type 1 tympanoplasty was achieved after approximately 24 cases, hearing and safety outcomes were maintained from the outset, and operative responsibility was shared safely without compromising care. These exploratory findings provide departments with a realistic, competency-based framework for what to expect and should be confirmed prospectively.

1. Background

Adopting a new surgical technique is a departmental and individual undertaking, and units need realistic, evidence-based expectations for how competence develops and how operating can be shared safely during the change. The learning curve is central to both, serving as a competency-based marker of safe performance and as a planning tool for what a department will experience[1].

Tympanic membrane (TM) perforation is a common otological condition arising from chronic otitis media, acute infection, trauma, or iatrogenic causes, and is frequently associated with conductive hearing loss, intermittent or recurrent otorrhoea, and impairment of health-related quality of life [2]. The primary goals of surgical repair are to restore a dry, self-cleaning, and water-sealed ear canal, reduce the risk of recurrent middle ear infection, and improve sound transmission by closing the air-bone gap (ABG) [3]. In this context, Type 1 tympanoplasty (myringoplasty) aims to reconstruct the TM when the ossicular chain is intact and mobile, and it has become a routine otological procedure in the UK [4, 5].

Tympanoplasty can be performed using either microscopic or endoscopic techniques[6, 7]. Traditional microscopic tympanoplasty has a long track record in the UK and internationally, offering wide exposure of the external auditory canal and middle ear, binocular depth perception, and the possibility of two-handed instrumentation under the operating microscope[8]. Large postauricular series report high TM perforation closure rates and meaningful ABG closure, often with 80-95% anatomical success and average ABG improvements of 10-20 dB, depending on perforation size, middle ear status, and follow-up duration[9–12]. However, postauricular microscopic approaches involve an external incision, more extensive soft-tissue dissection, and, in some cases, canaloplasty, which may influence postoperative pain, cosmesis, and recovery. Other microscopic techniques include permeatal and endaural techniques.

Over the last two decades, endoscopic ear surgery has gained popularity as either an adjunct to microscopic surgery or a primary operative modality for tympanoplasty[13]. Endoscopic tympanoplasty is typically performed through a transcanal approach using rigid endoscopes, which provide wide-angle, high-resolution views of the TM and middle ear recesses without the need for a postauricular incision[14, 15]. This minimally invasive access can reduce the extent of soft-tissue dissection and may decrease the need for canaloplasty, while offering excellent visualisation of anterior perforations and hidden recesses that are less accessible with conventional microscopic fields of view. As a result, endoscopic techniques have been increasingly adopted in the UK and international centres, particularly for Type 1 tympanoplasty and selected middle ear procedures.

Systematic reviews show that endoscopic Type 1 tympanoplasty achieves closure rate and ABG closure rates comparable to those of microscopic and postauricular approaches[16, 17]. They also report similar overall perforation-closure rates, with some analyses suggesting shorter operative times, reduced need for canaloplasty, and improved pain and cosmetic outcomes[18]. Complication rates are low and comparable to those of microscopic tympanoplasty, with reported adverse events including infection, graft failure or re-perforation, taste disturbance, and, rarely, sensorineural hearing loss[19].

Despite these advantages, endoscopic ear surgery introduces specific technical challenges that may influence adoption and training. The surgeon typically operates one-handed, holding the endoscope in the non-dominant hand while performing dissection, haemostasis, and graft manipulation with the dominant hand, in contrast to the two-handed technique standard in microscopic ear surgery. Endoscopic surgery also lacks optical depth perception, relies on interpretation of two-dimensional

images, and may be associated with lens soiling, fogging, and ergonomic strain during prolonged procedures[20]. These factors underpin a distinct learning curve for endoscopic tympanoplasty, in which operative times, workflow efficiency, and comfort with one-handed technique are expected to improve as experience accrues[21, 22]. While some learning-curve studies suggest that closure rate and hearing outcomes can remain acceptable from relatively early in endoscopic adoption, they also demonstrate reductions in operative duration across successive case series or chronological period[23, 24].

In the UK, tympanoplasty is a common otological procedure, but endoscopic practice remains heterogeneous across centres[25]. Some units have fully integrated endoscopic tympanoplasty as a primary modality for suitable TM perforations, whereas others continue to rely predominantly on postauricular microscopic approaches, sometimes reserving endoscopes for inspection or selected cases. Existing studies comparing endoscopic to postauricular tympanoplasty usually focus on overall outcomes rather than detailing how results evolve as a single surgeon transitions from conventional to endoscopic techniques as their principal approach[16, 26, 27]. There is a lack of granular, single-surgeon learning curve analyses that explicitly model endoscopic adoption as a staged process and situate these stages against a contemporaneous microscopic benchmark. This is clinically relevant for departments considering a shift to endoscopic Type 1 tympanoplasty. We therefore analysed one centre's transition to endoscopic Type 1 tympanoplasty to give departments and trainees a realistic, competency-based account of what to expect, how competence develops, whether outcomes are maintained, and how operative responsibility is shared, benchmarked against the same centre's microscopic tympanoplasty outcomes[24, 28, 29].

