# Artificial intelligence for predicting hearing improvement after myringoplasty: a pilot study

## INTRODUCTION

The four-frequency pure tone average (4FA) is used conventionally to determine hearing loss severity, but with the advent of automated technology in audiometers such as the CREARE,[1] AMTAS[2] and SHOEBOX,[3] a complete automated classification of hearing loss type and severity can be further achieved. At our local tertiary specialist Ear, Nose and Throat (ENT) outpatient clinic, an average of 13,000 hearing tests are ordered annually when patients present with ear-related symptoms, including hearing loss. One clinical problem statement involves perforated tympanic membranes, also known as ruptured eardrums, which are prone to infections and hearing loss.[4] Such perforations can be repaired with myringoplasty, a surgical procedure in which a graft is placed to seal the hole. The success of myringoplasty, in relation to improvement in hearing, may depend on various factors, including patient demographics and surgical approach. Despite current literature detailing various preoperative surgical factors that affect postoperative hearing outcomes, a consensus is yet to be established. Myringoplasty is currently indicated for recurrent infections[5] of the outer and middle ear with the primary objective of preventing further ear infections. Hearing improvement is not a guarantee,[6] and existing studies report conflicting results on postoperative hearing improvement. Hence, postoperative hearing improvement in patients who have undergone myringoplasty is a controversial issue. For instance, a retrospective study on 187 patients who underwent myringoplasty[7] concluded that there were no obvious predictive factors on hearing outcomes, although posterior perforations and the possibility of ossicular chain manipulations were factored into consideration. Conversely, other studies reported that patient parameters did not correlate with hearing improvement, but the size and location of perforation appeared to play a role in post-myringoplasty hearing outcomes.[8]

Given the wide range of factors that could potentially influence post-myringoplasty hearing outcomes, artificial intelligence (AI) utilising machine learning techniques may possibly be adopted to predict postoperative hearing outcomes by drawing conclusions from data analysis. Hence, the objective of this study was to use AI to predict hearing improvement after myringoplasty. The predictive model must first use a decision tree algorithm to classify the type and severity of hearing loss. This will also serve as the groundwork for approaching problem statements involving AI to predict hearing loss or improvement in different diseased states of the ear.

## METHODS

This was a service improvement collaborative project between clinicians and information system engineers to automate interpretation of audiograms and predict hearing improvement with AI. A service improvement audit notification was filed with the Department of Medical Informatics (DMI) under the Chief Medical Informatics Officer's (CMIO) office before the study began. The study aimed to develop an algorithm for automatic classification of hearing loss, which can be potentially integrated with our clinical audiometers and proprietary hearing software, NOAH, an integrated software system designed specifically for hearing health professionals and a unified system for client-related tasks. Once the algorithm was established, we approached a controversial problem statement on postoperative hearing improvement of patients who have undergone surgical repair of the eardrum alone (myringoplasty/Grade I tympanoplasty).

We retrospectively looked into patients who had undergone myringoplasty between January 2017 and December 2019. All patients were included as long as they had a pre- and postoperative audiogram. A total of 125 patients were included in this study to first develop the algorithm for automated classification of hearing loss type and severity. After excluding 26 patients with missing data, the data of the remaining 99 patients were used to train a regression-based neural network for prediction of postoperative air–bone gap (ABG). This study was conducted in two phases. The first phase consisted of designing a decision tree algorithm that automatically classifies hearing loss severity and type based on audiogram results. The second phase focused on prediction of hearing outcomes post-myringoplasty using predictor variables, including patient age, clinical presentations and surgical parameters, with the help of machine learning models. The variables used for training the AI model were extensively discussed with two highly trained otologists. Some input variables such as surgeon type, postoperative graft migration or ear infection may not be clinically useful, as they cannot be used to help patients make an informed decision on myringoplasty. Preoperative demographics (such as age, gender, size and location of perforation) and preoperative ABGs were determined to be more clinically useful for preoperative counselling, as these factors can be predetermined before operation. All variables were then subjected to further statistical tests in the AI training model to rank their contributions to the model.

## RESULTS

Of the 125 patients, 59 were male and 66 were female. Of the patients, 58 (46%) were Chinese, 35 (28%) were Malay, 8 (6%) were Indian and 24 (20%) belonged to other races. The mean age of the patients was 50.3 years (range 15–81). There was involvement of the right ear and left ear in 43% and 57% of the patients, respectively. Approximately 35% had a central perforation, followed by posterior perforation in 28%, subtotal perforation in 25% and anterior perforation in 12% of cases. The majority of patients underwent myringoplasty with a posterior auricular surgical approach (47%), and more than half of the cases had temporalis fascia as the graft type (66%). The end-aural and endoscopic approaches were used in 32% and 21% of cases, respectively. In a minority of cases, tragal cartilage (23%), fat plug (9%) and bio-design (2%) were the preferred graft materials used. The underlay surgical technique was used in 102 cases (81%), while the overlay and plug techniques were used in 10% and 9% of cases, respectively. A summary of the demographic and surgical profile is shown in Table 1. Regression using a neural network with root mean squared error (RMSE = 18.70 dB) and a decision tree with a maximum depth of 4 (RMSE = 17.25 dB) generated comparable results with most predictions falling within ±20 dB as seen in predicting postoperative ABGs. The

