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ORIGINAL ARTICLE TECHNOLOGY AND IMAGING

Using midfacial CT to design patient-matched, 3D printed nasal splints: a retrospective study

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Abstract

Background: Skin cancers on the nose are common in Australia and are often reconstructed with a full-thickness skin graft. Skin grafts on the nasal alar are prone to failure. We hypothesise that this is due to the mobility of the alar and we believe that patient-matched intranasal splints have the potential to support the alar during graft healing and improve graft take. This study aims to characterise nasal morphology in southeast Queenslanders affected by skin cancers, define the input modalities required to design patient-matched intranasal splints, and establish the workflow for the manufacture of these splints.

Methods: A series of 200 computed tomography (CT) scans were investigated and segmented into 3D models. They were then classified into groups according to nostril shape using a modified system derived from the literature. Statistical shape modelling was applied to each group to generate a design envelope of noses representative of our cohort.

Results: Participants were aged 16–97 years. A design envelope of six nose shapes was generated. These six nose shapes will be used as a basis to design and create patient-matched intranasal splints that will stabilise the nasal alar with the intention of improving graft take.

Conclusion: This study demonstrates that statistical shape models can be generated for a given nasal morphology known to be common in a target population. The results of this study will be used to support a future randomised controlled trial testing the safety, tolerability and efficacy of these nasal splints.

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Introduction

Skin cancers are one of the most common types of cancer in Australia. It is estimated that two in three Australians will be diagnosed with skin cancer by the age of 70.[1,2] Skin cancers of the nose are common[3] and present specific challenges. Alar defects following removal of nose skin cancers are often reconstructed with a full-thickness skin graft (FTSG). During a six-month period in 2024, 135 nose skin cancers were reconstructed with an FTSG at the Princess Alexandra Hospital (PAH).

An FTSG involves transferring the epidermis and dermis from a remote donor site to the wound area. There are various reasons why grafts may fail. Shearing forces due to movement of the graft or the wound bed can upset adhesion and subsequent stages of take that are essential to a graft's survival. Based on a cohort study of 91 individuals performed by the authors of this paper (unpublished data, 2025), FTSGs on the alar had lower rates of graft take than the nasal tip despite their close proximity. This is thought to be due to the mobility of the alar from respiration and facial expression generating shearing forces.

Partial or complete graft failure on the nose can cause significant functional and cosmetic problems,[4] including nasal obstruction, notching of the alar rim and asymmetry. Patients may require additional follow-up or corrective operations to address these issues.

Plastic surgeons use a variety of methods to stabilise the alar to optimise graft take, including bolster dressings and/or nasal packs. Steele and colleagues performed a literature review on 91 articles that showed tie-over dressings are the method most commonly used, and that no technique is superior in effectively improving graft take.[5] Davis and colleagues also reported inconclusive evidence regarding the efficacy of various techniques to stabilise the alar, and acknowledged that dressings are removed 5–7 days postoperatively and that grafts are 'temperamental for several days after bolster removal'.[6] Furthermore, available options to stabilise the nasal alar are not patient-matched and do not address the variability in nasal morphology.

Australia has a multicultural population and skin cancers can arise in any individual regardless of skin type;[7] however, Caucasians are more prone to skin cancers due to their relative lack of skin pigmentation.[7] This is consistent with our clinical observations and prior studies of patients with skin cancers (unpublished data, 2025). Therefore, Caucasian background was added to our inclusion criteria to reflect the predominant skin cancer demographic at PAH.

Due to advances in 3D technology, patient-matched nasal splints can be manufactured. These nasal splints will be 3D printed devices that are placed intranasally and can be easily inserted and removed without the need for sutures or tapes to secure them in place. The workflow of creating personalised medical devices involves analysing surface and/or structural imaging to design a device matched to the patient. The device can be 3D printed and post-processed according to standard protocols.

Imaging modalities available to define nasal anatomy include 3D surface scanning, computed tomography (CT) and magnetic resonance imaging (MRI). Handheld 3D surface scanners can capture the surface topography in an outpatient setting, are fast, safe and non-invasive, and do not expose the patient to radiation. However, they can cause discomfort due to the bright intermittent flashes of light emitted and are only able to reliably scan the external surface of the nose.[8] CT scans are fast, accurate and can provide information about the internal topography of the nose. However, they involve radiation exposure. MRI scans are non-invasive, have no radiation exposure and provide accurate information regarding soft tissue anatomy. However, they are slow, costly and contraindicated in those with claustrophobia or certain implantable devices.