2. Methods

Study design and setting

This was a single-centre, retrospective observational cohort study conducted in the Otolaryngology (ENT) department of a district general hospital in London. The study describes outcomes of Type 1 tympanoplasty performed by a single consultant otologist using both endoscopic and microscopic approaches, and examines the learning curve for endoscopic Type 1 tympanoplasty over time. The study protocol was pre-registered before the project was undertaken[30].

Study population and eligibility criteria

The study population comprised all patients who underwent Type 1 tympanoplasty between 2018 and 2025. Cases were initially identified from the electronic theatre management system using procedure codes for Type 1 tympanoplasty or myringoplasty. Operation notes and clinic correspondence were reviewed to confirm eligibility.

Patients were included if they had a Type 1 tympanoplasty for a tympanic membrane perforation with an intact ossicular chain, performed via either an endoscopic or a microscopic technique. Audiometry was not an inclusion requirement. Where preoperative and postoperative pure-tone audiometry for the

operated ear were available, with air- and bone-conduction thresholds at 0.5, 1, 2 and 4 kHz, the mean air-bone gap (ABG) improvement was calculated; cases without paired audiometry were retained for all other analyses. Where only a preoperative audiogram was available, it was used to confirm that the subgroups did not differ in baseline hearing status, even though ABG improvement could not be calculated for those cases. Only operations in which the consultant of interest was recorded as the primary responsible surgeon were included; second surgeon involvement was allowed, provided that the consultant was leading the case. At least one postoperative otoscopic or endoscopic examination was deemed sufficient to determine graft status. Cases were excluded if tympanoplasty was combined with planned mastoidectomy or ossiculoplasty beyond a Type 1 reconstruction, or if another consultant was the primary surgeon.

Data sources and data collection

Data were obtained from the theatre management system, electronic operative notes, outpatient clinic letters and audiology reports. A standardised proforma using Microsoft Excel was used for data extraction.

Demographic variables included age at surgery and laterality (right or left ear). Disease-related variables included whether the procedure was a primary or revision tympanoplasty, defined according to prior middle ear surgery on the same ear, and perforation characteristics. Perforation size was documented intraoperatively and categorised as small (<25% of tympanic membrane area), medium (25–50%), large (50–75%), subtotal (>75% but <100%) or total (100%). Perforation location (for example, anterior, posterior, or central) was recorded as described in the operative note. In cases with multiple tympanic membrane perforations, size and location were defined according to the largest perforation. The presence of multiple perforations was additionally recorded as a binary variable.

Operative details

For each case, the date of surgery and surgical approach were recorded and classified as endoscopic tympanoplasty or microscopic tympanoplasty, with microscopic cases including endaural, permeatal, and post-auricular approaches. The endoscopic technique was standardised: via a transcanal approach under a 0- or 30-degree 3mm endoscope, the perforation edges were freshened, a tympanomeatal flap raised, and temporalis fascia placed as an underlay graft, supported with absorbable Gelfoam. Topical ciprofloxacin was applied, and the harvest site was closed with 3-0 Vicryl and skin glue. Silastic sheeting and bismuth iodoform paraffin paste (BIPP) gauze were not used in any of the cases.

Audiological outcomes

Audiological data were obtained from formal pure-tone audiograms. For each operated ear, the closest suitable preoperative audiogram, typically within 12 months prior to surgery, was identified. The first postoperative audiogram was selected to assess postoperative hearing.

For each ear, the mean ABG was calculated as the average of the ABG (air minus bone conduction) at 0.5, 1, 2, and 4 kHz, both preoperatively and postoperatively. Where a postoperative audiogram was unavailable, the preoperative air-bone gap was still used to confirm that the early, mid, and late groups were comparable in baseline hearing, even though air-bone gap closure could not be calculated for those cases.

Graft integrity and complications

Graft status was determined from clinic documentation. For each case, the first postoperative outpatient review within a prespecified assessment window was used to classify graft outcome. Successful closure was defined as an intact tympanic membrane with no residual or recurrent perforation recorded at that visit. Graft failure was defined as a residual perforation or a re-perforation documented at the same assessment. Postoperative complications were identified by reviewing outpatient letters, emergency department attendances and hospital admission records related to the operated ear.

Study groups

Endoscopic cases were ordered chronologically by date of surgery and divided into three groups of approximately equal size, representing early, mid, and late endoscopic experience. All microscopic tympanoplasty cases, performed by the same surgeon over the same period, formed a single comparator group. The cohort was additionally stratified by primary versus revision status and by perforation size for descriptive analyses.

Data handling and cleaning

Categorical variables (perforation size and location, operative side, and revision status) were standardised to consistent category labels before tabulation, so that differences in text entry did not affect counts. Operative time was defined as the theatre-recorded interval from incision to skin closure and was screened for implausible data-entry values prior to analysis.

Audiometric data were handled as specified in the protocol, with the mean air-bone gap (ABG) calculated from the available frequencies among 0.5, 1, 2, and 4 kHz, provided that at least three frequency pairs were documented. Graft status was determined from the first postoperative review or, where this was not attended, from any alternative documented examination of the operated ear; cases with no documented postoperative examination were excluded from graft analysis only and retained for other analyses where data were complete.

