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Main Article

Radiological airway changes following bipolar radiofrequency volumetric tissue reduction

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Abstract

Objective: To characterise the appearance of lesions of the tongue base and soft palate induced by bipolar radiofrequency volumetric tissue reduction, using magnetic resonance imaging up to six weeks post-procedure.

Methods: Five men with sleep-disordered breathing were treated with one session of bipolar radiofrequency volumetric tissue reduction to a number of sites, including the tongue base and soft palate. Magnetic resonance imaging was performed pre-operatively and one week and six weeks after surgery.

Results: Lesions were visible from day one. T1 (spine lattice relaxation Time)-weighted images demonstrated areas of central hyperintensity, reflecting haemorrhagic, coagulative necrosis, surrounded by hypointensity, representing oedema; corresponding short tau inversion recovery (STIR) sequences showed central hypointensity with surrounding high signal. The lesions expanded up to day three and then gradually diminished, but were still evident at week six on short tau inversion recovery images.

Conclusion: The characterisation of lesions induced by bipolar radiofrequency volumetric tissue reduction enables us to elucidate the pathophysiology of this procedure, to optimise treatment benefits and clinical outcomes, and to explain patient symptoms.

Key words: Sleep Apnea Syndromes; Snoring; Magnetic Resonance Imaging; Palate; Radiofrequency Surgery

Introduction

Sleep-disordered breathing occurs as a result of changes outside the upper airway, within the upper airway walls and within the upper airway lumen. In individuals with sleep-disordered breathing, several relevant structures have a greater volume compared with control subjects, including the parapharyngeal fat pads, lateral pharyngeal walls, soft palate and tongue. Tongue volume is an independent risk factor for sleep apnoea.[1] The dimensions of the airway are smaller in sleep-disordered breathing subjects than in controls, particularly in the retropalatal region.[1] It therefore seems logical to target the tongue and soft palate in upper airway procedures performed to treat sleep-disordered breathing.

Since the 1970s, radiofrequency volumetric tissue reduction has been used in many fields of medicine to ablate soft tissue. Applications have included treatment of trigeminal neuralgia, benign prostatic hyperplasia, Wolf–Parkinson–White syndrome, Parkinson's tremor, and palliative treatment of head and neck tumours.[2–4]

The use of radiofrequency volumetric tissue reduction to manage sleep-disordered breathing was first reported in 1999 by Powell *et al.*, who conducted a pilot study on radiofrequency tongue base reduction.[2] This technique is now used as a minimally invasive treatment for the tongue, soft palate, inferior turbinates and tonsils.[5,6] Radiofrequency energy is delivered at a low temperature (55–90°C) by a needle electrode with a protected portion to prevent tissue trauma at the needle entry site. The effects of this technique are likely to be due to a combination of tissue reduction and increased stiffness, with a resulting reduction in collapsibility.[2,3,6] Clinical parameters such as the respiratory disturbance index, Epworth sleepiness score and snoring have been reported to improve significantly following treatment.[2,5,7–11] Several different sites can be treated during the same session, making radiofrequency volumetric tissue reduction an ideal management option for patients with sleep-disordered breathing. Post-operative pain is minimal, and the technique can be performed as a day-case procedure.[8–10,12–14]

Until recently, most of the work published on radiofrequency volumetric tissue reduction for sleep-disordered breathing has focused on

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monopolar energy application. The use of monopolar radiofrequency volumetric tissue reduction to reduce lesion size and soft tissue volume has been studied extensively.[2–7,15] Monopolar lesions have been characterised histologically in a porcine model,[3] and have also been assessed using magnetic resonance imaging (MRI) up to 24 and 72 hours post-operatively in the human tongue base and central nervous system, respectively.[4,15] The effect of bipolar energy application on clinical parameters has also been described and has been deemed safe and simple.[8–12,14] Bipolar radiofrequency volumetric tissue reduction of the tongue base uses much less energy per treatment session than monopolar application, and thus takes less time to perform. It enables precise placement of energy between two electrodes, with consequent avoidance of secondary thermal damage. These factors are of particular importance in the tongue base, where unpredictable energy distribution could result in damage to the hypoglossal and lingual nerves and other important structures.

