# Imaging of the Upper Airways During Hypoglossal Nerve Stimulation

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*Abstract*-**The upper airways were imaged in an anesthetized beagle to investigate the effect of selective stimulation of the hypoglossal nerve (HG) with a multi-contact peripheral nerve electrode. A fiberoscope lead (diam. 5 mm) was inserted transorally and positioned at various points in the upper airways while the head was fixed at either 30° or 90° from the horizontal. Images taken in the pharynx and near the base of the tongue show that stimulations delivered through the electrode contacts placed around the HG nerve trunk can generate several different patterns of tongue activation. A subset of these patterns substantially increase the size of the pharyngeal opening. These results suggest that selective stimulation of the whole HG nerve can be a useful technique to maximize the effect of the HG nerve stimulation in removing the obstructions in sleep apnea patients.**

***Keywords*- obstructive sleep apnea, selective nerve stimulation**

## I. INTRODUCTION

Obstructive sleep apnea (OSA) is the recurrent occlusion of the upper airways resulting in frequent arousals during sleep. Most commonly used treatment methods include a continuous positive airway pressure (CPAP) device and surgical procedures to remove excessive tissue in the pharyngeal area. All treatment methods suffer from severe drawbacks and limited success.

The development of occlusion in this disorder has been related to the prolapse of the tongue and its surrounding structure into the pharynx. Tongue prolapse has been attributed to diminishing neuromuscular activity in the upper airway (UAW) dilating muscles that occurs during sleep. This suggests that one should be able to compensate for the decreased muscle activity and preserve the UAW patency during sleep by electrical activation of the tongue muscles. The HG nerve innervates the protrusor and retractor muscles and thus the activation of the whole nerve at once may activate the retractor muscles that close the airways along with the protrusors [1]. Selective activation of the tongue muscles through HG nerve stimulation can potentially be a useful technique to maximize the upper airway dilation in several different modes of tongue movement by recruiting different sets of muscles. Having multiple stimulation paradigms for upper airway dilation can increase the rate of success for this approach in a patient population as well as providing alternative stimulation patterns for preventing muscle fatigue. This may lead to the development of a neuroprosthetic device as a treatment for OSA. Selective stimulation of the HG nerve with the FINE was demonstrated earlier using EMG and ENG responses as an output variable [3, 4]. The objective of this study is to investigate the functional outcome of the selective HG nerve stimulation with imaging of the upper airways.

## II. METHODS

A beagle (10kg) was anesthetized using Sodium Pentobarbital (30 mg/kg, IV). Surgical areas were shaved and the animal was transferred to a heated-top surgery table (T=38degrees). ECG and rectal temperature were monitored. Femoral artery and vein were catheterized for monitoring blood pressure and injection of fluids. Lactated Ringer's solution was administered intravenously. Tracheotomy was performed and the animal was connected to a mechanical ventilator through the tracheal tube. The depth of anesthesia was adjusted with further doses of Sodium Pentobarbital (6 mg/kg, IV) as needed.

A Flat-Interface-Nerve-Electrode (FINE), developed by Tyler and Durand [2], was implanted on the left hypoglossal nerve trunk immediately proximal to the bifurcation point of the distal branches occurring over the hyoglossus. The FINE had 12 sets of tripolar contacts positioned around the nerve trunk, 6 on top and 6 on the bottom side of the nerve [3] and numbered sequentially around the nerve. The electrode had a window size of 6mm by 0.6 mm and a radial inter-contact separation of 1.25 mm. Cathodic contacts, placed in the middle of each tripolar set, had an exposed area of 0.25x 0.25 mm. A Karl-Storz fiberscope lead (Small Animal Bronchoscope 60001VL, diam. 5 mm) was inserted transorally and fixed in place. Various locations of the tip and the tip angle were tried for best viewing. The animal's head was fixed at angles of either 30 or 90 degrees from the horizontal with the mouth open or closed. At each head and mouth position, the left hypoglossal nerve was selectively stimulated through the contacts of the FINE.

A single current pulse (pulse width=400µs, frequency=50Hz, train duration=2.5 s) of varying amplitude (0-3000µA) was applied through each one of the 12 tripolar contact sets of the nerve electrode while the pharyngeal and the tongue images were acquired into a computer using the FlashBus MV Lite (Integral Technologies) image grabber system; one frame before stimulation and one during the stimulation train. The stimulation threshold was determined for each contact set and position, and 4 to 5 suprathreshold stimulation strengths were tested.

## III. RESULTS

Stimulation through contacts 1 and 2 activated the intrinsic muscles on the left side shortening the tongue longitudinally and the base was depressed toward the mouth floor laterally (Fig. 1, middle). Stimulation through contacts 3, 4, and 5 caused the depression of the tongue base medially (Fig. 1, right). Both set of contacts also generated pharyngeal dilation (Fig. 2, middle and right), but in different directions in the transverse plane. Not all the modes of dilation are shown in Fig. 2, but only the two selected. The tongue and pharyngeal movements were unilateral since the electrode was implanted on the left hypoglossal only.

The remaining contacts generated various tongue movements, however, did not result in significant pharyngeal dilation that could be appreciated in the images. Stimulation through contact 6 did not result in tongue depression at the threshold current but rather activated intrinsic tongue muscles along the side ipsilaterally. Lateral depression of the base occurred at higher current levels (spillover to other fascicles). Activation through contacts 8, 9, and 10 mainly shortened the tongue on the left side. Activation through contacts 11, 12, and 13 primarily generated tongue depression at the base.

## IV. CONCLUSIONS

This experiment showed that selective activation of the tongue muscles can be achieved through HG nerve stimulation. Various modes of tongue movements obtained with a subset of the contacts resulted in pharyngeal dilation in different directions in the transverse plane while the others mainly activated the intrinsic muscles of the tongue. The images showed that contacts 3, 4, and 5 generated the best activation patterns resulting in substantial enlargement of the pharyngeal opening in addition to depression of the tongue at the base, which may further help reduce the overall upper airway mechanical resistance. Further studies will be conducted to determine the reproducibility of these observations.

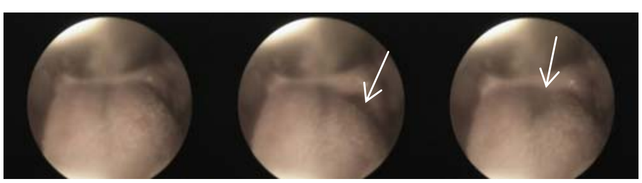

Fig 1. Tongue images for 90 degree, open mouth case: from left to right: without stimulation, stimulation through contact 1 causing depression of the tongue base laterally on the left side (arrow), and stimulation through contact 3 causing a depression of the tongue base medially on the same side (arrow). The structure in the upper half of the image is the retro-palate.

Fig 2. Pharyngeal images while the head is 30 degrees from the horizontal with the mouth closed; from left to right: without stimulation, stimulation through contact 1 dilating the pharynx dorsolaterally (up and to the right in the image), and through contact 3 dilating the pharynx mainly in the anterior (down) direction. The darker region in the middle is the proximal end of the trachea. The epiglottis is pushed aside by the fiberscope lead.


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