Statistical analysis

Continuous variables were summarised as mean and standard deviation, and categorical variables as counts and percentages. The pre-specified analyses were as follows. Operative time was compared across the early, mid, and late endoscopic groups using one-way analysis of variance (ANOVA), closure rate was compared across the three groups using the chi-square test, and ABG improvement was

compared across the three groups using one-way ANOVA. For comparisons between all endoscopic cases and the microscopic comparator group, continuous variables were compared using independent-samples t-tests assuming unequal variances (Welch correction), and categorical variables using the chi-square test.

For all categorical comparisons, the Pearson chi-square test without continuity correction was used when every expected cell count was five or greater. Where any expected count was below five, an exact test was used in its place: the Fisher exact test for two-by-two tables, and the Fisher-Freeman-Halton exact test for larger contingency tables. All tests were two-tailed, and a p-value below 0.05 was considered statistically significant.

Two further analyses were performed post hoc and were not part of the original protocol. A cumulative sum (CUSUM) analysis of closure rate was performed on the graft-evaluable endoscopic cases arranged in chronological order of surgery. Beginning at zero, each successful graft raised the running total by (1 − p0), and each failure lowered it by p0, where p0 was the overall closure proportion for the series. The case at which the cumulative sum reached its lowest point was taken as the turning point separating the initial learning phase from subsequent stable performance, and the closure rate before and after this point was compared descriptively using Fisher's exact test. As a further post hoc analysis, a binary logistic regression was fitted to the graft-evaluable endoscopic cases, with closure (success or failure) as the binary outcome and chronological case number as the sole continuous predictor, to test whether the odds of success changed with increasing experience. The odds ratio was reported per 10 cases with its 95% confidence interval. Data were stored in Microsoft Excel, and statistical analysis was conducted in Jamovi [31].

Results

Demographics

A total of 124 Type 1 tympanoplasties were performed between November 2018 and December 2025, of which 106 (85.5%) were endoscopic and 18 (14.5%) were microscopic (Fig. 1), of which 10 were postauricular, 7 permeatal, and 1 endaural. Baseline demographic and operative characteristics were comparable across the early, mid, and late endoscopic groups and between the endoscopic and microscopic groups (Tables 1 and 2), with no statistically significant differences in age, preoperative air-bone gap, operative side, perforation size or location, or revision status.

Table 1

Baseline characteristics across endoscopic learning-curve phases. Endoscopic cases were ordered chronologically by date of surgery and divided into three approximately equal phases representing early, mid and late experience. Continuous variables are presented as mean ± standard deviation and categorical variables as n (%). Phases were compared using one-way analysis of variance for age and preoperative air-bone gap, the Pearson chi-square test for operation side and revision status, and the Fisher-Freeman-Halton exact test for perforation size and location. No baseline characteristic differed significantly between phases. ABG, air-bone gap; ANOVA, analysis of variance; SD, standard deviation; TM, tympanic membrane.

Variable	Early (n = 36)	Mid (n = 35)	Late (n = 35)	P-value	Test used
Age ± SD (years)	38.9 ± 13.1	42.0 ± 13.0	41.6 ± 14.8	0.586	ANOVA
Operation side				0.548	Chi-squared
Left	17	18	21		
Right	19	17	14		
TM perforation size (n)				0.366	FFH exact
Small	8	7	3		
Moderate	20	21	17		
Large	4	4	9		
Subtotal	4	3	6		
Total	0	0	0		
TM perforation location (n)				0.317	FFH exact
Anterior	10	7	10		
Central	1	3	3		
Posterior	10	6	2		
Inferior	12	16	14		
Not applicable (Subtotal or Total)	3	3	6		
Primary versus revision tympanoplasty				0.343	Chi-squared
Primary procedure	32	27	27		
Revision procedure	4	8	8		
Pre-operative ABG, mean ± SD (dB)	25.8 ± 7.8 (n = 19)	22.0 ± 10.1 (n = 28)	22.9 ± 10.1 (n = 32)	0.404	ANOVA

Table 2

Baseline demographic, perforation and operative characteristics by surgical approach. Continuous variables are presented as mean ± standard deviation, and categorical variables as n (%). Groups were compared using the Welch t-test for age, the Pearson chi-square test for operation side, the Fisher-Freeman-Halton exact test for perforation size and location, and the Fisher exact test for revision status. Preoperative air-bone gap is shown for the endoscopic group only, as no microscopic case had usable audiometry, and is therefore presented descriptively without a between-group comparison. ABG, air-bone gap; SD, standard deviation; TM, tympanic membrane.