The purpose of this pilot study was to characterise the appearance of bipolar radiofrequency volumetric tissue reduction induced lesions using MRI, and to demonstrate the sequence of lesion changes in the tongue base and soft palate up to six weeks post-procedure. Corresponding changes in the airway and soft tissue dimensions were observed. Any adverse effects were also evaluated.

Methods

The study was registered with the research and development department of Barking, Havering and Redbridge Hospitals National Health Service Trust. The study protocol was reviewed and approved by the local research and ethics committee. Informed consent was obtained from all patients.

Patients

Five adult male patients with snoring or sleep-disordered breathing were treated with one session of bipolar radiofrequency volumetric tissue reduction. The patients underwent various combinations of treatment to the tongue base, soft palate only, or soft palate combined with palatal arches and uvula. One patient also underwent tonsillectomy. Sleep nasendoscopy was used as the evaluation technique to determine treatment modality, as per our usual departmental practice.

Procedure

The procedure was performed under general anaesthesia with nasotracheal intubation. A Boyle–Davis gag was used to hold the mouth open and to provide access to the tongue base.[13] Radiofrequency current was generated by the CelonLab ENT system (Olympus, Medical Systems Europa GmbH, Hamburg, Germany). The tongue base was treated using the Celon ProSleep Plus applicator, placing six 6 W applications 1 cm apart in a rectangular configuration around the foramen caecum.[13] Patients undergoing treatment to the palate received ten 10 W applications delivered to the soft palate by the Celon ProSleep Plus needle in a configuration previously described by the senior author and colleagues.[14] Radiofrequency-assisted uvulopalatoplasty was performed by trimming the uvula and redundant posterior tonsillar pillars with a Celon ProCut applicator. The CelonLab ENT system stops the flow of radiofrequency current when the tissue reaches a certain impedance threshold, usually after four to six seconds. The surgeon is made aware of this by an audible Autocut signal. At the settings used, 24–60 J was delivered per punctum.

Tonsillectomy was performed by the standard 'cold steel' method.

Imaging

In all patients, MRI scanning was performed pre-operatively and one and six weeks post-operatively. In some patients, additional scans were performed at other intervals between day one and week six, to demonstrate sequential changes in lesion appearance.

A Magnetom Avanto 1.5T MRI system (Siemens, Erlangen, Germany) was used for image acquisition. Patients lay in a supine position with their head fixed in a head and neck coil. They were asked to breathe gently but not to swallow, cough or move. A T1-weighted sequence was performed in the sagittal plane to assess airway and tissue dimensions (Spin Lattice Relaxation Time (T1) 1100 ms, Time to Repetition (TR) 1870 ms, Echo Time (TE) 3.9 ms, Time to Acquire (TA) 9.34 minutes, field of view 210, matrix 205×256, slice thickness 1 mm with 0.5 mm gap, two signals averaged, and anteroposterior phase encoding direction). Short tau inversion recovery (STIR) images were also acquired in the sagittal, coronal and axial planes to further characterise the lesions (T1 130 ms, TR 4410 ms, TE 27 ms, Number of Signal Averages (NSA) 1, field of view 210 mm^2, matrix 163×256, slice thickness 4 mm with 0.4 mm gap, phase over sampling 100 per cent, and phase encoding head > foot for sagittal sequences).

Data analysis

Image analysis was performed using a Siemens Leonardo workstation and Argus software. All dimensions and volumes were measured by the same radiologist (SC).

Lesion appearance was characterised over time by analysis of sequential images. Lesion dimensions were measured in one patient and volumes calculated.

