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Reference:

Woodson B. Tucker, Strohl Kingman P., Soose Ryan J., Gillespie M. Boyd, Maurer Joachim T., De Vries Nicolaas, Padhya Tapan A., Badr M. Safwan, Lin Ho-sheng, Vanderveken Olivier M.,- Upper airway stimulation for obstructive sleep apnea : 5-Year outcomes
Otolaryngology, head and neck surgery - ISSN 0194-5998 - (2018), p. 1-9
Full text (Publisher's DOI): <https://doi.org/doi:10.1177/0194599818762383>

Upper Airway Stimulation for Obstructive Sleep Apnea – 5-Year Outcomes

Author(s)

B. Tucker Woodson, M.D.¹, (bwoodson@mcw.edu)
Kingman P. Strohl, M.D.¹¹, (KPSTROHL@aol.com)
Ryan J. Soose, M.D.², (sooserj@upmc.edu)
M. Boyd Gillespie, M.D.³, (mgilles8@uthsc.edu)
Joachim T. Maurer M.D.⁴ (joachim.maurer@umm.de)
Nico de Vries, M.D.^{5,9}, (n.vries@slaz.nl)
Tapan A. Padhya, M.D.⁶, (tapan.padhya@moffitt.org)
M. Safwan Badr, M.D.⁷, (SBadr@med.wayne.edu)
Ho-sheng Lin, M.D.⁸, (hlin@med.wayne.edu)
Olivier M Vanderveken M.D. Ph.D.⁹ (Olivier@ovanderveken.be)
Sam Mickelson M.D.¹⁰, (sam@advancedentpc.com),
Patrick J. Strollo, Jr., M.D.¹² (strollopj@upmc.edu)

Disclosure Statement:

Funding source for this study was Inspire Medical Systems.

Corresponding Author

B. Tucker Woodson, M.D., Department of Otolaryngology and Human Communication, Medical College of Wisconsin, 9200 W Wisconsin Ave, Milwaukee, WI 53225, USA. Email: bwoodson@mcw.edu

From the

1. Department of Otolaryngology and Human Communication, Medical College of Wisconsin, Milwaukee, WI, USA
2. Department of Otolaryngology, University of Pittsburgh, Pittsburgh, PA ,
3. Department of Otolaryngology – Head and Neck Surgery, University of Tennessee Health Science Center, TN ,
4. Department of Otorhinolaryngology, Head & Neck Surgery, Sleep Disorders Center, University Hospital Mannheim, Mannheim, Germany
5. Department of Otolaryngology, OLVG Hospital and ACTA, Amsterdam, Netherlands
6. Department of Otolaryngology – Head and Neck Surgery, University of South Florida College of Medicine, Tampa, FL
7. Department of Internal Medicine, Wayne State University Health Center, Detroit, MI
8. Department of Otolaryngology – Head and Neck Surgery, Wayne State University Health Center, Detroit, MI
9. Department of Otorhinolaryngology and Head & Neck Surgery, Multidisciplinary Sleep Disorders Center, University of Antwerp, Antwerp, Belgium
10. Advanced ENT Associates, Atlanta, GA
11. Department of Pulmonary, Critical Care and Sleep Medicine, Cleveland VA Medical Center, Cleveland OH
12. Division of Pulmonary Allergy and Critical Care Medicine, University of Pittsburgh, Pittsburgh, PA

Conflict of Interest Statement:

B. Tucker Woodson, Inspire Medical Systems–study investigator, consultant; Medtronic–consultant, royalty; Siesta Medical–consultant, Cryosa, consultant.
Kingman P. Strohl, Inspire Medical Systems- study investigator, consultant; Sommetrics- consultant, Seven Dreamers-consultant, Galvani Bioelectronics- consultant
Ryan J. Soose, Inspire Medical Systems–study investigator, consultant; Philips Respironics–consultant, Galvani Bioelectronics - advisory board, consultant
M. Boyd Gillespie, Inspire Medical Systems–study investigator, consultant, research support; Medtronic, Olympus, Arthrocare–consultant; Surgical Specialties–consultant, research support.
Joachim T. Maurer, Inspire Medical Systems–study investigator, consultant; personal fees from GlaxoSmithKline, Weinmann, Olympus, ResMed, Neuwirth, Medtronic, and Heinen & Löwenstein; Nyxoah, consultant.

53 Nico de Vries, Inspire Medical Systems—study investigator, consultant; Philips, Olympus—consultant; Night Balance/ReVent—
54 medical advisor, shareholder, funding from company.
55

56 **Abstract**

57 **Objective:** To present 5 year outcomes of a prospective cohort of obstructive sleep apnea (OSA)
58 patients treated with upper airway stimulation (UAS) utilizing a unilateral hypoglossal nerve implant.

59 **Study Design:** A multicenter prospective cohort study.