In addition to selecting the appropriate imaging modality, it is important to understand alar morphology. We conducted a literature review looking into the morphological variations in nostril shapes. Farkas and colleagues[9] analysed 243 healthy young North Americans. Nostril types I–VII were established according to the inclination of the medial longitudinal axis, which was described as the most reliable method of classification. There were clear racial differences between nostril types and the type II nostril was most common in Caucasians. Another morphometric analysis of nostril shapes by Etöz and colleagues[10] on 173 young Caucasians simplified the Farkas classification[9] into four shapes: teardrop, heart, round and triangular.

To inform the topography of the alar, we used statistical shape modelling (SSM) to create a virtual patient model that represents a generalisation of the population. This model can be used for the design of personalised medical devices. Statistical shape modelling uses statistical methods to analyse

morphologic variations within a population, as per similar investigations by Keustermans and colleagues who applied SSM on 46 CT scans to capture variations in shape in relation to age and gender, and to conduct morphometric analysis of the entire nasal cavity.[11]

Our aims are to first characterise nasal alar morphology in a population that is representative of patients undergoing surgical treatment of skin cancer on the nasal alar in southeast Queensland. We will then define the input modalities required for the design of patient-matched splints to stabilise the nasal alar to improve skin graft take. Lastly, we aim to define the workflow for manufacture of patient-matched or customised nasal splints, including acquisition of input data and validation steps.

Methods

Study design and setting

This project was a retrospective single-institution qualitative study performed at PAH. Ethics and site-specific approvals were obtained from the Metro South Health Human Research Ethics Committee (reference number HREC/2024/QMS/111413). A waiver of consent was granted to enable access to retrospective data contained in patient medical records.

Study population

To achieve the benefits of structural imaging without exposing individuals to radiation, we interrogated an existing dataset of CT scans to generate virtual 3D models of the nasal anatomy.

As there were no other investigations, pilot studies or predicate device trials, it was not feasible to conduct a formal power calculation. Determination of sample size was based on assumptions rather than statistical methodology. Previous literature definitions of nasal types ranged from 5–12. This range, combined with our decision to restrict our cohort to Caucasians to reflect our target demographic, led us to assume we would need six to eight different design envelopes. As this is a proof-of-concept study, we assumed there would be 30 participants required per design envelope. Allowing for approximately 10 per cent attrition, this yields a cohort of between 162 and 216. This value was rounded to the upper limit, 200. On this basis, a cohort of 200 was selected to enable a sufficiently broad random cohort in which to create the design envelopes.

A list of CT scans was obtained in consultation with the PAH radiology department. We consulted an advanced radiographer who created a worklist of scans on the PAH picture archiving and communication system (PACS). The inclusion criteria were CT head scans performed on Caucasians at PAH within the past year, to ensure that scans were performed using contemporary technology. Each scan was screened by a single investigator who applied the exclusion criteria, which includes altered nasal anatomy (trauma, septal deviation, congenital abnormalities or reported sinonasal pathology), incomplete image of the nose and poor quality scans (eg, motion artefact) (**Figure 1**).