Soft tissue and airway measurements were taken from T1-weighted, sagittal images. Maximum uvula length and thickness were recorded. Tongue length was measured from the inferior margin of the mandible to the point at which the tongue bisected the occlusal plane. The maximum posterior airway distance between soft tissue and posterior pharyngeal wall was measured at the level of the hard palate (retropalatal distance), occlusal plane (retrolingual distance) and mandibular plane (retroepiglottal distance). The volume of the posterior airway space between the level of the hard palate and mandibular plane was calculated using Argus software (Siemens). Mean values for each of these dimensions were calculated using images taken pre-operatively and one and six weeks post-operatively. Statistical analysis of measurements was not performed due to the small study population.

Results

Four patients were simple snorers, and one patient had mild obstructive sleep apnoea. The patients' mean age was 55 years (range 42–67 years). Their mean body mass index was 27.7 (range 24.0–32.2).

Lesion imaging

Radiofrequency volumetric tissue reduction induced lesions were visible on MRI imaging from the first post-operative day. T1-weighted sequences initially demonstrated ovoid areas of central hyperintensity, representing haemorrhage, surrounded by areas of hypointense signal, representing oedema. These lesions expanded up to day three, with the haemorrhagic, necrotic centre increasing slightly in size. Lesions then began to shrink. Lesion definition steadily improved from day one to day seven, while peripheral oedema gradually decreased. Thereafter, lesion size, definition and oedema all diminished. By day 42, there were no remaining lesions evident on T1-weighted MRI scans.

STIR MRI scans demonstrated central hypointensity with a surrounding zone of high signal. This hyperintensity became even more pronounced at the periphery, and represented oedema (Figure 1). Lesion changes over time followed a similar pattern to that seen for T1-weighted imaging, with increasing definition and decreasing oedema until day seven, followed by diminishing size and definition and further reduction in oedema. However, in contrast to T1-weighted imaging, in two of the five patients lesions were still evident at day 42 as small, high signal areas.

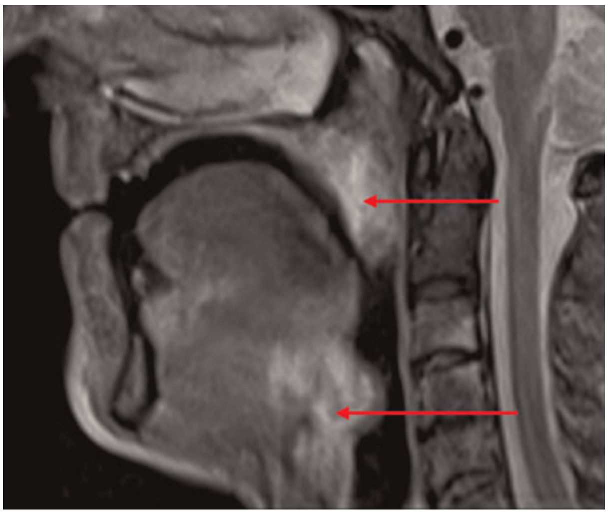

FIG. 1

Sagittal, STIR sequence, magnetic resonance imaging scan, demonstrating diffuse oedema of the tongue base and soft palate.

Lesion measurements were recorded for patient three (Table I).

Airway measurements

A general trend was noted towards a reduction in patients' uvula thickness and length and a small increase in their posterior airway space volume (Figure 2). Uvula thickness and length generally increased early in the first post-operative week, reaching maximum values by day seven and then decreasing up to day 42. The mean uvula thickness decreased from 12.7 mm pre-operatively to 10.3 mm on day 42, and the mean uvula length decreased from 35.7 mm pre-operatively to 33.3 mm on day 42. Unsurprisingly, the greatest increase in posterior airway space volume occurred in the patient who underwent tonsillectomy in addition to tongue base and soft palate radiofrequency volumetric tissue reduction (Figures 3 and 4). Patients' mean posterior airway space volume increased from 13.1 ml pre-operatively to 14.9 ml on day 42 (excluding the patient undergoing tonsillectomy; if this patient is included, the mean volume increased from 12.3 ml pre-operatively to 16.1 ml on day 42). Results for tongue length, retropalatal distance, retrolingual distance and retroepiglottal distance were very variable, and no obvious trends were observed.