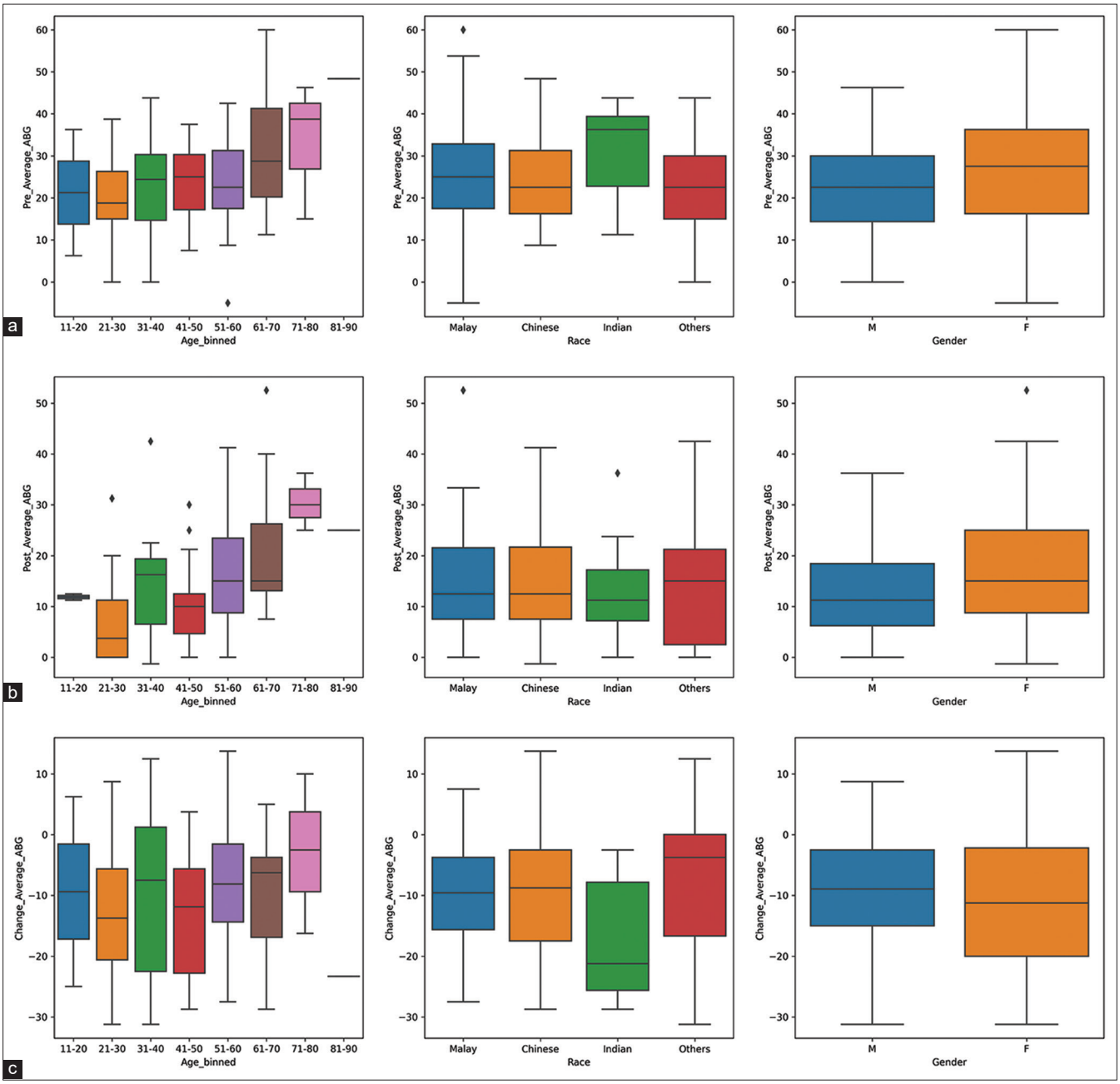


**Figure 1:** Box plots show (a) preoperative air–bone gap (ABG), (b) postoperative ABG, (c) change in ABG (post-op – pre-op) against age, race and gender.