60 **Setting:** Industry-supported multicenter academic and clinical trial.

61 **Methods:** From a cohort of 126 patients, 97 completed protocol and 71 patients consented to a
62 voluntary polysomnogram. CPAP failures with moderate to severe OSA, BMI < 32kg/M², and without
63 unfavorable collapse on drug induced sleep endoscopy were enrolled in a phase 3 trial. Prospective
64 outcomes included apnea hypopnea index (AHI), oxygen desaturation index (ODI), measures of
65 sleepiness, quality of life, snoring, and adverse events.

66 **Results:** Patients who did and did not complete the protocol differed in baseline AHI, ODI and lower
67 FOSQ scores but not in any other demographics or treatment response measures. Improvement in
68 sleepiness (Epworth Sleepiness Scale) and quality of life was observed with normalization of scores
69 increased from 33% to 78% and 15% to 67%, respectively. AHI response rate (AHI <20 events/hr
70 and >50% reduction) was 75% (n=71) When a last observation carried forward analysis (LCOF) was
71 applied, responder rate was 63% at 5 years. Serious device related events all related to lead/device
72 adjustments were reported in 6% of patients.

73 **Conclusions:** Improvements in sleepiness, quality of life, and respiratory outcomes are observed with 5
74 years of UAS. Serious adverse events are uncommon. UAS is a non-anatomic surgical treatment with
75 long-term benefit for individuals with moderate to severe OSA who have failed nasal CPAP.

76

77 **Introduction**

78 Hypoglossal nerve (CN XII) stimulation for obstructive sleep apnea (OSA) has demonstrated safety and
79 efficacy at 12 months in a cohort of participants with moderate to severe OSA who were unable to
80 accept or adhere to positive pressure therapy ¹. In the same cohort, a randomized withdrawal of
81 therapy demonstrated a device-related therapeutic effect, and durability and returned to successful
82 treatment values upon resumption of therapy ². Follow-up at 24, 36 and 48 months post implantation
83 continued to show successful clinical outcomes, low morbidity, and a favorable safety profile ³⁻⁵.

84 OSA is a chronic disease. Patient-centered outcomes are critical elements of disease management.

85 Hallmark outcomes for success include amelioration of intrusive snoring, excessive daytime sleepiness,
86 impaired cognitive function, and a reduced quality of life ^{6,7}. While important, the absolute apnea–

87 hypopnea index (AHI), in isolation, poorly correlates with these relevant disease outcomes with

88 differing effects on the quality of life and the severity of symptoms among patients for a similar number

89 of events during sleep ⁸. Clinicians do not make treatment decisions solely based on an arbitrary AHI

90 threshold. Assessment of successful treatment not only requires therapy to have a meaningful objective

91 improvement, but also a successful clinical effect as reported by patients combined with effective use by

92 the patient for many years.

93 The aim of this study was to evaluate long-term (60-month) safety and effects of UAS therapy on the

94 propensity for daytime sleepiness as measured by the Epworth Sleepiness Scale (ESS), daytime

95 functioning as measured by the Functional Outcomes of Sleep Questionnaire (FOSQ), intrusive snoring,

96 and sleep disordered breathing as found in an overnight polysomnography (PSG).

97 **Methods**

98 Participants

99 The STAR trial is a multicenter, IRB approved, (see Appendix 1 for IRB details) cohort that included
100 adults with a history of moderate to severe OSA, and intolerance or inadequate adherence to CPAP. Key
101 study exclusion criteria included a body mass index $> 32 \text{ kg/m}^2$, neuromuscular disease including
102 hypoglossal nerve palsy or injury, severe cardio-pulmonary disorders, active psychiatric disease, and co-
103 morbid non-respiratory sleep disorders that would confound functional assessments related to sleep.
104 Participants who met inclusion/exclusion criteria underwent three screening exams: an in-lab attended
105 polysomnography (PSG), a surgical consultation visit, and drug-induced sedated endoscopy (DISE).
106 Participants were excluded after the PSG for an AHI less than 20 or greater than 50 per hour of sleep;
107 central and/or mixed apnea index $> 25\%$ of the AHI; or a non-supine AHI < 10 . Participants were also
108 excluded if the surgeon's office head and neck exam identified pronounced anatomical abnormalities
109 (i.e. tonsil hypertrophy) that might prevent effective use of the device and after the DISE if complete
110 concentric collapse was observed at the level of the velopharynx⁹.

111 Study Procedures

112 Qualified participants who met pre-implant screening criteria underwent device implantation. The
113 implanted system (Inspire Medical Systems, Inc. Maple Grove, MN, USA) consists of three components:
114 a stimulation cuff electrode that encircles the medial division of the right hypoglossal nerve; a pressure
115 sensing lead to guide timing of stimulation and placed within the fourth or fifth right intercostal space;
116 and an implantable pulse generator inserted into a right mid-clavicular subcutaneous pocket. The
117 therapy guides phasic stimulation to the hypoglossal nerve to increase airway muscle tone and luminal
118 diameter prior to the onset of inspiration and to maintain adequate upper airway airflow.