Complications

None of the five patients in this study experienced intra- or post-operative complications.

Discussion

This study documented the sequence of changes occurring in the tongue and soft palate following bipolar radiofrequency volumetric tissue reduction. STIR images demonstrated central hypointense and peripheral hyperintense zones within radiofrequency volumetric tissue reduction induced lesions. Lesion definition increased until day seven post-operatively, following which it began to subside, until the lesions disappeared at around week six. This appearance is representative of central haemorrhage and subsequent coagulative necrosis surrounded by oedema. Oedema is maximal in the immediate post-operative period and subsequently gradually abates. These radiological changes broadly correlate with our airway measurements. Uvula dimensions initially increased with the expansion of the haemorrhagic

TABLE I

TONGUE LESION DIMENSIONS: PATIENT THREE

Lesion	Day			
	1	3	7	21
1 (cm^3)	3.0	4.0	3.6	0.8
2 (cm^3)	1.3	3.0	2.8	0.9

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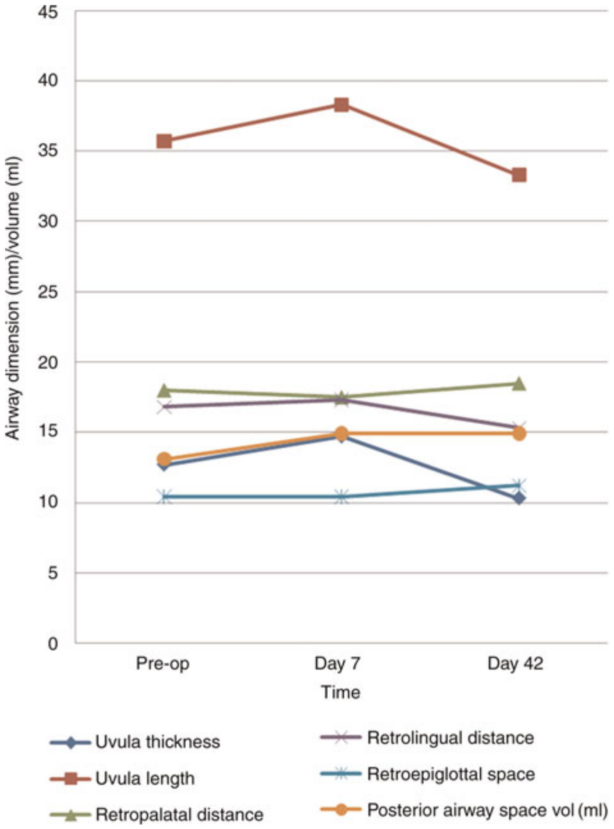

FIG. 2

Change in airway measurements over time. Vol = volume; Y axis has 5 measurements which relate to mm and 1 measurement which relates to volume so both included

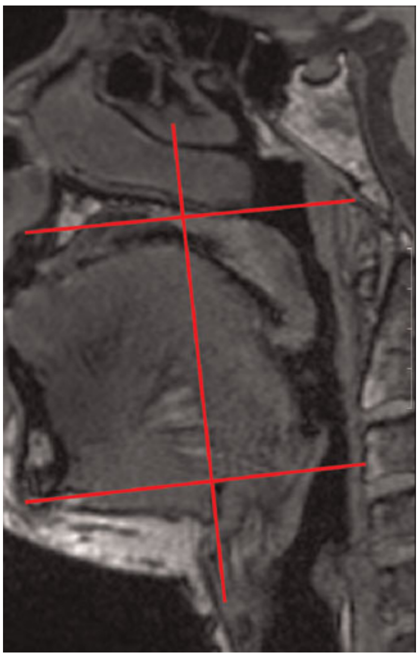

FIG. 3

Sagittal, STIR sequence, magnetic resonance imaging scan showing posterior airway space pre-operatively. Upper line = nasal plane; lower line = mandibular plane