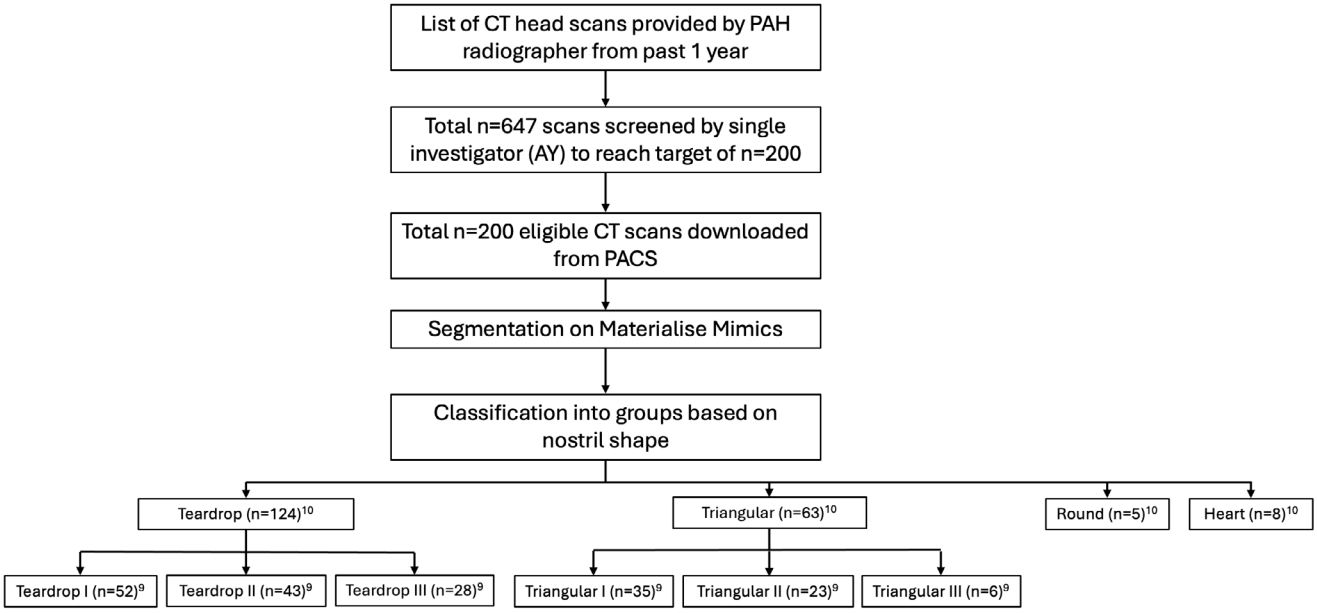


Fig 1. Recruitment and classification flowchart

To achieve our target recruitment population of 200, a total of 647 scans were screened. Demographic data, including gender and age, was drawn from the medical record.

Segmentation

Segmentation is the process of extracting specific anatomical structures from an imaging modality of choice so they can be converted into a 3D virtual model. The DICOM files of the CT scans were downloaded from PACS and imported into Materialise Mimics software (version 26.0, Materialise NV) to create virtual 3D models of noses.

The first step of segmentation is the creation of a 3D model. Thresholding refers to the selection of a range of Hounsfield units that best capture the anatomy of interest. The existing soft tissue thresholds on Materialise Mimics were used for our model. The model was then limited to the region of interest only. This was defined as the radix to columella-labial junction axially, nasal tip to the commencement of the inferior turbinates in the sagittal dimension, and either side of the alar flare in the coronal dimension.

Categorisation

Farkas's nostril classification[9] system helps differentiate the direction that noses project anteriorly, which is important in the design of our nasal splints. Although Etöz and colleagues' classification[10] was a simplification of Farkas's, we thought it provided more information about nostrils than Farkas's classification did. To decrease variability within groups, all 200 noses were categorised using a hybrid of both classification systems. This was done by viewing each nose from a worm's eye view to best capture the nostril shape and ensure repeatability. First, each nose was categorised as either teardrop, triangular, heart-shaped or round.[10] Then the protractor tool on Materialise Mimics was used to measure the inclination of the longitudinal axis of each nostril from the horizontal plane to classify nostrils into types I–VII. These measurements were recorded on a Microsoft Excel spreadsheet (version 16.113.3, Microsoft Corporation). This generated a total of eight groups: teardrop I, teardrop II, teardrop III, triangular I, triangular II, triangular III, round and heart.

According to Farkas, Caucasian individuals have type I–III nostrils.[9] Of the 200 noses in our cohort, 5 (2.5%) had round and 8 (4%) had heart-shaped nostrils. Given that our aim was to limit our study population to Caucasians, who had very few round and heart-shaped nostrils, we decided to omit these two groups from our study.

The six remaining groups were used to guide our next step, SSM.

Statistical shape modelling

The first of the three steps involved in SSM is warping, where each model is transformed to match each other in terms of triangle 'meshes'. In the second step, all of these meshes are aligned in the same region of space. The third step is a principal component analysis, a statistical method that involves assessing all anatomical variations to create an average shape.

Statistical shape modelling was conducted for each of the six groups. The virtual 3D models of the 52 teardrop I nostrils were exported to our Materialise 3-Matic Medical software (version 19.0, Materialise NV) on the same file, then SSM was undertaken to generate one model representative of teardrop I noses. This was repeated for the other five nostril groups to generate six different nose shapes. The authors accessed Materialise Medical software at ACISS when not required for surgical planning and clinical manufacturing purposes.