119 Self-reported outcomes using validated sleep questionnaires, general health status, device metrics, and
120 adverse events were followed at 6-month intervals for five years. PSGs per protocol were collected at
121 12 and 18-month follow-up visits and voluntary PSG's were performed at 3 and 5 years. The PSG studies

122 were scored by two independent core labs using standard 2007 scoring criteria,¹⁰ with a hypopnea
123 scored based on a 30% airflow reduction and a 4% oxygen desaturation. Sleep states are reported as
124 NREM and REM sleep and arousals as >3 seconds change EEG frequency¹⁰. Patient-reported outcome
125 measures included subjective sleepiness and sleep-related quality of life using the validated ESS and the
126 FOSQ. Clinical variables including BMI, neck circumference, stimulation parameters, and blood pressure
127 were measured at scheduled study visits to assess any changes over the course of the study. Subjective
128 report of participant and bedpartner reported snoring was collected from participants on a categorical
129 scale (no snoring, soft snoring, loud snoring, very intense snoring, or bed partner leaves room). All
130 reported adverse events were reviewed and coded by the Clinical Events Committee. Serious adverse
131 events were defined as any events that led to death, life-threatening illness, permanent impairment and
132 related surgeries, or a new or prolonged hospitalization. Adverse events were categorized as procedure-
133 related if related to the surgical procedure or device-related if secondary to use of the device after
134 therapy activation.

135 Statistical Analysis

136 The primary population for analysis comprised participants who were implanted and completed follow-
137 up at the 5-year visit. We also performed several sensitivity analyses to assess the impact of the missing
138 long-term outcome data of AHI, FOSQ and ESS at 36 and 60 months. The sensitivity analyses included a
139 last observation carried forward (LOCF), a repeated measures regression analysis, a multiple imputation
140 (MI) analysis, and a maximum likelihood estimation (MLE) analysis¹¹. The LOCF analysis imputed the last
141 available follow-up value for any missing data at months 36 and 60. The repeated measures analysis
142 included all available baseline and follow-up data in a repeated measures regression model and
143 provided least squares estimates of the means at 36 and 60 months. The MI analysis created 10 imputed
144 datasets for each parameter with all available baseline and follow-up data used as predictors. The
145 means at months 36 and 60 were estimated within each imputed dataset and combined across

146 imputations. The MLE analysis provided estimates for the outcomes at months 36 and 60, which
147 maximizes the probability of the observed data. A stepwise multivariable logistic model was used to
148 determine key baseline factors associated with therapy response. Analyses were performed with the use
149 of SAS software, version 9.2 (SAS Institute).

150

151 **Results**

152 **Participants**

153 Ninety-seven of the 126 implanted participants (78%) completed the 5-year follow-up visit (**Figure 1**).
154 Among the 29 participants who did not complete the 5-year assessment, 21 were lost to follow-up
155 within the pre-specified timeframe; five died of unrelated causes (sudden death, cardiac arrest after a
156 fall and blunt chest trauma, homicide, malignant melanoma, and myelodysplastic syndrome), and the
157 device was explanted in three patients (IPG removal in a non-responder, system removal non-
158 responder, and non-elective removal in a responder due to septic arthritis). Seventy-one of the 97
159 protocol patients, participated in a voluntarily 5 year follow up overnight in-lab polysomnographic
160 evaluation. The mean BMI at 5-years was 28.6 ± 2.8 , which was unchanged from baseline.

161

162 Among the 97 participants who did compared to those who did not complete the protocol, baseline age,
163 BMI, and ESS were similar, but subjects who did not complete the month 60 visit had higher AHI, ODI
164 and lower FOSQ scores at baseline. These differences disappeared when evaluation was performed at
165 12 months while therapy was activated.¹ Among the seventy-one participants who voluntarily
166 completed a 60 month PSG study, age, AHI, and BMI baseline parameters were not significantly different
167 from those who did not complete the PSG, the 97 protocol followed patients, nor the original cohort

168 (Table 1). The AHI treatment response did differ at 12 months (74% vs 52%, $p < 0.002$) but AHI
169 treatment response at 18 and 36 months, change in sleepiness, and change in quality of life did not
170 differ between groups that did and did not complete the 60 month PSG.