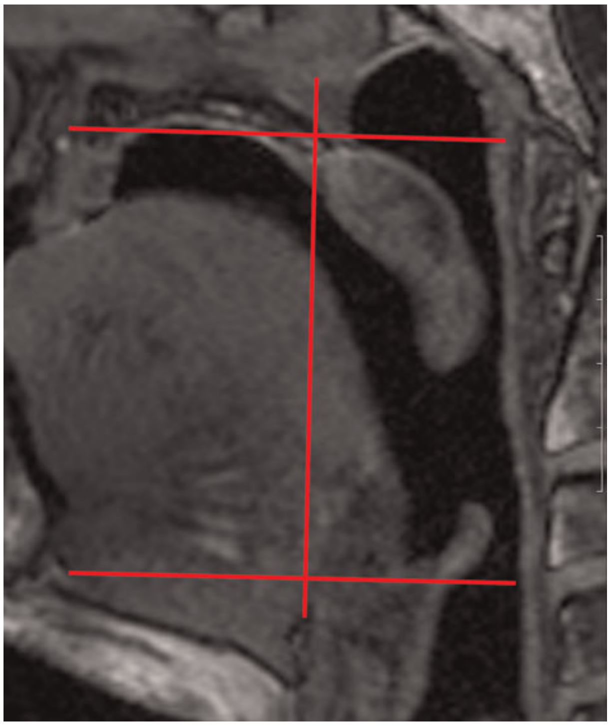

FIG. 4

Sagittal, STIR sequence, magnetic resonance imaging scan showing posterior airway space one week after tonsillectomy and radiofrequency volumetric tissue reduction to the palate and tongue base. Upper line = nasal plane; lower line = mandibular plane

area, and then decreased as oedema resolved and the tissue healed and retracted. This was accompanied by an increase in the posterior airway space. The lesions were still visible on STIR images at day 42, and may therefore go on to produce long term scar formation.

The radiological characteristics of the bipolar radiofrequency volumetric tissue reduction induced lesions broadly correlate with those seen in early monopolar radiofrequency induced lesions.[4,6,15] Monopolar lesions in the brain become increasingly defined with time, and increase in size up to day three.[4] The T1-weighted images of these lesions show foci of hyperintensity surrounded by a hypointense edge.[4] STIR sequences of monopolar lesions in the tongue base show hypointense areas with surrounding hyperintense oedema up to 24 hours post-operatively.[5] Magnetic resonance imaging characterisation of monopolar lesions has not been undertaken later than 24 hours post-operatively in the tongue base[15] and 72 hours post-operatively in the brain,[4] to enable radiological comparison of subsequent lesions. There has been no previous MRI characterisation of palatal lesions. The current study used MRI to document radiological changes in bipolar radiofrequency induced lesions of both the palate and tongue base, up to six weeks post-procedure.

The consecutive radiological changes documented by this study correspond to the macroscopic tissue changes previously observed in a porcine model,[3] and studied by our group in a human cadaveric model.[16] Macroscopic section of tissue following

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monopolar radiofrequency volumetric tissue reduction initially reveals central brown and peripheral pale, hyperaemic tissue within the lesion. The central area becomes grey-brown with time; white tissue surrounds it, and the whole lesion contracts. This process is evident on STIR sequences as central hypointense and peripheral hyperintense regions which increase in definition and then regress.

These changes represent the orchestrated sequence of events that occur in normal wound healing. In the immediate post-operative period, there is central haemorrhage, thrombosis and coagulative necrosis with interstitial and peripheral oedema. Oedema then starts to subside, and granulation tissue begins to appear by day three. Over the ensuing days to weeks, there is resorption of necrotic material and resolution of inflammation. Fibroblasts proliferate and collagen deposition occurs.