Proposed workflow for manufacture

The design envelope will determine the fit of the splint within the nasal vestibule. It will be combined with clinical assessment, 2D photography and/or 3D surface scanning to determine the external contour of the alar and opening so that the splint can be optimised to fit the nostril and support the alar. The current version of Materialise Mimic software available at PAH does not permit quantitative validation of the SSM-generated design envelopes, but we aim to perform quantitative validation once a version with these tools becomes available.

Artec software (Artec Studio 17 Professional, Artec 3D) will be used to take and post-process the 3D images. Designing the 3D models using 3D surface and CT scans will be done using Materialise 3-Matic Medical. The printer used and printing times will depend on the material of choice (eg, silicone). Printing times can vary between one and six hours. These nasal splints are listed on the TGA as a class I medical device, meaning there is no need for sterilisation.

Results

Patient demographics

The age of the cohort ranges from 16–97 years with an average of 57 years. There were 120 (60%) males, 79 (39.5%) females and 1 (0.5%) person who identified as other.

Imaging quality

Most CT scans were performed using the SOMATOM Force (VB30, Siemens Healthineers) scanner (n = 80, 90%); the others used the IQon Spectral (V4.7.7, Philips Healthcare) machine (n = 20, 10%). This is because there are more SOMATOM Force machines at the PAH as it has a greater speed, which is beneficial in a large tertiary hospital. All CT scans were of consistent slice thickness and reported by a radiologist.

Findings

Of our cohort, 52 (26%) had teardrop I-shaped nostrils, 43 (21.5%) had teardrop II-shaped nostrils, 28 (14%) had teardrop III-shaped nostrils, 35 (17.5%) had triangular I-shaped nostrils; 23 (11.5%) had triangular II-shaped nostrils and 6 (3%) had triangular III-shaped nostrils (**Table 1**). The round-shaped nostrils group (n = 5, 2.5%) and heart-shaped nostrils group (n = 8, 4%) were omitted, as mentioned previously.

The SSM found distinct vestibular morphology for the six shapes. The most important differences that are relevant to nasal splint design are the contour of the alar rim and the longitudinal axis of the nostrils. We believe these are the key features that are important in designing a comfortable splint that immobilises the alar. Only four noses failed the SSM and were excluded, as their overall nasal anatomy was likely too varied despite their similarities in nostril shape.

Discussion

The nasal alar morphology of our cohort of Caucasians in southeast Queensland were characterised into six groups: teardrop I, teardrop II, teardrop III, triangular I, triangular II and triangular III. The literature states that nostril types I–III[9] and teardrop and triangular shaped nostrils[10] are the most common in Caucasians. Therefore, the results of our study are consistent with the literature.

Various input modalities were considered for the design of patient-matched intranasal splints. An existing series of CT scans were investigated and combined with SSM technology to generate a design envelope. Further design inputs that will be considered are 2D photography, 3D surface scanning and the splint depth required to optimise comfort and efficacy in supporting the alar. The hybrid of multiple modalities helps take advantage of the benefits of one technique to overcome the limitations of the other.

This study has several limitations. The first comes from the automated alignment and warping steps of segmentation and SSM. While automation of these steps facilitated an unbiased analysis, it was unclear what landmarks were being used. There was an optional step to set landmarks for the alignment stage; however, it was technically challenging to select specific point or surface landmarks, so this step was omitted.

Second, the measurement of the longitudinal axis of the nostril may differ based on the orientation of the nose, as even small variations in the viewing angle can change the measurements significantly. Measurements need to be taken from a perfect worm's eye view, which is easier to achieve with virtual 3D models. The classification system also requires validation as it was performed by a single investigator. Future studies should be conducted with multiple investigators to facilitate interobserver reliability testing, such as kappa.