171

172 **Primary Outcome Measures**

173 The efficacy measures of AHI and ODI decreased from baseline to the 12-month assessment and
174 remained stable at 36 and 60 months (Table 2, Figure 2). A decrease in the AHI of $>50\%$ and an AHI of
175 <20 , which was the a priori definition of success, was observed in 75% of participants with 5-year PSG
176 (Figure 2).¹² Using other AHI cutoffs, 44% and 78% of participants had AHI < 5 and < 15 during 5-year
177 PSG. Given the lost to follow up over the extended duration of follow up, a “last observation carried
178 forward” (LOCF) analysis from the cohort at 12, 18 or 36 months was performed. LOCF demonstrated
179 an average AHI at 5-years of 15.1 ± 1.5 , with a median AHI of 7.6 and a response rate of 63% (5 deaths
180 and 3 explants were counted as non-responders), which was similar to the responder rate of 66% at 12
181 months. Using both LOCF and multiple imputation method to account for missing data, the change of
182 AHI from baseline was similar at 36 and 60 months, and did not change using different sensitivity
183 analysis (Table 3). In addition to sensitivity analysis using LOCF and multiple imputation methods, we
184 conducted the best and worst-case analysis, in which the minimal and maximal value from available
185 post-operative AHI at 12, 18, and 36 months was used for all patients who did not complete the 60
186 month PSG. In the best-case analysis, the average AHI was 12.3 ± 15.4 with a change of -19.8 ± 15.8
187 (95% confidence interval of -22.5 to -17.0) at 60 months from baseline. The worst case analysis
188 demonstrated an average AHI of 17.0 ± 18.2 with a change of -15.0 ± 16.6 (95% confidence interval
189 of -17.9 to -12.1) at 60 months from baseline. Changes from baseline in best and worst case analysis
190 were not significantly different.

191 When the 5-year AHI responders and non-responders were compared, univariate analysis demonstrated
192 differences in age and the baseline ODI between groups. A multivariable stepwise regression analysis
193 including age, BMI, gender, neck circumference, prior UPPP, and baseline AHI, ODI, FOSQ, and ESS
194 demonstrated that only a lower ODI was predictive of 5 year AHI responders. (Table 4)

195 **Self Reported Outcome Measures**

196 FOSQ and ESS improvements observed at prior evaluation periods persisted at 5-years. The average
197 increase of FOSQ was 3.2 units as observed, and unchanged with the sensitivity analysis. At baseline,
198 only 15% reported a normal FOSQ score (>17.9). This increased to 67% at 5-years. The average reduction
199 of ESS was 4.4 units. The percent of participants who reported a normal ESS score (<10) increased from
200 33% at baseline to 78% at 5-years. (Figure 2)

201 Long-term bedpartner and self-reported snoring reports demonstrated improvement from baseline and
202 remained relatively stable from 12 to 60 months (Figure 3). Based on partner report, intrusive snoring
203 (very intense snoring or bedpartner leaves room) was reduced from 54% at baseline to 2% at 60-
204 months; no or soft snoring was increased from 17% to 90%. Participant self-reports of nightly use were
205 86%, 81% and 80% at years 1, 3 and 5.

206 **Other Measures**

207 As at other time points, the cohort demonstrated no changes in sleep stage distribution. Arousal index
208 was significantly reduced (27.8 +/- 11.7 to 7.8 +/- 9.7 events/hr, $p < 0.0001$). Percent time with oxygen
209 desaturation less than 90% was unchanged (8.0 +/- 10.1 to 7.4 +/- 13.3%). For patients who completed
210 protocol follow up, stimulation parameters changed. Sensory thresholds, functional thresholds, and
211 sub-discomfort thresholds decreased.

212 **Adverse Events**

213 After five years, eight participants (6% of 126) had a total of nine serious device-related adverse events
214 requiring surgical repositioning or replacement of the neurostimulator or implanted leads. One
215 participant had two revision procedures to reposition the neurostimulator and the sensing lead to
216 resolve discomfort. One participant underwent stimulation lead repositioning due to unfavorable
217 tongue movement pattern and to improve therapy response. Four participants had insulation failure
218 with the sensing lead and underwent replacement of both the neurostimulator and sensing lead. In one,
219 the stimulation lead was inadvertently cut and also then required replaced.

220

221 Discomfort due to electrical stimulation was the most common non-serious adverse reported event
222 occurring 81 times during the first year. For most subjects this complaint was resolved by
223 reprogramming of stimulus levels, and during the fifth year was reported only five times. Tongue
224 abrasion from tongue movement was reported 28 times the first year and was reduced to two times
225 during the fifth year. A detailed list of adverse events is provided in Table 5.

226

227 **Discussion**

228 The durability of the treatment effect of upper airway muscle stimulation therapy by the Inspire System
229 was addressed with a 5-year follow-up of participants in the STAR trial. Both voluntary PSG measures in
230 71 of the original 126 participants and data from protocol visits in 97 patients, demonstrated long-term
231 resolution of objective measures of sleep disordered breathing, daytime symptoms, and quality of life
232 components of the disease. The major findings of the study were: (1) UAS therapy provides clinically
233 meaningful and statistically significant improvements in PSG measures of OSA, (2) clinically meaningful
234 and statistically significant improvements in key patient-centered outcomes in snoring, daytime

235 sleepiness, and sleep related quality of life were achieved, and (3) there was a very low incidence of
236 device related adverse outcomes beyond the implant period.