However, on macroscopic tissue section, monopolar radiofrequency volumetric tissue reduction induced lesions have been shown to shrink rapidly after day three. Investigators have reported that cross-sectional lesion area diminishes by some 40 per cent between days three and seven, and that lesions disappear by three to four weeks.[3] In our study, MRI images of bipolar-induced lesions demonstrated a slow decrease in size after day three, but persistence past six weeks in some patients despite much lower energy application. This was probably due to differences in needle configuration and thereby energy delivery. Alternatively, monopolar lesions may still be present on MRI imaging when no longer apparent to the naked eye; however, unfortunately this cannot be assessed since there are no reported data detailing the MRI characteristics of monopolar lesions past 24 hours.

The MRI characteristics of bipolar radiofrequency induced lesions observed in our study enable us to explain patients' clinical symptoms post-procedure. Snoring is reportedly worse in the first few post-operative days, and is accompanied by a globus sensation in some individuals. These symptoms are worst around day three, the time of maximal lesion size. Conversely, the worst pain is reported at the time of maximal oedema rather than greatest lesion size. Four of the patients in our study completed visual analogue scales for post-operative pain, as part of another study by our group of 100 patients who underwent bipolar radiofrequency volumetric tissue reduction.[17] These four patients' mean pain score was highest on day one, the time of maximal oedema; it then decreased between days one and four from 4.4 to 3.5, while lesion size (in particular the haemorrhagic, necrotic centre) increased. The patients' mean pain score then increased a little between days four and seven to 3.9, as lesion size began to decrease but lesion definition continued to improve. From day seven onwards, pain scores and lesion size, definition and oedema all diminished. Pain had completely subsided by day 20 but lesions were still visible (some were still visible more than six weeks post-operatively on STIR sequences).

Comparison of individual MRI scans demonstrated minor differences between the RFTVR induced tongue base lesions in each patient. The periphery of many lesions was diffuse; lesion dimensions were not recorded for these images due to difficulty in precisely delineating their borders. Generally, placement of punctums 1 cm apart resulted in merging of tissue response into a single lesion visible on MRI images. One patient had two discrete but adjacent lesions. Analysis of MRI images also raised several questions regarding tissue response to bipolar radiofrequency volumetric tissue reduction. In patients one and two, the areas treated, number of applications and power used were identical; however, patient one had little demonstrable oedema surrounding the area of necrosis (on MRI images) while patient two had widespread oedema. Lesions were also seen to differ in intensity in different patients, which may be due to differing amounts of energy delivered; this is influenced by individual variation in fat–liquid density and lesion cooling (determined by local vascular perfusion). Therefore, surgical results could potentially be optimised by using MRI to study the number and position of application sites and the effect of the power used.

Posterior airway space was felt to be the most important airway measurement in our study, since an increase in airway calibre should make this area less prone to collapse (due to the Bernouilli effect). Posterior airway space volume was shown to increase post-treatment, implying a beneficial effect. This largely agrees with other reports on monopolar radiofrequency application, as regards upper airway changes. Stuck *et al.*[7] and Powell *et al.*[5] both demonstrated shrinkage of the free edge of the soft palate on cephalometry. Stuck *et al.*[6] found no change in the retrolingual space following radiofrequency volumetric tissue reduction of the tongue base. Powell *et al.*[5] showed an increase in posterior airway space of 53.7 per cent on cephalometry 12 weeks post-procedure. Steward[18] studied a small number of patients and could find no statistically significant increase in airway volume, using acoustic pharyngometry; however, a trend towards such an increase was noted.

