

ENDOSCOPIC COLOUR ANALYSIS OF NASAL MUCOSA: METHODOLOGY AND CLINICAL DATA

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*Diseases of the nasal mucosa are common in clinical practice; on average, every third ENT (ear, nose, throat) patient complains of nasal mucosa problems. Mucosa pathologies change the structure and composition of tissue; the presence of different cells, variation in biochemical composition and dilation or constriction of blood vessels lead to mucosa colour changes that help setting the diagnosis. However, experience and colour vision vary between doctors, so a more objective mucosa colour examination could be helpful. The aim of this study was to investigate whether colour analysis of camera-captured endoscopic images can distinguish healthy from pathological nasal mucosa and how specific such analysis could be for various diseases. A total of 66 participants (four groups, including healthy volunteers) underwent anterior nasal endoscopy, and the taken photos and videos were further analysed using self-developed Matlab software. The procedure involved selection of the region of interest (inferior nasal turbinate), segmentation and averaging the colour parameters over selected areas, exploiting the RGB and L*a*b colour scales. Allergic, chronic hyperplastic and inflamed (chronic and acute) nasal mucosa conditions in comparison with healthy mucosa were studied in this work. A relatively wide spread of colour parameter values was observed in the healthy volunteer group as well as in all patient groups. The most sensitive colour parameters for each of the pathology groups were identified.*

Keywords: endoscopic imaging, nasal cavity pathologies, colorimetry, ENT diagnostics.

INTRODUCTION

Statistically, every third ENT (ear, nose, throat) patient has some nasal mucosa pathology (Schwartz *et al.*, 2019). Diagnostics of such pathologies is generally based on the doctor's experience in analysis of intranasal endoscopy images that are observed visually or by an adapted camera on a monitor screen, with respect to the colour/shade of the pathology region. Subjective colour analysis, however, can be influenced by individual colour perception and by colour reproducibility of the exploited monitor. Therefore, a more objective approach to support the diagnosis would be helpful; one of the options might be image colour analysis using separated R-, G- and B-channel outputs of a digital photo-camera (Seymour, 2009). Software of digital colour cameras converts the signals produced by the array image

sensors at three spectral bands — red (R, ~600–700 nm), green (G, ~500–600 nm), and blue (B, ~400–500 nm) — into the corresponding colour of each image pixel by means of specific conversion algorithms. Separated R, G, and B signal values can be extracted from the image data set and exploited as specific colour parameters; they can also be converted into parameters of other colour spaces, for instance, the L^*a^*b colour space (see reference to Colormath converter...).

Colour parameters of diseased nasal mucosa have been considered in several previous studies. Chromaticity of the nasal mucosa was represented by two parameters, x (red component in RGB colour space) and y (green component) values, measured with a chromameter MINOLTA Co., CS-100 (Yoko *et al.*, 1996). Chromaticity of the inferior

turbinate was compared among patients with 1) perennial nasal allergy (PNA, $n = 19$), 2) cedar pollinosis (CP, $n = 11$), and 3) normal subjects serving as a control group ($n = 15$). The obtained x (or R) values in the PNA and CP groups were significantly lower than those in the control group ($p < 0.01$), and the y (or G) values were significantly higher ($p < 0.02$). The results generally agreed with the observations of trained rhinologists. The same group reported more detailed results in Yoko *et al.* (2002), where the colour of nasal mucosa was evaluated for patients with Japanese cedar pollinosis (CP; $n = 70$), perennial allergic rhinitis (PAR; $n = 49$), and normal subjects ($n = 60$). In the normal subject group, the averages of the x and y values were 0.4264 ± 0.0119 and 0.3204 ± 0.0067 , respectively. The x ($=R$) value of chromaticity in PAR patients was significantly lower than that in normal subjects. There was no significant difference in the y ($=G$) value between PAR patients and the normal group. In the CP group, the x and y values were not significantly different from values in normal subjects. This study found that the chromaticity of the nasal mucosa reflects local blood flow and that the circulatory dynamics in CP patients changes with time during the pollinosis season.