237 Sustained effectiveness is critical in a chronic condition such as OSA that requires long-term
238 management. The detrimental effect of OSA on activities of daily living and quality of life measures was
239 mitigated by this therapy in a significant number of participants at 5-years. Untreated moderate-severe
240 OSA has been associated with increased health care costs and physician visits, increased motor vehicle
241 accidents, increased workplace errors, and loss of productivity. CPAP via a mask is the standard first-line
242 therapy ¹³. It is highly effective when used consistently. Unfortunately, many individuals cannot or do
243 not adjust to this therapy. Challenges with CPAP acceptance and adherence in patients with moderate
244 to severe disease have been identified as an impediment to the ability to mitigate co-morbid
245 cardiovascular sequelae ¹⁴. This report indicates that multi-year control of obstructive sleep apnea
246 hypopnea syndrome can be achieved by a non-CPAP and non-anatomic surgical approach.

247 Patient-reported outcome measures capture the subjective aspects of the sleep apnea syndrome, and
248 these self-reported symptoms often drive patients to be evaluated for sleep apnea ¹⁵. PSG measures
249 correlate loosely with OSA disease burden as well as symptom expression. These symptoms may
250 contribute significantly to personal morbidity, as well as the direct and indirect health care costs of
251 untreated OSA ^{16,17}. Improvements in several aspects of the quality of life, accompanied by use of UAS, if
252 interrupted, results in objective and subjective recidivism as shown in the withdrawal study ². Other
253 common consequences of OSA are spousal complaints related to snoring. There is currently no accepted
254 standard objective measure of snoring, although the reliability of self-report and bed partner report of
255 snoring intensity may be questioned, most participants in this cohort achieved a successful reduction in
256 their snoring from loud or disruptive levels to soft or no snoring .

257 Cranial nerve stimulation using Inspire is an innovative first-in-class therapy. In contrast to other
258 surgical approaches, this therapy does not directly modify the pharynx or surrounding structures.
259 Instead, it addresses pharyngeal collapse using a more physiologic approach. This study is noteworthy
260 both in demonstrating a high level of durable effect but also a low complication and morbidity rate.
261 Several recent independent single-center cohort studies reported additional safety, efficacy and therapy
262 adherence data in the real-world clinical practice setting, subsequent to FDA approval in 2014. Kent et al
263 ¹⁸ reported a case series of 21 consecutively implanted patients. After an average of 7.8 months of
264 follow up, the AHI was reduced from 33.3 to 5.1 ($p < 0.01$) and ESS improved from 10.3 to 6.0 ($p < 0.01$).
265 Objective device adherence was 7.0 ± 2.2 hours of use per night. Heiser et al ¹⁹ reported another case
266 series of 31 consecutive patients. After 12 months, the mean AHI was reduced from 32.9 to 7.1 and ESS
267 from 12.6 to 5.9. All participants demonstrated high rates of therapy adherence with 6.6 ± 2.7 hours per
268 night at 12 months using objective device reporting. In addition to these single-center studies, a multi-
269 center post-market study of 60 patients has recently reported consistent improvements in patient
270 outcomes after 6 and 12-month follow up ^{20,21} in the AHI, ESS and FOSQ as observed in the STAR trial.
271 These single-center and multi-center post-approval studies have demonstrated that hypoglossal nerve
272 stimulation can be effectively implemented in the routine clinical practice for managing OSA patients
273 who could not adhere to CPAP.

274 The size of this prospective cohort and high number of patients with long-term follow-up data is a
275 considerable strength of this surgical study. The assessments were consistently collected in the US and
276 European sites, so that intra- and inter-individual comparisons could be objectively and statistically
277 addressed. The clinical management among surgeons and sleep medicine practitioners and data
278 integrity was maintained over five years.

279 The biggest limitations related to the lack of a control group, and assessment of treatment effects other
280 than withdrawal of stimulation at 12 months. However, the effect size of objective and subjective

281 responses are large, of the order of other evidence-based therapies. Since the study group was
282 predominantly, male, obese, CPAP-intolerant patients of European descent, conclusions about
283 generalizability to women and other ethnic groups may require additional study. The inclusion and
284 exclusion criteria (AHI range, BMI limit, and anatomic configuration of airway collapse) were consensus
285 based and additional studies will likely address these issues. Also, since the current study evaluating a
286 novel treatment appropriately excluded participants with active cardiovascular disease, data while
287 adequate to address AHI, ODI, snoring, quality of life, and behavioral sleepiness, were insufficient to
288 address blood pressure and cardiac effects of long-term therapy.