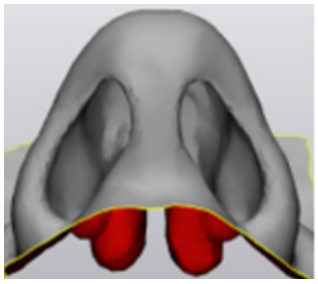
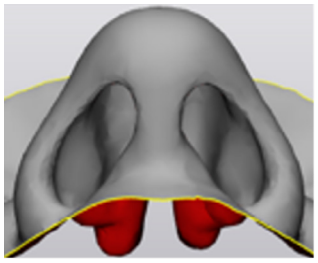
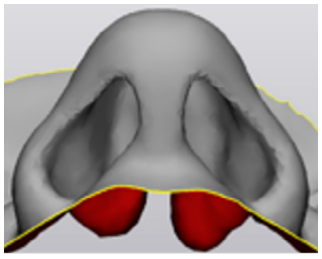
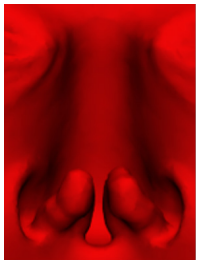
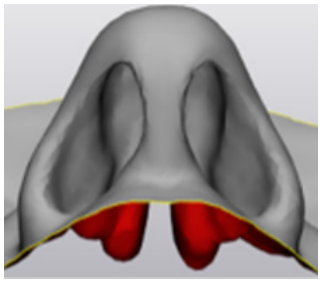
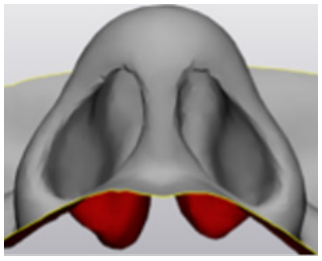
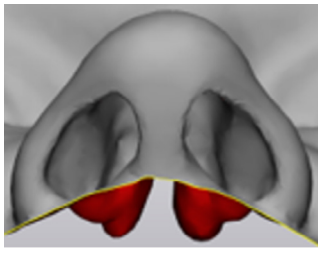
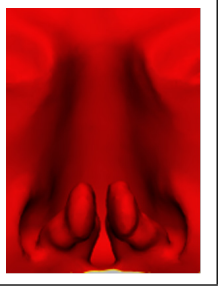
Third, the results of this study are not truly generalisable to the broader multicultural Australian population. Although challenging, future studies can be conducted to define nasal morphologic variations across the entire population. The demographic of this cohort is also slightly different from people with skin cancers. The average age of this study (57 years) is different to the average age of patients with nasal skin cancers that we studied previously (67 years, unpublished data, 2025). This has potential implications for the morphology of the nose as the tip descends and the nasal aperture shape changes with ageing.

Finally, there are limitations regarding the manufacturing workflow that need to be addressed. Our aim is to be able to manufacture nasal splints on the same day as surgery. The time taken to print, cure and post-process certain materials limits our ability to achieve this. We conducted workflow feasibility testing: by removing the steps involved in imaging patients and designing the splints and replacing them with a design envelope, the workflow was reasonable, supporting the concept of patient-matched nasal splints as a means to optimise workflow.

Conclusion

The results of this study show that statistical shape models can be generated for alar morphologies known to be common in Caucasians. Thus, it is feasible to generate a design envelope to create patient-matched nasal splints. These splints will be

Table 1. Classification of nostrils

Shape of nostril	Key features	Number (percentage)	Alar morphology (worm's eye view)	Internal vestibule morphology
Teardrop I	Defined by a teardrop shape[10] with inclination of 70–90 degrees[9]	52 (26%)		
Teardrop II	Defined by a teardrop shape[10] with inclination of 55–60 degrees[9]	43 (21.5%)		
Teardrop III	Defined by a teardrop shape[10] with inclination of 40–54 degrees[9]	28 (14%)		
Triangular I	Defined by a triangular shape[10] with inclination of 70–90 degrees[9]	35 (17.5%)		
Triangular II	Defined by a triangular shape[10] with inclination of 55–69 degrees[9]	23 (11.5%)		
Triangular III	Defined by a triangular shape[10] with inclination of 40–54 degrees[9]	6 (3%)		

tested in a randomised controlled trial for safety, tolerability and potential benefit in improving graft take on the alar. The cost-effectiveness of these splints is difficult to predict as potential improvements in graft take must be balanced against production costs. However, patient-reported outcomes are important, as patients may value additional interventions that improve aesthetic and functional outcomes. In addition, we believe that SSM and these splints have potential for use in a wide range of other indications.

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Patient consent

A waiver of consent to access retrospective data in patient medical records was requested and granted by the Metro South Health Human Research Ethics Committee (reference number HREC/2024/QMS/111413).

Conflict of interest

Michael Wagels is a Section Editor for this journal and was not involved in the editorial review or the decision to publish. The other authors have no conflicts of interest to disclose.

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