# Respiratory Gating of Endoscopic OCT Images of the Upper Airway

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## ABSTRACT

Anatomical optical coherence tomography (*a*OCT) is an endoscopic imaging modality that can be used to quantify size and shape of the upper airway. We report the application of respiratory gating to *a*OCT images. Our results show that respiratory gating can reduce motion artefact in upper airway images. Using an error metric based on distance to the dominant reflection in each A-scan, we found notable improvements when the breath cycle was partitioned into approximately four gates, but only minor improvements as the number of gates was further increased.

**Keywords:** anatomical optical coherence tomography, *a*OCT, upper airway, respiratory gating

## 1. INTRODUCTION

Obstructive sleep apnoea (OSA) is estimated to affect 2-4% of middle-aged adults [1]. Evidence suggests it is causal in the development of hypertension [2] and it is implicated in the initiation and progression of cardiovascular disease [3]. While repetitive collapse of the upper airway during sleep is the cardinal feature of OSA, understanding upper airway behaviour, in terms of its changes in shape and size, has been limited by the absence of suitable quantitative techniques. There is increasing interest in dynamic quantification of the upper airway in OSA [4,5,6,7,8,9].

Anatomical optical coherence tomography (*a*OCT) is a recently developed endoscopic imaging technique utilising long-range OCT [10]. It has been demonstrated as useful in imaging of the human upper airway, especially in the assessment of airway metrics such as diameter and area [11,12].

Respiratory-related motion of the upper airway presents a significant challenge to such quantification. Breathing-induced motion artefact has been addressed in other imaging modalities through the use of respiratory gating [8,9,13]. Each breath cycle is partitioned into a regular number of gates, and data obtained within each gate is aggregated across multiple breaths. However, there is no published literature describing the respiratory gating of OCT images.

This paper describes respiratory gating of OCT images of the upper airway, and examines the impact of varying the number of gates per breath cycle on the quality of the gated image.

## 2. METHODS

The *a*OCT system comprises an optical coherence tomography imaging system with a revolving endoscopic probe delivered through a catheter. The probe rotates at approximately 2.2 Hz and is inserted through the nostril into the upper airway. The distance between the probe head and the air–tissue interface of the airway is determined from the reflected light using a low-coherence optical interferometer. Adopting the terminology of ultrasound, each 1 D axial acquisition is referred to as an A-scan. By aggregating multiple A-scans over a full revolution of the probe head, it is possible to

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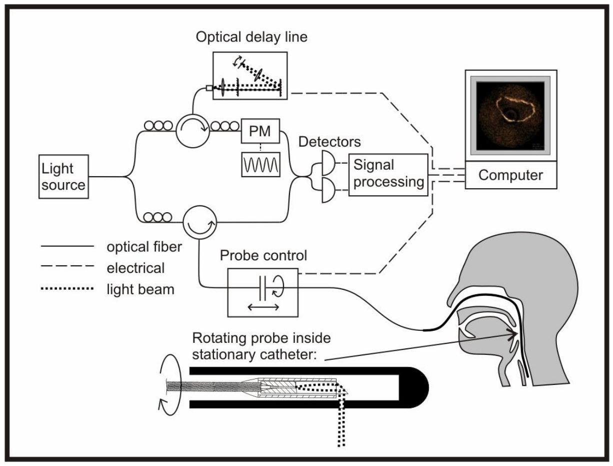


**Figure 1: *a*OCT system schematic and deployment in the upper airway.**

reconstruct a 2D image showing the airway shape and size at a particular location. A system schematic indicating deployment of the probe is shown in Figure 1 and further details are given elsewhere [11].

For this study, *a*OCT scanning was performed on 3 volunteers at two locations in the pharynx and during several different breathing patterns. All volunteers remained awake during image acquisition. After an initial scout scan of the entire airway, locations were selected for scanning in the oropharynx and velopharynx. At each location, scans were acquired while breathing was maintained at three frequencies using a metronome: slow (~3.75 breaths/min); medium (~7.5 breaths/min); and fast (~15 breaths/min). Two minute scans were acquired during both normal (Normal) and increased depth (Deep) at each breathing frequency. An additional acquisition was obtained while volunteers breathed at the medium breathing rate against an inspiratory threshold load of 20 cm$H_2O$. Under this condition each breath required greater inspiratory effort, and greater activity of the muscles in the upper airway. There were 7 breathing conditions for each of the 3 volunteers at two anatomical locations, used to generate a total of forty two data sets.

Respiratory cycle was determined from inductive plethysmography (Respitrace). This required the placement of elastic inductive bands around the abdomen and rib cage. Rib cage and abdominal signals were calibrated using an isovolume manoeuvre and electronically summed in order to provide a measure of overall lung volume change. Data were collected on a PowerLab data acquisition system (ADInstruments, Sydney, Australia).