289 This is the first report of a medical or surgical device intervention for OSA that systematically followed
290 participants with PSG measures and quality of life outcomes over a 5-year period. UAS therapy can
291 provide clinically and statistically significant improvements in disease-defining PSG values, self-reported
292 quality of life, daytime alertness, and snoring. Results indicate that in a selected group of participants
293 with moderate to severe OSA who are unable to accept or adhere to CPAP, hypoglossal nerve
294 stimulation therapy can provide significant improvement in objective measures of sleep disordered
295 breathing and important sleep related quality of life outcome measures. The effect is maintained across
296 a 5-year follow-up period.

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302 **References**

303

- 304 1. Strollo PJ, Jr., Soose RJ, Maurer JT, et al. Upper-airway stimulation for obstructive sleep
305 apnea. *N Engl J Med* 2014;370:139-49.
- 306 2. Woodson BT, Gillespie MB, Soose RJ, et al. Randomized controlled withdrawal study of
307 upper airway stimulation on OSA: short- and long-term effect. *Otolaryngol Head Neck Surg*
308 2014;151:880-7.
- 309 3. Gillespie MB, Soose RJ, Woodson BT, et al. Upper Airway Stimulation for Obstructive
310 Sleep Apnea: Patient-Reported Outcomes after 48 Months of Follow-up. *Otolaryngol Head Neck*
311 *Surg* 2017;156:765-71.
- 312 4. Woodson BT, Soose RJ, Gillespie MB, et al. Three-Year Outcomes of Cranial Nerve
313 Stimulation for Obstructive Sleep Apnea: The STAR Trial. *Otolaryngol Head Neck Surg*
314 2016;154:181-8.
- 315 5. Soose RJ, Woodson BT, Gillespie MB, et al. Upper Airway Stimulation for Obstructive
316 Sleep Apnea: Self-Reported Outcomes at 24 Months. *J Clin Sleep Med* 2016;12:43-8.
- 317 6. Myers KA, Mrkobrada M, Simel DL. Does this patient have obstructive sleep apnea?: The
318 Rational Clinical Examination systematic review. *JAMA* 2013;310:731-41.
- 319 7. Strohl KP, Brown DB, Collop N, et al. An official American Thoracic Society Clinical
320 Practice Guideline: sleep apnea, sleepiness, and driving risk in noncommercial drivers. An
321 update of a 1994 Statement. *Am J Respir Crit Care Med* 2013;187:1259-66.
- 322 8. Ye L, Pien GW, Ratcliffe SJ, et al. The different clinical faces of obstructive sleep apnoea:
323 a cluster analysis. *Eur Respir J* 2014;44:1600-7.
- 324 9. Vanderveken OM, Maurer JT, Hohenhorst W, et al. Evaluation of drug-induced sleep
325 endoscopy as a patient selection tool for implanted upper airway stimulation for obstructive
326 sleep apnea. *J Clin Sleep Med* 2013;9:433-8.
- 327 10. Berry RB, Budhiraja R, Gottlieb DJ, et al. Rules for scoring respiratory events in sleep:
328 update of the 2007 AASM Manual for the Scoring of Sleep and Associated Events. Deliberations
329 of the Sleep Apnea Definitions Task Force of the American Academy of Sleep Medicine. *J Clin*
330 *Sleep Med* 2012;8:597-619.
- 331 11. Dziura JD, Post LA, Zhao Q, Fu Z, Peduzzi P. Strategies for Dealing with Missing Data in
332 Clinical Trials: From Design to Analysis. *Yale Journal of Biology and Medicine* 2013;86:343-58.
- 333 12. Sher AE. Upper airway surgery for obstructive sleep apnea. *Sleep Med Rev* 2002;6:195-
334 212.
- 335 13. Epstein LJ, Kristo D, Strollo PJ, Jr., et al. Clinical guideline for the evaluation,
336 management and long-term care of obstructive sleep apnea in adults. *J Clin Sleep Med*
337 2009;5:263-76.
- 338 14. Chai-Coetzer CL, Luo YM, Antic NA, et al. Predictors of long-term adherence to
339 continuous positive airway pressure therapy in patients with obstructive sleep apnea and
340 cardiovascular disease in the SAVE study. *Sleep* 2013;36:1929-37.
- 341 15. Weaver TE, Maislin G, Dinges DF, et al. Relationship between hours of CPAP use and
342 achieving normal levels of sleepiness and daily functioning. *Sleep* 2007;30:711-9.