Allergic rhinitis was examined by red-green-blue analysis of nasal mucosa, similarly to the study of another group (Degirmenci *et al.*, 2020). 73 patients with allergic rhinitis (allergy group) and 73 normal healthy individuals (control group) were included in the study. Endoscopic photographs of the septum and both inferior turbinates were taken. The Adobe Photoshop Elements 7.0 software programme was used to determine the numerical values of red-green-blue (RGB) colour components in endoscopic photographs of nasal mucosa. The obtained G and B values were significantly higher in the allergy group compared to the control group (both $p < 0.05$) and the cumulative R , G , and B values of all measurement points were significantly higher in the allergy group compared to the control group. Still, one may note that the reported elevated G -responses disagree with the results presented in Yoko *et al.* (2002). Unfortunately, the used endoscope, light source and camera have not been specified in Degirmenci *et al.* (2020) so it is difficult to validate the reported results.

Consequently, no complete understanding of nasal mucosa colour characteristics has been achieved so far, and more knowledge on this topic must be accumulated. Our study was aimed to further develop the methodology of endoscopic colour analysis and to evaluate the possibility of automated colour-based grouping in cases of allergic, chronic hyperplastic and inflamed (chronic and acute) nasal mucosa conditions.

MATERIALS AND METHODS

Participants-volunteers with complaints about nasal mucosa disease, as well as apparently healthy individuals were examined. The study included five patients with allergic mucosa, seven patients with chronic hyperplastic mucosa, and

20 patients with inflamed (chronic and acute) nasal mucosa. The group of healthy volunteers comprised 34 persons. Participants were initially provided with information about the study and filled/signed a consent form. The study did not include individuals with age < 18 years, pregnant women and those having undergone nasal surgery within the last five years.

Each participant was consulted by a certified otolaryngologist before performing nasal endoscopy. The patient's nasal mucosa was examined with the anterior rhinoscopy method, and each participant was classified into one of four study groups: allergic, chronic hyperplastic, inflamed (chronic and acute) nasal mucosa and healthy mucosa (control group). In the next step, anterior nasal endoscopy was performed on each side of the nose; one-two photos were taken, as well as a brief (up to 30 seconds long) video fragment; all image data were stored in a flash memory. During the procedure, the endoscope was inserted into the nasal cavity at a distance up to two centimetres from the nostril. Images of mucosa of the anterior pole of inferior nasal turbinate were captured by a TH110 camera attached to a Karl Storz rigid endoscope 7230AWA. A video system HD Tele pack LED was used for image processing and target illumination by a white LED source, keeping the same intensity in all cases.

After turning on the hardware (Tele Pack), image capturing was initiated after at least one minute to allow the endoscope lighting system to warm up. Before each patient's measurement, a white reference was placed ~ 2 cm from the distal end of endoscope and white balance was calibrated using the built-in camera function. After performing the procedure, the endoscope was placed in Aniosyme XL3 0.5% solution for five minutes, then washed under running lukewarm water, further placed in Steranios 20% solution for 20 minutes, then repeatedly washed, dried, and prepared for the next participant.

To improve video analysis, an originally developed video processing algorithm exploiting video-recording features was developed. As a standard video recording contained 25 images (frames) per second, and the study of the nasal cavity was performed within 10–20 s, at least 250 video-frames were obtained. The main idea of the algorithm was to correct over-exposed areas as much as possible by combining several video frames within a temporal range ± 200 ms. Passing through the frames, a video with reduced over-exposure effects was created. The scheme of this algorithm is shown in Figure 1. Our observations showed that larger video buffer sizes (several dozens of adjacent frames) might lead to even better video quality, but this significantly increased the video processing time.

The colour analysis of endoscopic images and videos of the nasal mucosa was performed as follows. Initially, the video frame (in which the anterior pole of the inferior nasal turbinate was clearly visible) was manually selected. Next,