Tongue volumes were not measured in our study as this was felt to be too inaccurate. The borders between the intrinsic and extrinsic tongue muscles and the posterior tongue and tonsillar tissue were indistinct and could not be differentiated clearly. Other researchers have had similar problems,[19–21] and have included the volume of the intrinsic tongue musculature plus some or all of the genioglossus, hyoglossus and mylohyoid muscles in their tongue volume measurements. Lesion volume has previously been measured using *in vitro* microultrasonic piezoelectric crystals[3] and MRI scanning.[4,15] In our study, the posterior airway space volume was felt to be the most important measurement; we therefore included this parameter plus other, more accurately measured airway dimensions.

Bipolar radiofrequency treatment has several advantages over similar monopolar methods. In the current study, the average total energy use was 576 J per tongue base treatment, and 500 J for the one interstitial treatment of the soft palate. In contrast, one session of monopolar treatment requires

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between 1250 and 3680 J.[12] Bipolar treatment thus requires much less energy; consequently, treatment duration is reduced from up to 17 minutes (for monopolar delivery of four 600 J applications)[3] to several seconds per bipolar lesion. Bipolar application enables precise placement of energy between two electrodes integrated into an application handset, and therefore avoids secondary thermal damage to the patient, both in adjacent neurovascular structures and at other sites. As we have demonstrated, lesion characteristics, and their effect on airway dimensions, are comparable to monopolar radiofrequency induced lesions. Bipolar radiofrequency volumetric tissue reduction may therefore be used as a safe and quicker alternative to monopolar radiofrequency volumetric tissue reduction, with similar results.

- **Magnetic resonance imaging (MRI) has previously been used to demonstrate monopolar radiofrequency volumetric tissue reduction induced lesions of the human tongue base, up to 24 hours post-operatively**
- **This pilot study assessed bipolar radiofrequency volumetric tissue reduction induced lesions of the tongue base and soft palate, up to six weeks post-procedure, using MRI**
- **Characterisation of these lesions enables: elucidation of lesion healing pathophysiology; explanation of patients' post-operative symptoms; and optimisation of operative technique and clinical outcome**

This pilot study demonstrated general trends in MRI images of bipolar radiofrequency volumetric tissue reduction induced lesions, and corresponding airway dimensions, over time. This information was obtained from a small sample of patients undergoing heterogeneous procedures and post-procedure scans of variable timing. We intend to perform a further study with a larger study population and more standardised treatment and MRI protocols, to obtain results amenable to statistical analysis. We hope that the information thus gained will be used: to elucidate the pathophysiology of bipolar radiofrequency volumetric tissue reduction induced lesions; to characterise, and subsequently to improve, the effects of treatment; and to explain patient symptoms. In this way, we hope to show that the operative technique and consequent clinical outcome of bipolar radiofrequency volumetric tissue reduction may be improved by MRI examination of lesions with respect to site, size, number and definition. It may be possible to increase the amount of energy applied per lesion and thereby to improve the treatment effect. Routine post-operative MRI scanning three days post-procedure, the time of maximal lesion size, may be of benefit to confirm optimal lesion placement. Future work should also assess the correlation of lesion parameters with clinical effects; for example, to establish whether patients with more intense lesion definition have better clinical outcomes in terms of improvement in polysomnography parameters and decreased snoring. In the current study, some lesions persisted six weeks post-procedure; therefore, further studies should assess when such lesions resolve and whether there is any long term evidence of scar formation (which may explain why the clinical effects of radiofrequency volumetric tissue reduction seem to dwindle with time).

Conclusion

This pilot study characterised the MRI appearance and sequence of changes occurring in bipolar radiofrequency volumetric tissue reduction induced lesions, up to six weeks post-procedure. The findings enable us: to elucidate the pathophysiology of bipolar radiofrequency volumetric tissue reduction; to characterise and subsequently to improve the effects of treatment; and to explain patient symptoms. The observed radiological features broadly correlated with those of monopolar radiofrequency volumetric tissue reduction induced lesions. No complications were experienced in this group of patients. Bipolar radiofrequency volumetric tissue reduction offers a safe, quicker, alternative treatment and requires less energy application, compared with monopolar radiofrequency application.

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