**Table 1. Demographic details and clinical characteristics of patients who underwent myringoplasty (*n*=125).**

| Variable | *n* (%) |
|---|---|
| Gender | |
| Male | 59 (47.2) |
| Female | 66 (52.8) |
| Ethnicity | |
| Chinese | 58 (46.4) |
| Malay | 35 (28.0) |
| Indian | 8 (6.4) |
| Others | 24 (19.2) |
| Age[a] (yr) | 50.3 (15–81) |
| Perforation side | |
| Right | 54 (43.2) |
| Left | 71 (56.8) |
| Perforation location | |
| Central | 44 (35.2) |
| Posterior | 36 (28.8) |
| Subtotal | 30 (24.0) |
| Anterior | 15 (12.0) |
| Surgical approach | |
| Posterior auricular | 59 (47.2) |
| End aural | 40 (32.0) |
| Endoscopic | 26 (20.8) |
| Graft material | |
| Temporalis fascia | 83 (66.4) |
| Tragal cartilage | 29 (23.2) |
| Ear lobe fat | 11 (8.8) |
| Bio-design | 2 (1.6) |
| Surgical technique | |
| Underlay | 102 (81.6) |
| Overlay | 12 (9.6) |
| Plug | 11 (8.8) |

[a]Data presented as median (range); male and female median ages were 50.3 years and 49.9 years, respectively.

top three significant predictors were age, size of perforation and preoperative ABG.

It was observed that age was positively correlated with both pre- and postoperative pure tone ABG. In the preoperative ABG, most of the confidence intervals across the age groups were overlapping, suggesting that the differences could be insignificant. However, in the postoperative ABG, the confidence interval for patients in the 71–80 years old category was nonoverlapping with that of below 50 years, which may suggest that the effect of the surgery may be more limited in people aged from 71 to 80 years. Figure 1 shows a box plot illustrating the correlation of audiogram results against patient age, race as well as gender. Also, the mean decrease in ABG (improvement in hearing loss) was lower compared to the other age groups, although the difference did not appear significant. Figure 2 shows the relative and cumulative importance levels of the various features in the predictive model.

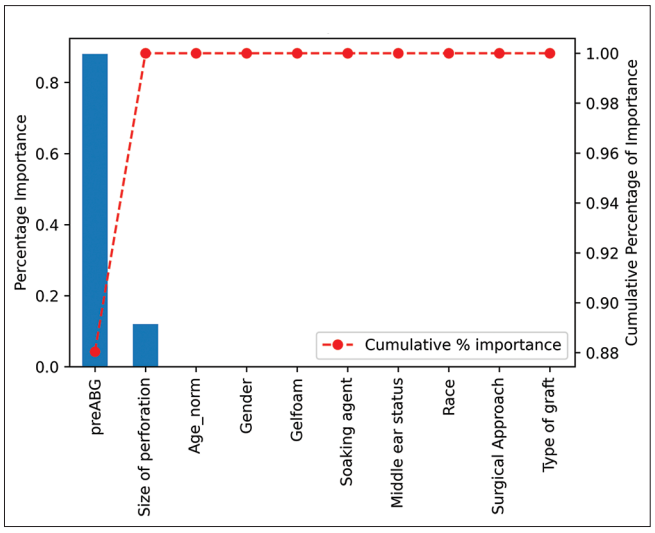


**Figure 2:** Graph shows the rank of features by importance levels in descending order. ABG: air–bone gap

The size of perforation was found to be the second most important feature in determining postoperative hearing outcomes. This is reasonable as the size of perforation is one of the indicators of the clinical severity of the perforation, which, in turn, affects hearing. The findings here are also in line with the results of two studies,[8,9] both of which concluded that post-myringoplasty hearing outcome is affected by the perforation size of the tympanic membrane.

## DISCUSSION

The key findings of this novel pilot study are the potential use of preoperative variables such as ABG, size of perforation and age to predict the hearing levels after myringoplasty. The decision tree and neural network algorithm can also be engineered into a graphical user interface (GUI) via Windows command prompt (CMD), which will allow integration into proprietary software such as the NOAH (interface for audiometry applications).

Limitations of this study include a relatively small sample size for neural network training. Larger databases are required to improve the model and modify the AI architecture. For example, although other variables such as middle ear status did not reveal any statistical significance in the predictive modelling, this may change with an expanded dataset with further refinement and training of the AI model. However, it is of note that perioperative factors such as middle ear status may not be clinically useful, as it can only be determined perioperatively and patients cannot be counselled before the operation. It has further been suggested that middle ear status correlates with preoperative ABG,[10] and since preoperative ABG is a significant predictor, it can be used to counsel patients on their decision regarding myringoplasty. This study has paved the way forward for an expansion

of dataset to further refine and train the AI model. Once accuracy is achieved to be within ±10 dB of the thresholds predicted (comparable to gold standard test–retest reliability), clinical validation by prospectively recruiting patients listed for myringoplasty is warranted. We can then apply the predictive algorithm prospectively via GUI and validate its accuracy by comparing it with postoperative manual interpretation of hearing levels.

The value of this study is in bridging the knowledge gap, where the correlation between postoperative outcomes and several preoperative parameters remains unknown and debatable. Both models in this study produced moderately precise predictions, with a mean squared error around 10 dB and a 95% confidence interval of less than 20 dB in terms of absolute prediction error. Once the results of this project are expanded and refined, they could also be used as a proof of concept and starting point for future research on related applications, such as the prediction of postsurgical outcomes using preoperative parameters in specialities outside that of the ENT department.

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## Conflicts of interest

There are no conflicts of interest.

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