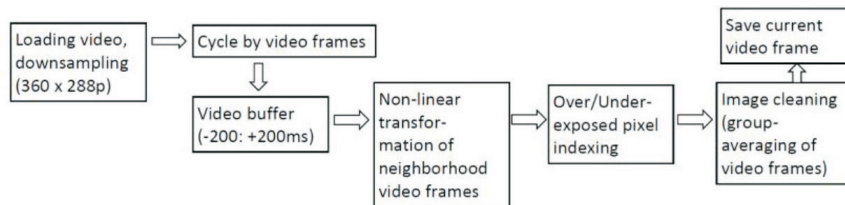
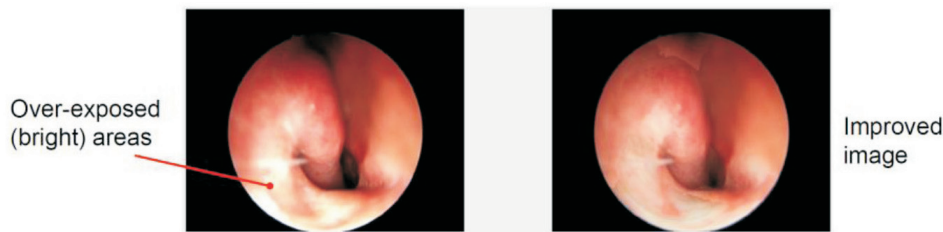


Fig. 1. Scheme of algorithm for correcting the over-exposed areas of an endoscopic image.

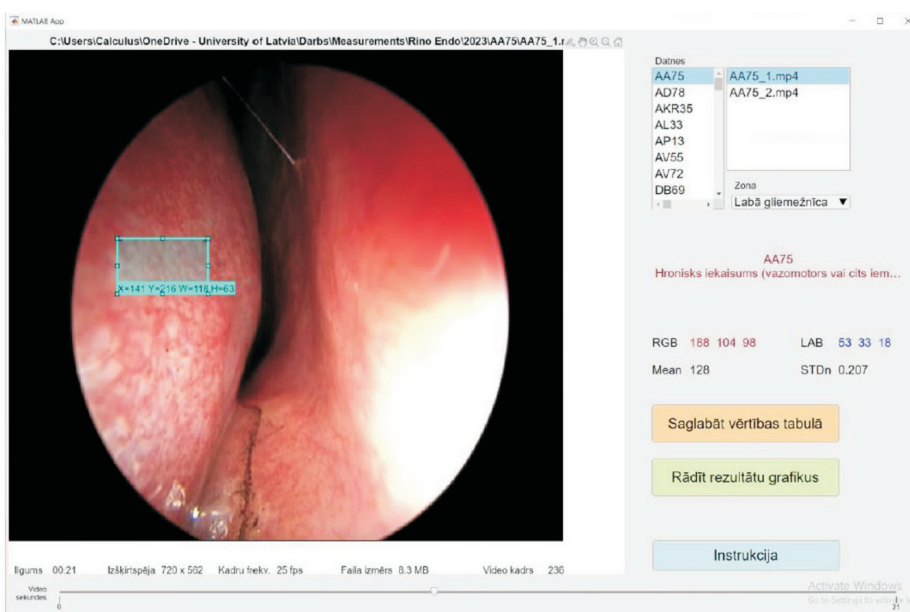


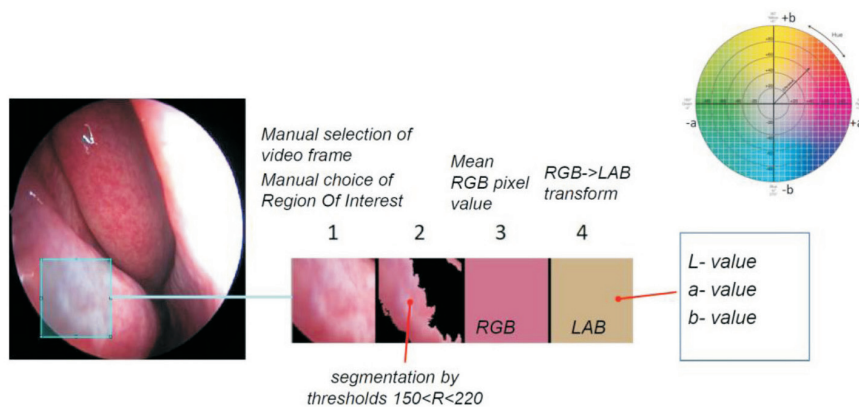
Fig. 2. The programme interface: list of measurement data (right, top), endoscope video image (left) with manually selected area of interest, video frame slider (bottom) for selecting a suitable image from the video and tools for displaying and saving the colour parameters (left).

