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METHODS TO IMPROVE SURGICAL EFFICIENCY BY USING ARTIFICIAL INTELLIGENCE IN THE MANAGEMENT OF PATIENTS WITH MAXILLARY SINUS CYSTS

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Abstract
Maxillary sinus cystic lesions include mucous retention cysts, pseudocysts, postoperative maxillary cysts, mucoceles, and odontogenic cystic lesions extending into the sinus. Mucous retention cysts and pseudocysts are usually benign incidental findings and may be seen in up to 13% of adults, but differential diagnosis remains important because CT or CBCT is often needed to distinguish them from lesions that require surgery. In recent years, artificial intelligence has emerged as a promising adjunct for detecting maxillary sinus pathology, segmenting lesion volume, and supporting surgical planning. Systematic reviews of CT and CBCT studies report diagnostic accuracy roughly in the 85% to 97% range, sensitivity from 87% to 100%, and specificity from 87.2% to 99.7%, while automated maxillary sinus segmentation models based on nnU-Net v2 have achieved F1-scores around 0.96, sensitivity 0.96, Dice coefficients about 0.96, and IoU near 0.93.
The aim of this modeled study was to evaluate whether an AI-assisted workflow could improve surgical efficiency and perioperative decision-making in 140 patients with maxillary sinus cysts managed at the TDTU ENT Department. The modeled protocol combined standard clinical assessment, nasal endoscopy, CT or CBCT imaging, AI-based lesion triage, automatic 3D segmentation, and a decision-support layer for choosing observation, standard endoscopic surgery, or extended endoscopic access. Synthetic outcomes suggested that AI support improved diagnostic concordance, shortened time to final operative planning, reduced additional imaging, improved selection of the endoscopic corridor, and modestly reduced recurrence and operative time in anatomically complex lesions.

Keywords: Maxillary sinus cyst, mucous retention cyst, postoperative maxillary cyst, mucocele, artificial intelligence, CBCT, CT, endoscopic sinus surgery, prelacrimal approach, surgical planning.

Introduction

Maxillary sinus cystic lesions are common findings in otorhinolaryngology and dentomaxillofacial practice. Their spectrum includes mucous retention cysts, pseudocysts, postoperative maxillary cysts, mucoceles, and odontogenic cystic lesions secondarily involving the sinus. Mucous retention cysts and pseudocysts are benign, frequently asymptomatic, and reported in up to 13% of adult patients, yet they may still cause facial pressure, recurrent sinus symptoms, or treatment-planning dilemmas when dental or endoscopic intervention is being considered. CT is regarded as a key tool for

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establishing the correct diagnosis and for differentiating these lesions from more aggressive benign or malignant maxillary sinus processes.

Conventional diagnosis depends on symptoms, nasal endoscopy, and imaging. However, treatment planning may be difficult when lesion type, wall of origin, sinus compartment, odontogenic contribution, or lateral extension are unclear. This is particularly relevant in postoperative maxillary cysts and laterally placed lesions, where standard middle meatal access may not provide sufficient visualization or safe drainage. Recent endoscopic literature shows that, for symptomatic maxillary retention cysts, inferior meatal antrostomy with basal mucosal electrocoagulation may provide recurrence advantages over middle meatal antrostomy alone, while for anterior and lateral postoperative maxillary cysts, direct anterior-lateral endoscopic approaches such as DALMA can help preserve the infraorbital nerve and maintain durable drainage.

Artificial intelligence offers a potential solution to this planning problem. Recent reviews of sinonasal and maxillary sinus imaging show that deep-learning models can classify maxillary sinus lesions on panoramic radiography, detect pathology on CT or CBCT, and perform highly accurate automatic sinus segmentation. In parallel, the CLAIM 2024 update emphasized that AI imaging studies should be transparent, clinically grounded, and reported in ways that facilitate translation into practice.

Against this background, an AI-assisted surgical workflow for maxillary sinus cysts is clinically attractive because it could improve lesion characterization, define the safest access corridor, predict operative complexity, and reduce avoidable surgery in incidental lesions.

Materials and Methods

This manuscript was designed as a modeled prospective cohort study. A total of 140 patients with suspected maxillary sinus cystic lesions were included. The modeled inclusion criteria were unilateral or bilateral maxillary sinus cystic pathology identified on CT or CBCT, with or without symptoms such as facial pressure, unilateral nasal obstruction, recurrent rhinosinusitis, postnasal discharge, or dental complaints. Exclusion criteria were suspected malignancy, invasive fungal sinusitis, major facial trauma, or incomplete imaging.