Variable	Microscopic (n = 18)	Endoscopic (n = 106)	P-value	Test used
Age ± SD (years)	36.6 ± 10.5	40.8 ± 13.6	0.146	Welch t
Operation side			0.126	Chi-squared
Left	6	56		
Right	12	50		
TM perforation size (n)			0.381	FFH exact
Small	3	18		
Moderate	10	58		
Large	2	17		
Subtotal	2	13		
Total	1	0		
TM perforation location (n)			0.422	FFH exact
Anterior	4	27		
Central	3	7		
Posterior	1	18		
Inferior	7	42		
Not applicable (Subtotal or Total)	3	12		
Primary versus revision tympanoplasty			0.426	Fisher exact
Primary procedure	16	86		
Revision procedure	2	20		
Pre-operative ABG, mean ± SD (dB)	Not recorded (n = 0)	23.5 ± 9.8 (n = 79)	n/a	Not calculable

Table 3

Operative and clinical outcomes across endoscopic learning-curve phases. Continuous variables are presented as mean ± standard deviation and categorical variables as n (%). Operative time and air-bone gap closure were compared using one-way analysis of variance, closure rate and second-surgeon involvement using the Pearson chi-square test, and complications using the Fisher-Freeman-Halton exact test. Air-bone gap closure was calculable only for cases with adequate pre- and postoperative audiometry, and the denominator is given in the table. ABG, air-bone gap; ANOVA, analysis of variance; SD, standard deviation.

Variable	**Early (n = 36)**	**Mid (n = 35)**	**Late (n = 35)**	**P-value**	**Test used**
Operative time (mean ± SD) (mins)	63.4 ± 17.6	67.9 ± 16.7	59.6 ± 18.1	0.144	ANOVA
Closure rate, n (%)	25/35 (71.4)	28/32 (87.5)	26/31 (83.9)	0.215	Chi-squared
ABG improvement, dB (mean ± SD)	8.6 ± 7.5 (n = 8)	7.2 ± 8.0 (n = 15)	6.1 ± 10.8 (n = 15)	0.825	ANOVA
Complications				0.460	FFH exact
Infection	1	0	4		
Graft-site infection	0	1	1		
Granulation tissue	1	0	0		
Post-operative neuralgia	0	1	0		
Sensorineural hearing loss	0	0	0		
Facial nerve palsy	0	0	0		
Total number of complications	2	2	5		
Second surgeon involved, n (%)	1 (2.8)	21 (60.0)	12 (34.3)	< 0.001	Chi-squared

Table 4

Operative and clinical outcomes by surgical approach. Continuous variables are presented as mean ± standard deviation, and categorical variables as n (%). Operative time was compared using the Welch t-test, and closure rate, complications, and second-surgeon involvement were compared using Fisher's exact test. Closure rate is expressed per case with a documented postoperative outcome, whereas complications are expressed per the full operated cohort. Air-bone gap improvement is shown only for the endoscopic group, since no microscopic case had usable audiometry, and no between-approach hearing comparison was possible. Second-surgeon involvement is a contextual measure of operative delegation rather than a clinical outcome; the difference reflects the endoscopic series serving as the principal teaching vehicle, while all microscopic cases were performed by the consultant alone. ABG, air-bone gap; SD, standard deviation.

Outcome	Microscopic (n = 18)	Endoscopic (n = 106)	P-value	Test used
Operative time, min (mean ± SD)	69.4 ± 20.0	63.6 ± 17.6	0.263	Welch t
Closure rate (n (%))	16/17 (94.1%)	79/98 (80.6%)	0.299	Fisher exact
ABG improvement, dB (mean ± SD)	Not recorded (n = 0)	7.0 ± 9.0 (n = 38)	n/a	Not calculable
Complications (n (%))			1.000	Fisher exact
Infection	1 (5.6)	5 (4.7)		
Graft-site infection	0	2 (1.9)		
Granulation tissue	0	1 (0.9)		
Post-operative neuralgia	0	1 (0.9)		
Sensorineural hearing loss	0	0		
Facial nerve palsy	0	0		
Total number of complications	1/18 (5.6)	9/106 (8.5)		
Second surgeon involved, n (%)	0/18 (0)	34/106 (32.1)	0.003	Fisher exact

Operative time

Mean operative time did not differ significantly across the three endoscopic phases (early 63.4 ± 17.6 min; mid 67.9 ± 16.7 min; late 59.6 ± 18.1 min; one-way ANOVA, p = 0.144) (Table 3), and was comparable between endoscopic and microscopic approaches (approximately 63 versus 69 min; Welch t-test, p = 0.263) (Table 4).

Closure rate

Graft outcome was documented in 115 of 124 cases; 9 were excluded from the graft analysis owing to the absence of a postoperative examination. Across the three endoscopic phases, the closure rates were

71.4% (25/35), 87.5% (28/32), and 83.9% (26/31), respectively, a difference that did not reach statistical significance in a chi-square test (p = 0.215). On CUSUM analysis of the 98 graft-evaluable endoscopic cases in chronological order, the curve reached its turning point at the 24th case (Fig. 2). Closure rate was 58% (14/24) in the cases preceding this point and 88% (65/74) thereafter (Fisher's exact, p = 0.006). Overall endoscopic closure rate was 80.6% (79/98), compared with 94.1% (16/17) for microscopic cases (Fisher's exact, p = 0.30). On a post hoc basis, post-turning-point endoscopic closure rate (88%, 65/74) did not differ significantly from that of the microscopic group (94%, 16/17; Fisher's exact test, p = 0.681). On binary logistic regression of closure against case number across the 98 graft-evaluable endoscopic cases, the odds of success increased with experience (odds ratio 1.20 per 10 cases, 95% confidence interval 0.99 to 1.45, p = 0.058), a trend that approached but did not reach statistical significance.