the sufficiently illuminated (neither too dark nor over-exposed) area of interest was selected on the inferior turbinate. Then the selected image area was automatically segmented by choosing pixels where the R-intensity ranged from 150 to 220 (full range 0–255) and the average values of the colour parameters of the selected pixel groups was calculated. Both RGB and L^*a^*b colour scales were exploited, with transforming the obtained R, G, and B values into the corresponding L , a and b values. A computer programme in MATLAB was developed, with interface presented on Figure 2; it runs in the Microsoft Windows 11 environment. After capturing, images or video files were automatically transferred from the endoscope device to the computer via an FTP internet connection. In the computer programme, any individual measurement could be selected from a list. In the video data mode, first a video image that was suitable for processing (areas of interest was clearly visible, image not overexposed) was selected using the video frame slider. The mucosal area of interest was then selected manually and further processed; all obtained data were saved in the database. If necessary, the analysis could be repeated. By analysing a sufficiently large volume of data, statistical data

analysis of colour parameters was performed by visualising parametric correlations.

The video analysis consisted of: 1) pre-processing to improve the image quality, 2) selection of video image and area, 3) segmentation using image pixels located in a certain range of values ($150 < R < 220$), 4) calculation of average values of RGB pixels, 5) calculation of values in the L^*a^*b colour scale, and 6) calculation of statistical values and graphical representation. The average value of the segmented pixels in the L^*a^*b colour scale was obtained from the selected area; the related algorithm is illustrated in Figure 3. Parameters a and b are sensitive to the typical colour tones of the mucosa in cases of various pathologies, from yellowish to bright red. Thus, a and b values potentially may serve as criteria for differentiating pathologies such as rhinosinusitis or an allergic condition.

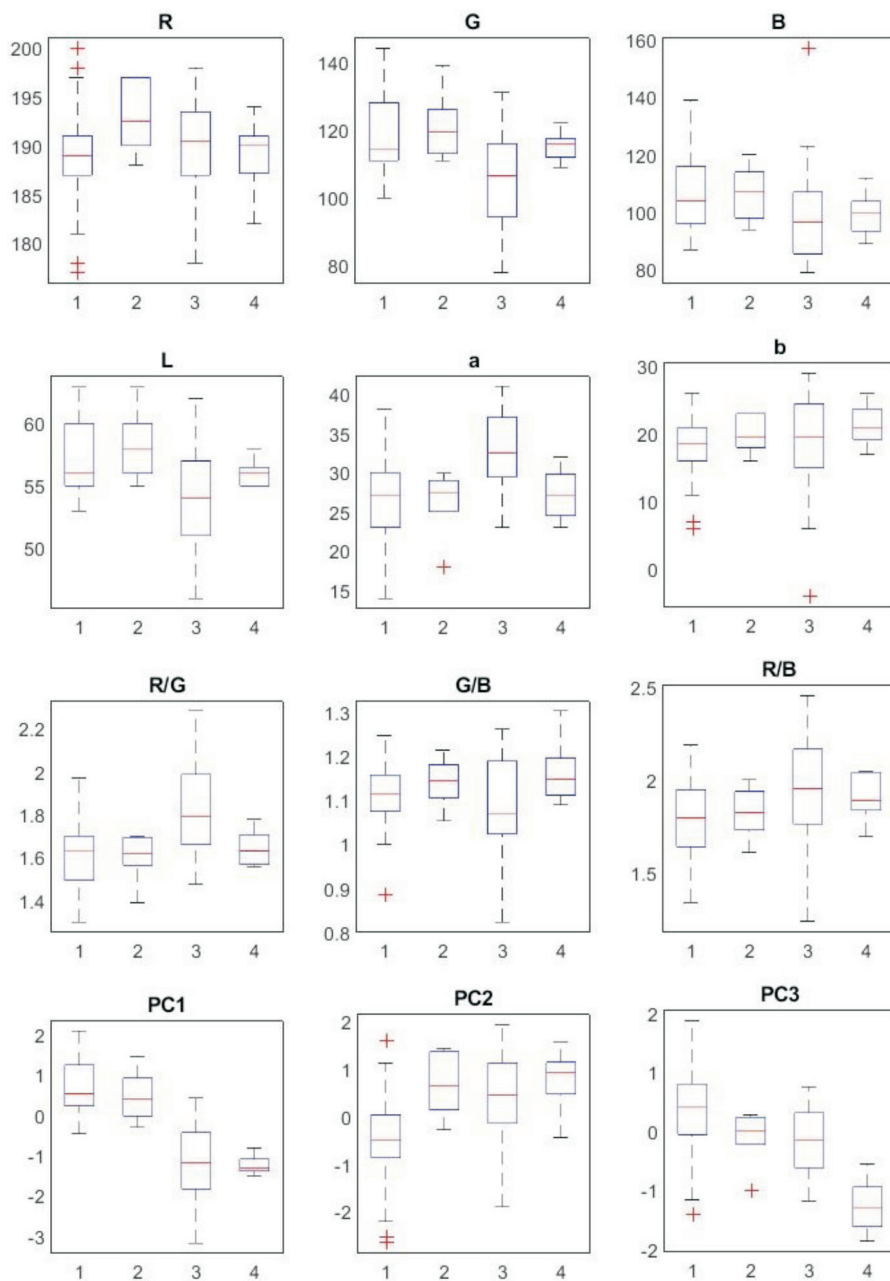
Besides standard procedures of calculating the R, G, B, L , a , and b values, the data processing also included calculation of ratios R/G, G/B and R/B; principal component analysis (PCA) (Jolliffe and Cadima, 2016) of the RGB values from the selected areas of nasal mucosa images was performed as well.