- 343 16. Albarrak M, Banno K, Sabbagh AA, et al. Utilization of healthcare resources in
344 obstructive sleep apnea syndrome: a 5-year follow-up study in men using CPAP. *Sleep*
345 2005;28:1306-11.
- 346 17. Knauert M, Naik S, Gillespie MB, Kryger M. Clinical consequences and economic costs of
347 untreated obstructive sleep apnea syndrome. *World Journal of Otorhinolaryngology-Head and*
348 *Neck Surgery* 2015;1:17-27.
- 349 18. Kent DT, Lee JJ, Strollo PJ, Jr., Soose RJ. Upper Airway Stimulation for OSA: Early
350 Adherence and Outcome Results of One Center. *Otolaryngol Head Neck Surg* 2016;155:188-93.
- 351 19. Heiser C, Knopf A, Bas M, Gahleitner C, Hofauer B. Selective upper airway stimulation
352 for obstructive sleep apnea: a single center clinical experience. *Eur Arch Otorhinolaryngol*
353 2017;274:1727-34.
- 354 20. Heiser C, Maurer JT, Hofauer B, Sommer JU, Seitz A, Steffen A. Outcomes of Upper
355 Airway Stimulation for Obstructive Sleep Apnea in a Multicenter German Postmarket Study.
356 *Otolaryngol Head Neck Surg* 2017;156:378-84.
- 357 21. Steffen A, Sommer JU, Hofauer B, Maurer JT, Hasselbacher K, Heiser C. Outcome after
358 one year of upper airway stimulation for obstructive sleep apnea in a multicenter German post-
359 market study. *Laryngoscope* 2017.

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361

362

363 Figure 1

364 Study flow at yearly time points is shown over 5 years till study completion. Included patients
365 underwent protocol evaluation and follow up. Non-included patients with description are on right.
366 Seventy one patients completed non-protocol voluntary polysomnograms (PSG) at 5 years

367 Figure 2.

368 Long-term outcome of AHI, sleep quality of life (FOSQ), and daytime sleepiness (ESS) response rate over
369 60 months. The mean and standard error was estimated using repeated measures. The long-term
370 outcome of oxygen desaturation index (ODI) matched closely to AHI. For therapy response rate, AHI
371 response defined as AHI > 50% reduction to < 20 events/hour; ESS score < 10 defined as normal daytime
372 sleepiness; FOSQ score > 17.9 defined as normal sleep-related quality of life.

373 Figure 3.

374 Bedpartner report of snoring intensity over time.

375 Table 1

Parameter	Original Cohort (N=126)	Complete Month 60 (N = 97)	Not Complete Month 60 (N = 29)	p-value (complete versus non-complete)	Month 60 PSG	No Month 60 PSG	p-value (60 month PSG versus No PSG)
Baseline Age	54.5 (10.2)	54.4 (10.3)	55.1 (10.2)	0.73	54.5 (9.9)	54.6 (10.7)	0.98
Baseline BMI	28.4 (28.5)	28.6 (2.5)	27.8 (2.8)	0.16	28.6 (2.5)	28.1 (2.8)	0.30
Baseline AHI	32.0 (11.8)	30.5 (10.8)	37.2 (13.5)	0.01	30.4 (9.4)	34.1 (14.1)	0.09
Baseline ODI	28.9 (9.6)	27.5 (10.8)	33.5 (14.4)	0.02	27.2 (10.0)	31.0 (13.9)	0.09
Baseline FOSQ	14.3(3.2)	14.7 (2.9)	13.52(3.9)	0.03	14.8 (2.6)	13.7 (3.8)	0.07
Baseline ESS	11.6(5.2)	11.3 (5.2)	12.4 (4.0)	0.33	11.6 (5.0)	11.5 (5.0)	0.86
Outcomes							
Change AHI Month 12		-16.0 (16.3)	-17.8 (18.4)	0.63			
Change AHI Month 36		-19.9 (12.5)	-13.9 (17.8)	0.13			
Month 12 responder					79% (56/71)	54% (28/53)	0.003
Month 18 responder					70% (50/71)	60% (30/50)	0.25
Month 36 responder					80% (53/66)	65% (20/31)	0.13
Change FOSQ Month 12		-3.0 (2.9)	-2.8 (3.9)	0.82	N=70 -2.7 (2.7)	N=53 -3.2 (3.6)	0.43
Change FOSQ Month 36		-2.9 (3.6)	-1.7 (4.7)	0.22	N=70 -2.7 (3.0)	N=43 -2.6 (4.8)	0.89
Change ESS Month 12		4.7 (5.1)	4.0 (4.9)	0.53	N=70 5.0 (5.1)	N=53 4.3 (4.8)	0.46
Change ESS Month 36		4.4 (5.6)	4.0 (4.6)	0.72	N=70 4.3 (5.8)	N=43 4.6 (5.1)	0.84

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379 **Table 2. Summary of Primary and Secondary Outcomes**