All patients underwent standard otorhinolaryngologic assessment, rigid nasal endoscopy, and CT of the paranasal sinuses. CBCT was additionally available in selected cases, especially when dental pathology or sinus floor origin was suspected. The conventional workflow consisted of radiologic interpretation by the treating team and subsequent classification into three management pathways: observation, standard endoscopic sinus surgery, or extended endoscopic/maxillofacial combined management. This approach reflects current practice in which CT or CBCT defines lesion size, location, relationship to sinus walls, and odontogenic associations.

The AI-assisted workflow was modeled with three components. The first was a 2D triage model for panoramic images, conceptually based on previously published deep-learning classifiers that distinguish normal sinus appearance, retention pseudocysts, and clinically important pathologic lesions. The second was a 3D segmentation model for CT/CBCT, modeled on nnU-Net-type approaches that automatically delineate the maxillary sinus and the cystic lesion, estimate lesion volume, and map extension toward the anterior, lateral, inferior, or prelacrimal recess regions. The third was a decision-support layer that integrated symptoms, endoscopy, lesion size, location, odontogenic signs, prior surgery, and AI-derived morphometric features to recommend one of the

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following: follow-up only, middle meatal antrostomy, inferior meatal antrostomy, prelacrimal extended access, or combined ENT-dental surgery. AI segmentation performance reported in the literature supports the plausibility of this design.

The reference standard was histopathology in operated patients and 12-month radioclinical stability in conservatively managed patients. The primary modeled endpoints were diagnostic concordance with the reference standard, time from first imaging to final surgical decision, operating time, intraoperative need to modify the access corridor, and 12-month recurrence. Secondary endpoints included the number of additional imaging studies, postoperative symptom improvement, and the proportion of patients in whom AI changed the planned surgical strategy.

Results

In the modeled cohort, 140 patients were included: 82 women and 58 men. The mean age was 42.6 ± 11.8 years. Eighty-eight patients were symptomatic and 52 had incidental lesions detected during imaging performed for other reasons.

Table 1. Baseline characteristics of the modeled cohort

Variable	Value
Number of patients	140
Mean age, years	42.6 ± 11.8
Female, n (%)	82 (58.6)
Male, n (%)	58 (41.4)
Symptomatic patients, n (%)	88 (62.9)
Incidental lesions, n (%)	52 (37.1)
Facial pressure/pain, n (%)	69 (49.3)
Unilateral nasal obstruction, n (%)	51 (36.4)
Recurrent rhinosinusitis, n (%)	44 (31.4)
Dental or implant-related referral, n (%)	47 (33.6)
Prior maxillary sinus surgery, n (%)	19 (13.6)

Final modeled diagnoses were mucous retention cyst/pseudocyst in 94 patients, postoperative maxillary cyst in 18, odontogenic cystic lesion involving the sinus in 16, and mucocele in 12.

Table 2. Final diagnosis in the modeled cohort

Diagnosis	n	%
Mucous retention cyst / pseudocyst	94	67.1
Postoperative maxillary cyst	18	12.9
Odontogenic cystic lesion involving the sinus	16	11.4
Mucocele	12	8.6

The mean maximal lesion diameter was 24.2 ± 8.7 mm, and the mean lesion volume estimated by AI segmentation was 5.6 ± 3.4 cm^3. Inferior wall or sinus floor predominance was seen in 58 cases, medial wall in 26, anterior or anterolateral location in 21, lateral recess extension in 19, and diffuse/multicompartment involvement in 16.

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In the modeled analysis, conventional clinician-only diagnosis showed 83.6% concordance with the reference standard. After adding AI triage, segmentation, and decision support, concordance increased to 94.3%. The AI trilevel workflow was also associated with a reduction in additional imaging requests from 26 to 11 cases and shortened time to final treatment planning from 4.1 ± 1.8 days to 2.3 ± 1.2 days.

Table 3. Modeled diagnostic and workflow performance

Metric	Clinician-only workflow	AI-assisted workflow
Concordance with reference standard, n (%)	117 (83.6)	132 (94.3)
Additional imaging studies required, n	26	11
Time to final treatment decision, days	4.1 ± 1.8	2.3 ± 1.2
Mean imaging interpretation time, min	12.8 ± 3.6	7.4 ± 2.3
Correct initial treatment-pathway selection, n (%)	114 (81.4)	131 (93.6)

The modeled 2D triage block achieved an AUC of 0.90 for panoramic-image classification. The 3D segmentation block achieved a Dice coefficient of 0.93 and IoU of 0.88 for lesion delineation. These modeled values are aligned with published literature showing high performance for both detection and segmentation of maxillary sinus pathology on CT/CBCT.

AI changed the initial management plan in 31 patients. In 13 of these, surgery was avoided because the lesion was reclassified as a small incidental retention cyst/pseudocyst without clinically meaningful obstruction. In 8 patients, the system recommended inferior meatal rather than middle meatal access because of inferior wall attachment and favorable geometry for short operative drainage. In 7 patients with anterior or lateral postoperative cysts, the plan changed to a prelacrimal or DALMA-type extended access. In 3 patients, combined ENT-dental surgery was selected because the model flagged strong odontogenic involvement.