The summed Respitrace signal was then used to partition the *a*OCT A-scan data into separate respiratory gates. In-house image processing software was utilised to extract the points of maximum lung volume for each breath. This was automated by applying Gaussian smoothing to the breath signal and identifying regularly spaced local maxima. Each breath was partitioned into equal-sized breath gates (number of breath gates was varied from 1 to 10), with the first gate being centred on the point of maximum lung volume. Each subsequent A-scan was then allocated to its respective breath gate, and data within each gate were averaged to form an image representing the combination of multiple breaths.

An error metric for the gated data was defined based on an estimate of the location of the air-tissue interface. For upper airway imaging, the air-tissue interface is typically the dominant reflection in the signal. To estimate the error, the maximum reflection was extracted from each A-scan and compared against the location of the maximum reflection in the corresponding gated average image at the same angular orientation. The average distance between these two points was calculated and this value averaged over all A-scans in the acquisition, providing a measure of the distance between the gated and actual air-tissue interface. The error was calculated for each of 1 to 10 gates per breath.

## 3. RESULTS AND DISCUSSION

Figure 2 shows the resulting gated images for the case of an inspiratory threshold load breath pattern at a medium rate, The entire 2 minute acquisition (in this case, 17 breaths cycles) has been separated into 1, 2, 4 and 8 gates per cycle and images averaged across breath cycles. Breathing against a threshold load was found to elicit substantial changes in

**Figure 2: 1, 2, 4 and 8-gate image sequences of inspiratory threshold-loaded breathing at medium rate. Note blurring in 1-gate image, and large degree of shape change in 4- and 8-gate images.**

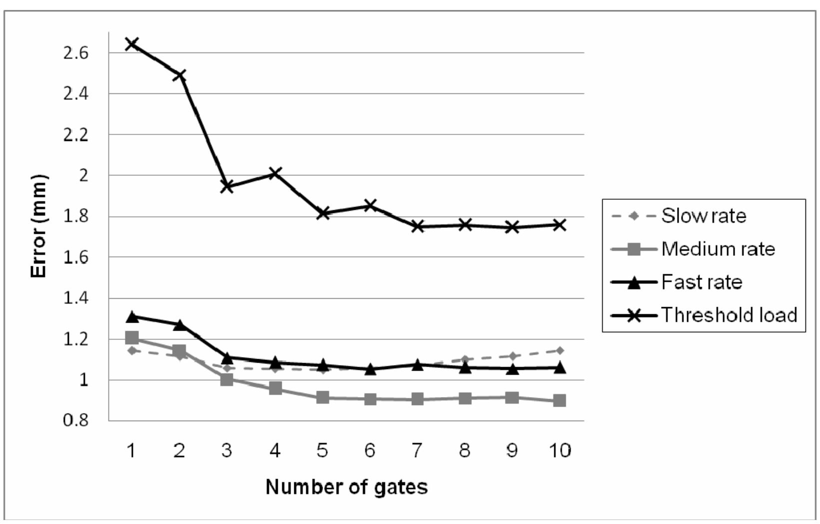


**Figure 3: Error measure in mm plotted against number of gates per respiratory cycle.**

airway shape and size over the respiratory cycle. Note the degree of blurring evident when the entire data set is aggregated into a single gate (top row). The change in airway shape over the respiratory cycle is evident in both the 4-gate and 8-gate images (bottom two rows).

Figure 3 plots the average error as a function of number of gates. Results are plotted for each of three breath rates, aggregated across normal and deep breaths. Our results suggest only minor improvements if more than four gates are utilised for medium, fast and threshold loaded breathing patterns. Gating had little effect on the slow breathing pattern.

The importance of breath gating is closely related to the degree of movement of the upper airway. In the case of unloaded slow breathing, we observed minimal movement in the upper airway and, thus, there was little gain in gating the data. In contrast, threshold loaded breathing elicited large changes in airway shape. In this situation, respiratory gating yielded a substantial reduction in motion artefact.

As with other imaging modalities, respiratory gating of *a*OCT data assumes that the respiratory motion is regular. This is often the case during sleep in healthy individuals, and during periods of stable flow-limitation in individuals with OSA. Respiratory-gated OCT is well-suited to providing novel information on airway behaviour during these conditions. Earlier work in OSA quantification [5][6] has assessed differences in the airway size for patients with sleep apnoea. We believe that the generation of the gated breath images may enable more sophisticated shape analysis of the airway structure and more accurate analysis of dynamic changes in airway calibre with phase of respiration.

## 4. CONCLUSION

Breath gating of *a*OCT data allows clear visualisation of the regular movement of the upper airway. The use of at least four gates was found to substantially reduce motion artefact. Future work will use respiratory gating to examine the relationship of airway wall motion to upper airway pressure and flow.

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