Within the endoscopic cohort, closure rate did not differ significantly by perforation size (small 78% (14/18), medium 85% (44/52), large or greater 75% (21/28); Fisher-Freeman-Halton exact, p = 0.65) or location (anterior 67% (16/24), posterior 76% (13/17), central 83% (5/6), inferior 92% (36/39); p = 0.14), though anterior perforations showed the numerically lowest success.

Hearing outcomes

Air-bone gap improvement did not differ significantly across the three phases (early 8.6 ± 7.5 dB, n = 8; mid 7.2 ± 8.0 dB, n = 15; late 6.1 ± 10.8 dB, n = 15; one-way ANOVA, p = 0.825). Paired audiometric data were unavailable for the microscopic group, precluding comparison of hearing outcomes between approaches.

Complications

After excluding residual perforation (analysed as graft failure), the overall endoscopic complication rate was 8.5% (9/106), comprising infection (5/106, 4.7%) and graft-site infection (2/106, 1.9%) together with a single case of granulation tissue requiring treatment (0.9%) and postoperative neuralgia (0.9%). There were no cases of sensorineural hearing loss or facial nerve injury. By phase, recorded complications were 5.6% (2/36), 5.7% (2/35), and 14.3% (5/35) in the early, mid, and late groups, respectively. This apparent increase did not reach statistical significance (Fisher-Freeman-Halton exact, p = 0.460).

Operative delegation

The proportion of cases involving a second operating surgeon rose from 2.8% (1/36) in the early phase to 60.0% (21/35) in the mid phase, then fell to 34.3% (12/35) in the late phase (Fig. 3), while overall operative time remained statistically unchanged. Cases involving a second operating surgeon were longer than those performed by the consultant alone (71.0 ± 14.0 versus 60.2 ± 18.2 minutes; Welch t-test, p = 0.001) but did not differ significantly in closure rate (88% (28/32) versus 77% (51/66); Fisher exact, p = 0.284) or air-bone gap improvement (7.4 ± 9.1 versus 6.9 ± 9.0 dB; Welch t-test, p = 0.875).

Discussion

This single-surgeon retrospective analysis describes the adoption of endoscopic Type 1 tympanoplasty in a district general hospital over seven years. Three findings define the study. First, operative time did not shorten across early, mid, and late experience. Second, closure rate and hearing outcomes were maintained, with CUSUM analysis localising the early learning phase to the first 24 cases. Third, operative responsibility was progressively delegated to second surgeons without compromising outcomes, and the pattern of that delegation itself traced a teaching trajectory.

The absence of a falling operative time is informative rather than disappointing. The operating surgeon was already an experienced microscopic ear surgeon, and surgeons with microscopic training are reported to negotiate a shorter, flatter time-based learning curve when adopting the endoscope than endoscopic-native second surgeons[23, 29]. In such cases, efficiency is largely present from the outset, so a declining operative duration is not the most sensitive marker of competence. Maintained graft and hearing outcomes alongside stable operative time are the expected signature of competent adoption[24, 28].

The more sensitive signal came from CUSUM analysis, which is increasingly used to characterise surgical learning curves because it detects shifts in performance that grouped comparisons obscure[32, 33]. Whereas our pre-specified tertile comparison of closure rate was non-significant, CUSUM identified a clear turning point after approximately 24 cases, with successful TM perforation closure rising from 58% to 88%. This was supported by binary logistic regression, in which the odds of successful closure increased by approximately 20% per 10 cases (OR 1.20 per 10 cases, 95% CI 0.99 to 1.45, p = 0.058). Although this trend only approached significance, it matches the CUSUM signal in both direction and magnitude, and, on the success-rate scale, corresponds to a model-predicted improvement from approximately two-thirds in the earliest cases to around 90% by the end of the series, with the steepest gains occurring early, before plateauing as proficiency was reached. This threshold is consistent with the 15 to 40 cases reported in the literature for endoscopic tympanoplasty and provides a realistic expectation for departments planning a transition from microscopic to endoscopic tympanoplasty[24, 28].

A less commonly reported dimension is the graduated sharing of operative responsibility that accompanied competence. The second surgeons involved were of varying grades, including other consultants, registrars, speciality and associate specialist grades, and a GP speciality trainee, reflecting operative delegation more broadly than formal trainee teaching alone. Reassuringly, cases involving a second surgeon did not differ in closure rate or hearing improvement, indicating that sharing the operation did not compromise patient outcomes, consistent with evidence that supervised operative autonomy can be achieved without harming results[34]. Such graduated entrustment of defined operative responsibility is a core mechanism of competency-based surgical training[35]. As the consultant's competence consolidated, operating was increasingly shared with second surgeons, peaking in the mid-phase; the subsequent fall in the late phase is open to interpretation, since training-

grade surgeons may have progressed to independent operating while changes for non-training colleagues may reflect list composition, and the records cannot distinguish these.