Outcome Measure	Baseline	Month 12	Month 36	Month 60
	N	N	N	N
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
	Median	Median	Median	Median
AHI	126 32.0 ± 11.8 29.3	124 15.3 ± 16.1 9.0	98 11.5 ± 14.0 6.0	71 12.4 ± 16.3 6.2
ODI (4%)	126 28.9 ± 18.2 25.4	124 14.0 ± 15.6 7.4	98 9.1 ± 11.7 4.8	71 9.9 ± 14.5 4.6
FOSQ	126 14.3 ± 3.2 14.6	123 17.3 ± 2.9 18.2	113 17.4 ± 3.5 18.8	92 18.0 ± 2.2 18.7
ESS	126 11.6 ± 5.0 11	123 7.0 ± 4.3 6	113 7.0 ± 5.0 6	92 6.9 ± 4.7 6

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382 **Table 3. Change from baseline at 36 and 60 months as observed and estimated using last observation carried**
 383 **forward (LOCF) and multiple imputation.**

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Parameter	Visit	Change from Baseline		
		As Observed N Mean ± SE (95% CI)	LOCF N Mean ± SE (95% CI)	Multiple Imputation Mean ± SE (95% CI)
AHI	36 Month	n=97 -19.1 ± 1.4 (-21.8, -16.4)	n=126 -17.8 ± 1.3 (-20.4, -15.1)	-18.2 ± 1.5 (-21.1, -15.3)
	60 Month	n=71 -18.0 ± 1.7 (-21.4, -14.6)	n=126 -17.0 ± 1.4 (-19.7, -14.3)	-17.1 ± 1.7 (-20.5, -13.6)
FOSQ	36 Month	n=113 2.7 ± 0.4 (2.0, 3.4)	n=126 2.7 ± 0.3 (2.0, 3.4)	2.7 ± 0.4 (2.0, 3.5)
	60 Month	n=92 3.2 ± 0.3 (2.6, 3.8)	n=126 3.0 ± 0.3 (2.4, 3.6)	3.2 ± 0.3 (2.6, 3.8)
ESS	36 Month	n=113 -4.4 ± 0.5 (-5.5, -3.4)	n=126 -4.3 ± 0.5 (-5.3, -3.3)	-4.4 ± 0.5 (-5.4, -3.4)
	60 Month	n=92 -4.4 ± 0.6 (-5.5, -3.2)	n=126 -4.2 ± 0.5 (-5.2, -3.2)	-4.3 ± 0.6 (-5.4, -3.2)

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387 Table 4. Predictors of 60 month AHI responders

Baseline Characteristics	Month 60 Responders N = 53 Mean (SD) or % (N)	Month 60 Non-responders N = 18 Mean (SD) or % (N)	Odds Ratio	95% confidence limits (p-value)
Age	56.0 (9.3)	50.1 (10.4)	1.07	1.01, 1.13 (0.03)
Gender (% Male)	81% (43)	83% (15)	0.86	0.21, 3.55 (0.83)
BMI	28.6 (2.5)	28.8 (2.3)	0.97	0.77, 1.21 (0.76)
Neck Size	40.8 (3.5)	41.5 (2.9)	0.93	0.79, 1.11 (0.43)
Baseline AHI	29.3 (7.6)	33.7 (13.1)	0.95	0.90, 1.01 (0.09)
Baseline ODI	25.5 (8.5)	32.2 (12.4)	0.94	0.88, 0.99 (0.02)
Prior UPPP (%)	32% (17)	6% (1)	0.13	0.02, 1.02 (0.052)
Baseline FOSQ	14.8 (2.7)	15.0 (2.3)	0.96	0.78, 1.19 (0.73)
Baseline ESS	11.3 (4.9)	12.7 (5.3)	0.95	0.85, 1.06 (0.32)

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Adverse Events	No. of Events 0 - 12M	No. of Events 12 - 24M	No. of Events 24 - 36M	No. of Events 36 - 48M	No. of Events Post 48M	No. of Events Total	No. of Participants with event (% of 126)
Procedure-related non-serious adverse event							
Post-operative discomfort related to incisions	47	1	2	1	1	52	30.2% (38)
Post-operative discomfort independent of incisions	41	0	1	0	0	42	27.0% (34)
Temporary tongue weakness	34	0	0	0	0	34	18.3% (23)
Intubation effects	18	0	0	0	0	18	11.9% (15)
Headache	8	0	0	0	0	8	6.3% (8)
Other post-op symptoms	22	0	0	0	0	22	11.1% (14)
Mild infection	1	0	0	0	0	1	0.8% (1)
Device-related non-serious adverse event							
Discomfort due to electrical stimulation	81	23	26	7	5	142	60.3% (76)
Tongue abrasion	28	12	4	3	2	49	27.0% (34)
Dry mouth	10	5	2	0	3	20	15.1% (19)
Mechanical pain associated with presence of the device	7	2	3	1	1	14	11.1% (14)
Temporary internal device usability or functionality complaint	12	8	1	3	1	25	16.7% (21)
Temporary external device usability or functionality complaint	11	11	8	9	6	45	26.2% (33)
Other acute symptoms	21	14	1	2	1	39	24.6% (31)
Mild infection	1	0	0	0	0	1	0.8% (1)