In the 63 operated patients, the AI-assisted group had a shorter modeled mean operating time than the conventional planning pathway, 41.2 ± 10.6 minutes versus 49.8 ± 12.4 minutes. Intraoperative change of access corridor was needed in 6.3% of AI-assisted cases compared with 19.0% of conventionally planned cases. Mucosal preservation was graded as satisfactory in 87.3% versus 74.6%, respectively.

Table 4. Modeled surgical outcomes in operated patients

Variable	Conventional planning	AI-assisted planning
Operated patients, n	63	63
Mean operating time, min	49.8 ± 12.4	41.2 ± 10.6
Intraoperative access change, n (%)	12 (19.0)	4 (6.3)
Satisfactory mucosal preservation, n (%)	47 (74.6)	55 (87.3)
Hospital stay, days	1.8 ± 0.7	1.4 ± 0.5
Early postoperative complication, n (%)	6 (9.5)	4 (6.3)
Twelve-month recurrence, n (%)	7 (11.1)	3 (4.8)

At 12 months, symptom relief was modeled as complete or substantial in 87.3% of AI-assisted surgical cases. Recurrence was lowest in patients for whom AI recommended inferior meatal

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antrostomy for inferiorly based symptomatic retention cysts and in those assigned to extended prelacrimal/DALMA access for postoperative anterior-lateral cysts.

The present modeled manuscript suggests that AI may improve surgery not by replacing the surgeon, but by enhancing preoperative precision. This is consistent with the current literature, where AI has shown value in classifying maxillary sinus lesions, improving lesion localization, and automating sinus segmentation on CBCT and CT. Reviews published in 2024 and 2025 indicate that these models already perform well enough to support, though not replace, expert radiologic and surgical judgment. The strongest practical contribution of AI in this setting is likely to be better surgical triage. A substantial proportion of mucous retention cysts and pseudocysts are incidental and asymptomatic, and many can be managed conservatively. Because these lesions can mimic more significant pathology on 2D imaging, surgeons may otherwise overuse advanced imaging or overtreat benign findings. The modeled reduction in unnecessary surgery and repeat imaging is therefore clinically plausible and consistent with the literature showing both the benign nature of many retention cysts and the diagnostic difficulty of distinguishing them from other sinus lesions on planar radiography.

The second major benefit is access planning. For symptomatic retention cysts, published surgical evidence indicates that inferior meatal antrostomy with basal mucosal electrocoagulation can provide similar symptom control but shorter operating times and lower recurrence than middle meatal antrostomy alone. For postoperative maxillary cysts extending laterally or anteriorly, newer endoscopic approaches such as DALMA or related prelacrimal routes can improve visualization and help avoid infraorbital nerve injury. In the modeled cohort, AI-derived geometry and wall-of-origin mapping made these choices more consistent and reduced intraoperative changes of plan.

The segmentation component is especially relevant for surgical efficiency. Published nnU-Net v2 studies report near-expert automatic segmentation of the maxillary sinus on CBCT, with Dice values around 0.96 and high sensitivity. In practice, such performance can support faster morphometric analysis, help less experienced surgeons appreciate sinus boundaries and hidden recesses, and improve communication within ENT-dental multidisciplinary teams. That makes AI particularly useful in lesions involving the sinus floor, prelacrimal recess, or lateral recess, where geometry directly influences the safest route of entry.

Even so, AI implementation in sinonasal surgery remains an emerging field. The available literature still includes small datasets, single-center development cohorts, and limited external validation. The CLAIM 2024 update explicitly emphasizes transparent reporting, clinically relevant endpoints, and reproducibility as prerequisites for trustworthy translation into practice. Any real prospective study on AI-assisted management of maxillary sinus cysts should therefore include external validation, calibration assessment, failure-mode analysis, and subgroup analysis by cyst type and sinus compartment.

Conclusion

In this modeled 140-patient study, an AI-assisted workflow improved the preoperative management of maxillary sinus cysts by increasing diagnostic concordance, reducing avoidable imaging, shortening time to definitive decision-making, and improving selection of the endoscopic approach. The greatest potential gains were seen in two areas: avoiding unnecessary intervention for incidental

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benign retention cysts, and selecting the most efficient surgical corridor for symptomatic inferior, anterior, or lateral lesions.

From a surgical standpoint, the most promising use of AI is not autonomous decision-making, but structured support for lesion classification, 3D segmentation, and access-route optimization. A future real-world TDTU ENT study could validate this model prospectively and determine whether the observed synthetic improvements in operating time, recurrence, and hospital stay are reproducible in clinical practice.

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