These observations align with established models of surgical education. Deliberate, supervised practice with feedback underpins skill acquisition, and proficiency-based progression frameworks advocate advancing trainees against defined competence benchmarks rather than on case numbers alone [36, 37]. Simulation and modular endoscopic trainers shorten the early learning curve for endoscopic ear surgery, and our real-world data complement that experimental work by demonstrating sustained outcomes during live, supervised training and graduated handover of operative responsibility[22].

Benchmarked against the same surgeon's microscopic tympanoplasty, endoscopic outcomes were comparable, with no significant difference in operative time or closure rate, consistent with systematic reviews reporting equivalent outcomes between approaches[16, 17]. The numerically higher microscopic closure rate (94% versus 81% overall) should be interpreted with caution and was driven largely by the initial learning phase. The overall endoscopic closure rate of 81% understates established performance because it incorporates the early learning phase, in which closure rates were lower (58% before the turning point). Once those cases are set aside, post-turning-point success was 88%, within a few percentage points of the microscopic benchmark and consistent with the logistic regression projection that success would approach 90% with experience. This comparison is exploratory and post hoc, and the microscopic group is small, but it indicates that beyond the learning phase, endoscopic closure rate is, in practice, comparable to microscopic surgery. In addition, the transcanal endoscopic route avoids the associated soft-tissue dissection and, frequently, canaloplasty, with the potential benefits for postoperative pain and cosmesis reported in comparative series[16–18]. The small comparator group nonetheless warrants caution in interpreting the absolute difference.

For a department, these findings translate into a realistic set of expectations during transition rather than a single competence number. Competence on outcome measures should be expected to consolidate over the first 20 to 25 cases; operative time need not fall for a surgeon already trained in microscopic otology, and graft, hearing, and safety outcomes can be maintained from the outset while operative responsibility is progressively shared. In summary, a department adopting endoscopic Type 1 tympanoplasty can anticipate:

- Competence on outcome measures consolidating after roughly 20 to 25 cases (exploratory).
- Operative time that does not shorten for an already microscope-trained surgeon; theatre lists should be planned on that basis.
- Hearing and complication rates maintained from the outset, with no sensorineural hearing loss or facial nerve injury; closure rate consolidating to a level comparable with microscopic surgery after roughly 24 cases.
- Operative responsibility that can be progressively shared with second surgeons of varying grades without compromising outcomes.

Limitations

This was a retrospective, single-centre, single-surgeon study, which limits generalisability but suits a pragmatic learning-curve description. Audiometric data were incomplete and unavailable for the microscopic group, precluding hearing comparison between approaches. The degree of trainee involvement could not be quantified, as noted above. Because other consultants and resident doctors operated in a growing share of later cases, the surgeon's individual learning curve cannot be fully separated from the teaching effect, and operative time is interpreted at the level of the practice rather than the individual.

Conclusion

Endoscopic Type 1 tympanoplasty was adopted safely in a district general hospital, with closure rate and hearing maintained from early in the series, competence on CUSUM analysis reached at approximately 24 cases, and operative times comparable to microscopic surgery. The marker of successful adoption in an experienced microscopic surgeon was not a falling operative time but the ability to maintain outcomes while progressively and safely transferring operative responsibility to second surgeons. These findings support endoscopic tympanoplasty as a teachable primary modality and offer a realistic framework for departments and trainees planning the transition.

Abbreviations

ABG
air-bone gap
ANOVA
analysis of variance
BIPP
bismuth iodoform paraffin paste
CI
confidence interval
CUSUM
cumulative sum
ENT
ear, nose and throat
FFH
Fisher-Freeman-Halton
GP
general practitioner
OR
odds ratio
SD

standard deviation
STROBE
Strengthening the Reporting of Observational Studies in Epidemiology
TM
tympanic membrane.

Declarations

Ethics approval and consent to participate

This study was registered as a service evaluation by the Quality and Patient Safety Team of Homerton Healthcare NHS Foundation Trust, London, United Kingdom (reference number 22959). The Research and Innovation Department of the same Trust confirmed that the project was classified as a service evaluation rather than research under the UK Health Research Authority and Medical Research Council framework, and that review by an NHS Research Ethics Committee was therefore not required[38]. The evaluation used patient records collected during routine clinical care, accessed by the clinical team responsible for those patients under Trust information governance approval. Individual informed consent to participate was not required; this was confirmed by the Research and Innovation Department in keeping with HRA guidance for service evaluations using routinely collected data. No identifiable patient information is presented in this manuscript. The study was conducted in accordance with the Declaration of Helsinki and the UK Data Protection Act 2018.

Consent for publication

Not applicable as the manuscript contains no identifiable individual person's data, images, or videos.

Competing interests

The authors declare that they have no competing interests.

Authors' information

ADG and AE are resident ENT doctors. MW is a consultant otologist and clinical director of the ENT department.

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None.

Author Contribution

Conceptualisation, ADG, MW; Methodology, ADG, MW; Data collection, ADG, AE; Data Analysis, ADG; Writing the manuscript, ADG; Reviewing and editing the manuscript, ADG, AE, MW; Visualisation, ADG; Supervision, MW. All authors have reviewed the submitted version of this manuscript. Corresponding author: Antoni D. Gardener.

