

ContinuousLy Adaptive Windowing Strategy (CLAWS): an automatic technique for achieving the best possible respiratory efficiency regardless of the breathing pattern.

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The efficiency of respiratory navigator techniques using a fixed 5mm acceptance window is highly dependent on the initial user-placement of the acceptance window and on the breathing pattern of the subject during the subsequent acquisition. Respiratory drift is a major problem and results in decreased respiratory efficiency and in failure of the acquisition due to overly prolonged scan time in a significant minority of patients (Sakuma et al, JACC 2006). Although end expiratory tracking algorithms have been developed to adapt to changes in breathing pattern, these are not necessarily very efficient and the resulting images are, by definition, acquired with a greater and unknown range of diaphragm motion than those with a fixed window (Sinkus et al 1999). To address these problems, we present a technique, ContinuousLy Adaptive Windowing Strategy (CLAWS), which is designed to automatically provide the fastest possible acquisition with a 5mm acceptance window for any given breathing pattern, regardless of respiratory drift or other changes.

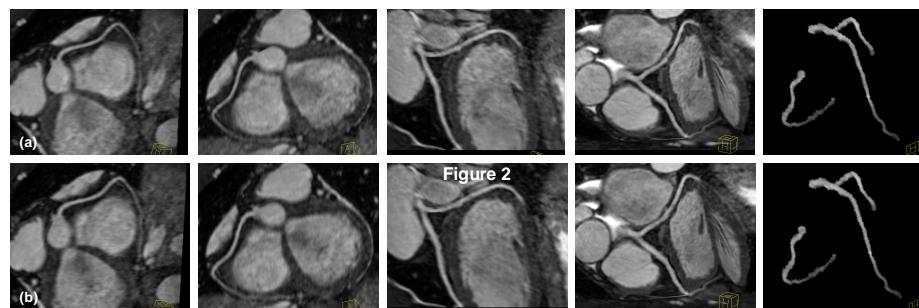
Methods: The user is not required to set up an initial window as the algorithm assumes that all possible 5mm windows are equally relevant. All data is therefore stored so as to be able to contribute to the final image if required. CLAWS uses predetermined algorithms which are independent of the breathing pattern of a subject and robust against changes in breathing. Initially each datablock is acquired once to ensure that the scan can be terminated at any point in the future and "the best" current image reconstructed. Subsequent datablocks to reacquire are determined by taking into account the respiratory positions at which each datablock has already been acquired, the distribution of respiratory positions and the number of times a datablock has already been acquired. The aim of the CLAWS algorithm is: if n datablocks are required within a range of x mm, as soon as n respiratory contiguous positions have occurred within a range of x mm, n unique datablocks should have been acquired. This equates to the most efficient and best scan time. The CLAWS technique is compared against a standard accept/reject algorithm (ARA) with a fixed 5mm window positioned around the end-expiratory pause position.

Simulations: Respiratory traces were acquired in 30 healthy subjects and analysed to compare respiratory efficiencies for acquisitions of varying size (30 - 240 datablocks). For a given respiratory trace, the best possible respiratory efficiency was determined and was compared with that obtained using ARA and with CLAWS.

In vivo studies: Whole heart coronary artery acquisitions (240 datablocks) were performed in 20 healthy volunteers using both techniques, the order of acquisition being random. Image quality of the left and right arteries was assessed on a scale of 1 - 5 (1 = coronary not visible, 5 = sharp vessel borders with no artefact) by two independent observers and a consensus score determined. Respiratory traces during the acquisitions were stored and analysed to compare respiratory efficiencies.

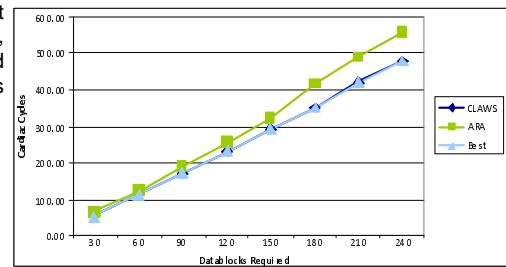
Results : **Simulations:** Figure 1 shows the mean number of cardiac cycles required to complete datasets of different sizes in the 30 healthy volunteers when using (i) the most efficient window, (ii) the CLAWS algorithm and (iii) a 5mm window positioned around the end expiratory pause. For all datablock sizes, the results using the CLAWS algorithm are within 1% of those obtained using the most efficient window ($p = ns$). For ARA, the difference increases with increasing block size. The percentage difference in scan time when using ARA instead of CLAWS is significantly greater for all datablock sizes ($p < 0.01$).

In vivo studies: Of the 40 whole heart acquisitions (20 CLAWS, 20 ARA), 1 (5%) of the ARA acquisitions failed to complete due to excessive and variable respiratory drift. In the remaining acquisitions, there were no significant differences in image quality between the CLAWS and ARA scans (left coronary: 3.45 vs 3.5 ($p = ns$) and right coronary: 3.6 vs 3.75 ($p = ns$)). The CLAWS scans completed on average 12% faster than the ARA scans (cardiac cycles: 479 vs 534, $p < .05$). However, this is not a true reflection of



where the CLAWS scan (a) was acquired in the most efficient time while ARA (b) took over 2.5 minutes (25%) longer to complete.

Conclusion: A technique is presented which removes the need for manual user window selection, is robust against changes in breathing and which acquires an image with a given acceptance window in the fastest time possible for any given respiratory trace. The respiratory efficiency is typically 17% higher than when using an ARA algorithm for the same image quality and unlike respiratory tracking techniques, results in acquisitions with a fixed range of respiratory motion. As a complete dataset is acquired in the first pass, it is possible to reconstruct a best possible image at any time. Further, the user does not need to monitor the reliability of the acceptance window during the scan.



the efficacy of the techniques as the breathing patterns were not identical for the two scans. When compared to the best scan time possible, CLAWS was within 1% of this time ($p = ns$); ARA was significantly slower ($p < .05$). Had CLAWS been used to acquire the ARA datasets, CLAWS would have completed in the best possible time in each case ($p = ns$). An example is shown in Figure 2