RESULTS

Results of the clinical study are graphically presented in Figure 4. The upper row of sub-figures represents the R , G , and B values for the four examined groups; the respective L ,

a , and b values and the ratios R/G , G/B and R/B are shown below. The calculated values for the first three principal components PC1, PC2 and PC3 are presented at the lower row of sub-figures in Figure 4.



A relatively large statistical spread of the colour parameter values was observed in the healthy volunteer group (1) and in all three patient groups (2–4). The standard deviation was < 3% for R , 14% for G , 20% for B , 5% for L , 22% for a and 41% for b . The spread for the RGB ratios was correspondingly higher, while that for the principal components even exceeded 100%. In result, notable overlap of the data for different groups was observed. As the imaging conditions were the same in all cases, such data spread most probably was caused by individual specific features of the nasal mucosa, both healthy and diseased. Eventually, increased number of examined persons would lead to decreased spread of data and better separation of colour parameters related to specific diseases, but the current study was limited to the available number of volunteers. The data spread also could be influenced by yet unidentified drawbacks in the image processing methodology.

Regarding the mean values, the colour parameter R shows the best differentiation potential for group 2 (chronic hyperplastic mucosa), while the parameters G , a , and R/G appear being more sensitive to the group 3 pathology (inflamed mucosa). Allergic mucosa (group 4) is hard to distinguish from the healthy mucosa by any of the colour parameters, but it stands out well in the PC3 representation. The mean PC1 values are nearly equal for the groups 1–2 and 3–4, respectively, while the mean PC2 value for healthy volunteers (group 1) are well separated from those related to the three patient groups — 2, 3, and 4.

DISCUSSION

The clinical results of this proof-of-concept study provided more light on possible correlations between nasal mucosa pathologies and the colour parameters related to segmented parts of camera-captured endoscopic images. Since the number of pathologic cases in the selected patient groups was relatively low (5 ... 20), the presented results cannot be regarded as statistically significant; future studies should involve a larger number of patients. Nevertheless, some main trends were revealed. In particular, none of single R , G , or B values nor single L , a or b values were clearly correlated with any of the studied mucosal pathologies. Still, combinations of such values could be an option for colour parameter-based nasal mucosa diagnostics. The best separation potential was shown by the combined G -, R/G -, and a -values for the inflamed mucosa (group 3). More specifically, the simultaneously combined value ranges $90 < G < 110$, $1.7 < R/G < 2.0$ and $a > 30$ could serve as a diagnostic criterion for inflamed mucosa. One should note that in this study acute rhinitis and chronic inflammation were merged into one group “inflamed mucosa”; to distinguish between them, patient feedback can be taken into account.