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Data Availability

The dataset generated and analysed during this study is not publicly available. It consists of individual patient-level clinical data from a single-centre cohort, in which the combination of demographic, operative, and audiometric variables would carry a meaningful risk of patient re-identification even after direct identifiers are removed. Furthermore, public release also falls outside the scope of the study's service-evaluation approval.

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Figures

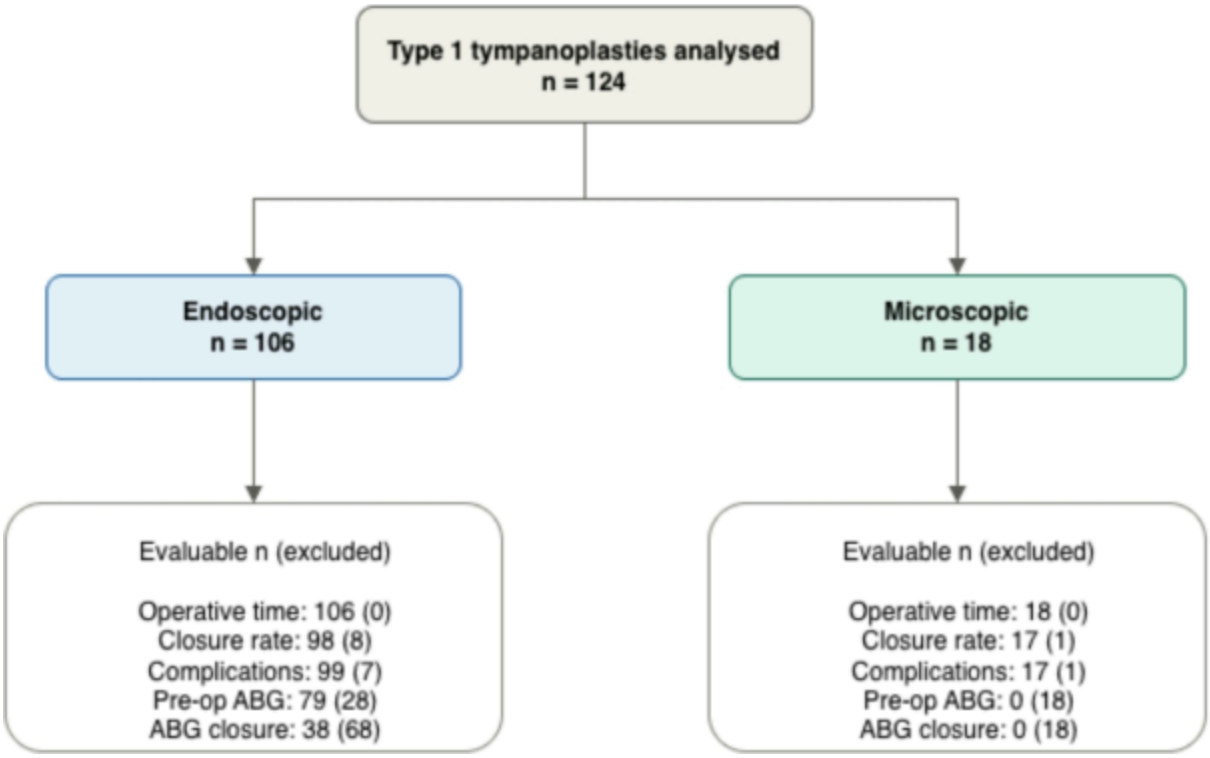


Figure 1

Flow of Type 1 tympanoplasty cases and analysis populations. All 124 Type 1 tympanoplasties performed by the single operating surgeon entered the study; procedures miscoded to another surgeon or a different operation were corrected at source and were not counted as exclusions. Cases were grouped by surgical approach into endoscopic (n = 106) and microscopic (n = 18). For each approach, the number of cases evaluable for each outcome is shown, with the number excluded for missing data in parentheses. These missing-data exclusions are outcome-specific and overlapping, so the evaluable populations are presented in parallel rather than as a sequence of subtractions from the cohort. Operative time was available for every case. Closure rate and complications were excluded only where no postoperative examination of the operated ear was documented. Air-bone gap (ABG) analyses were

restricted to endoscopic cases with sufficient audiometric data, since no microscopic cases had usable pre- or postoperative thresholds. ABG, air-bone gap.

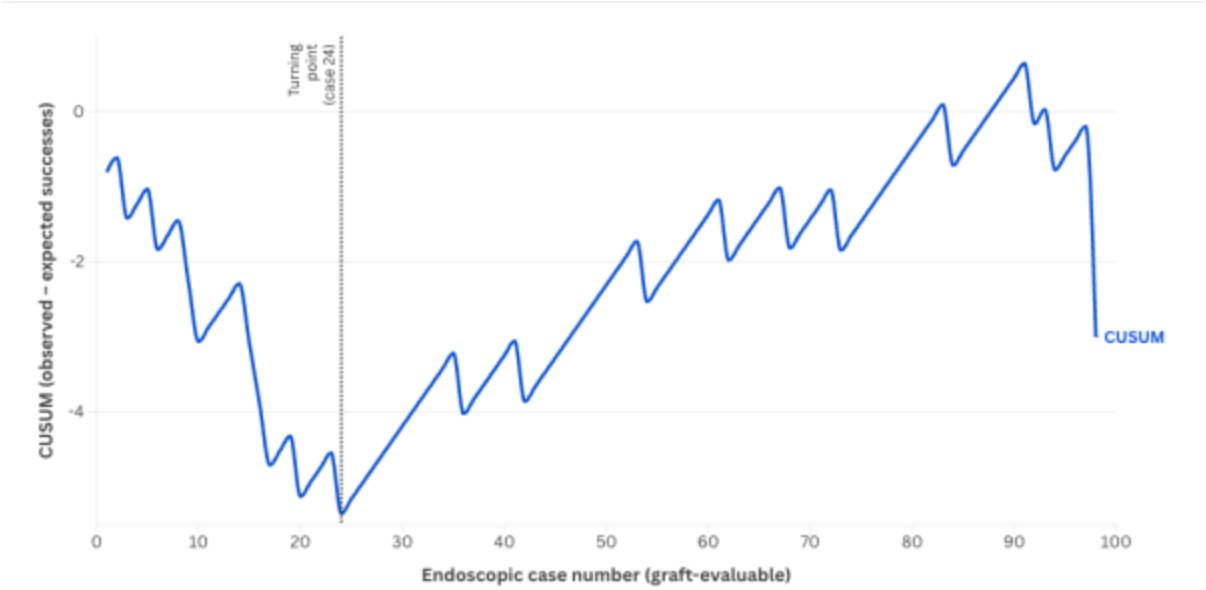


Figure 2

Cumulative sum (CUSUM) chart of closure rate across 98 consecutive graft-evaluable endoscopic Type 1 tympanoplasties in chronological order. Each successful graft raises the curve, and each failure lowers it relative to the cohort mean success rate, so the lowest point marks the transition from the learning phase to stable performance. The turning point occurred at the 24th case (dashed line), separating an early phase with 58% closure rate from a later phase with 88% closure rate.

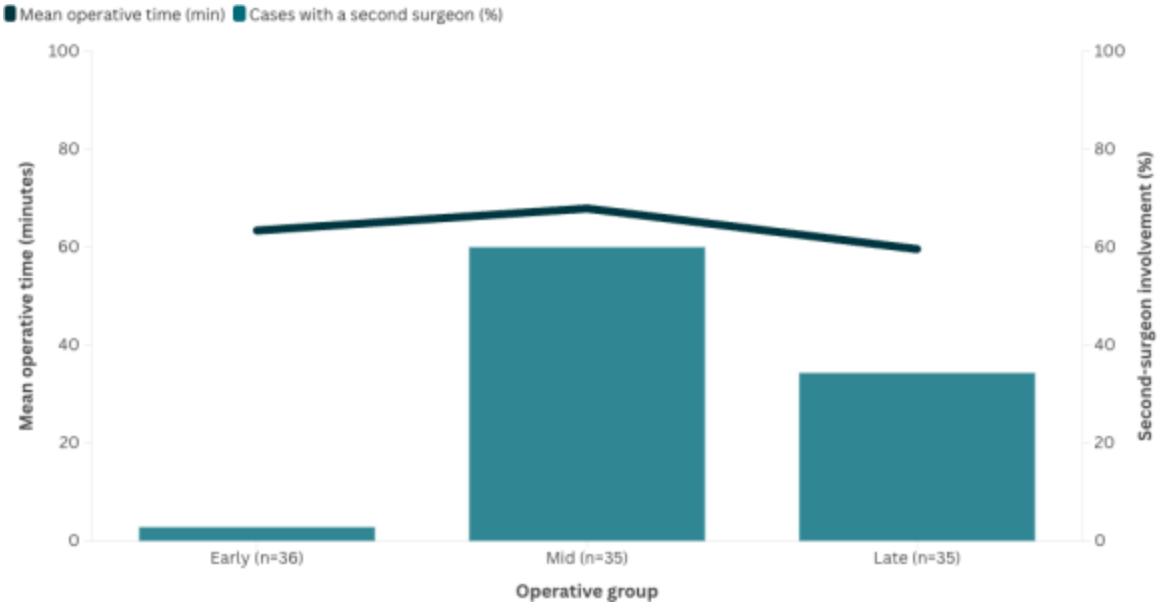


Figure 3

Mean operative time with 95% confidence intervals (navy line and shaded band, right axis) and the proportion of cases involving a second operating surgeon (teal bars, left axis) across the early (n = 36), mid (n = 35), and late (n = 35) endoscopic phases. Operative time did not differ significantly across the three phases (one-way ANOVA, p = 0.144), whereas second-surgeon involvement varied markedly (2.8%, 60.0%, and 34.3% respectively; chi-square p < 0.001), reflecting progressive delegation of operative responsibility as the surgeon's proficiency became established. The contrast illustrates that operative efficiency was maintained throughout adoption, even as an increasing share of cases was performed with a second surgeon.