Another colour-based quantitative diagnostics option would be usage of the calculated values for the first principal component PC1 (related to the differences of RGB values) and for the third principal component PC3 (related to the differ-

ences of colour hues), and/or some combined PC values. As an example, the value range $-1.8 < PC3 < -0.7$ potentially could be used as a quantitative criterion for allergic nasal mucosa.

The methodology of endoscopic image capturing and processing could be further improved as well. One of the identified problems was non-uniform illumination intensity and even over-exposure of different segments of the endoscopic field of view. This is hard to avoid as such segments are located at various distances from the distal end of endoscope. Still, over-exposure (that may cause nonlinear photo-response) can be minimised by decreasing the illumination intensity. The protocol of this study required equal intensity for all procedures, and it was kept at maximum; somewhat lower illumination eventually could ensure good enough quality of images, as well. Also, effort could be made to make the illumination beam less directed (or more scattered), e.g., by using diffusive elements in the optical path of illumination. One more issue is the limited colour information in video images as the video frames are compressed; therefore, a part of colour information is lost. Our processing approach included extraction of colour parameters from video frames; steady photos are more sensitive from this point, so in future studies the main information source should be endoscopic photos. And, finally, the human factor could also lead to some inadequacies as several possible diagnoses of one pathology could not be fully excluded in some cases.

CONCLUSIONS

To conclude, this study facilitated better understanding of the technical and software challenges for automated colour-based endoscopic diagnostics of nasal mucosa. Original software solutions for extracting specific colour parameters from digital camera image data were introduced and clinically approbated. The clinical results confirmed the possibility of colour-based mucosal diagnostics, but instead of single R , G , B or L , a , b values their combinations (e.g., simultaneously falling into specific value ranges of three parameters — R , R/G , and a) appear to be a more promising approach. This study also helped to identify some methodology bottlenecks that should be considered in the further studies of nasal mucosa colour as a potentially objective diagnostic tool.

ETHICS

This study was performed under approval No. 71-35/135 of the Medical Ethics Committee of the Faculty of Medicine, University of Latvia.

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DEGUNA ĢĻOTĀDAS ENDOSKOPISKĀ KRĀSU ANALĪZE: METODOĻĢIJA UN KLĪNISKIE DATI

Deguna ģlotādas slimības ir bieži sastopamas klīniskajā praksē; vidēji katrs trešais LOR (ausu, kakla, deguna) slimnieks sūdzas par deguna ģlotādas problēmām. Ģlotādas patoloģijas maina audu struktūru un sastāvu; dažādu šūnu klātbūtne, bioķīmiskā sastāva izmaiņas un asinsvadu paplašināšanās vai sašaurināšanās noved pie krāsas izmaiņām, kas palīdz noteikt diagnozi. Tomēr pieredze un krāsu redze dažādiem ārstiem atšķiras, tāpēc objektīvāka ģlotādas krāsas pārbaude varētu būt noderīga. Šī pētījuma mērķis bija izpētīt, vai ar kameru uzņemto endoskopisko attēlu krāsu analīze var atšķirt veselus brīvprātīgos un cik specifiska šāda analīze varētu būt dažādām slimībām. 66 dalībniekiem (četras grupas, ieskaitot veselus brīvprātīgos) tika veikta priekšējā deguna dobuma endoskopija. Uzņemtie foto- un videoattēli tika analizēti, izmantojot pašu izstrādātu *Matlab* programmatūru. Procedūra ietvēra interesējošā reģiona (apakšējā deguna gliemežnīca) atlasīšanu, segmentāciju un vidējotu krāsu parametru noteikšanu atlasītajos apgabalos, izmantojot RGB un L^*a^*b krāsu skalas. Šajā darbā tika pētīti alerģiski, hroniski hiperplastiski un iekaisuši (hroniski un akūti) deguna ģlotādas stāvokļi salīdzinājumā ar veselū ģlotādu. Novērota salīdzinoši plaša krāsu parametru vērtību izkliede veselo brīvprātīgo grupā, kā arī visās pacientu grupās. Tika identificēti potenciāli visjutīgākie krāsu parametri katrai patoloģijas grupai.