Introduction:
Robotic surgery is rapidly becoming accepted as a standard and even preferred surgical method. Robotic surgery in the larynx with current technology is difficult because the equipment consists of robotic instruments attached to rigid rods that must be angled far apart from each other. This is unfeasible in the small confines of the larynx and has limited robotic surgery of the upper aerodigestive tract largely to the oropharynx, hypopharynx and supraglottis [1,2]. The need for more dexterous manipulating robotic hands to work within the larynx has prompted a search for different robotic configurations[3]. The ideal tools for robotic laryngeal surgery would involve small grasping instruments on flexible arms that do not require angulation, such as with a snake like robot. In [4] we proposed TNRS and demonstrated the feasibility of accessing the larynx on a mannequin using a snake-like robot in a cadaver model. In [5] we demonstrated the feasibility of trans-nasal access in a cadaver model. In this study we had three aims: 1) to use a cadaveric model to evaluate the feasibility of laryngoplasty with TNRS, 2) to measure in situ robot insertion forces and 3) to identify operational challenges that will further guide the development of a complete TNRS system.

Methods:
We performed injection laryngoplasty with standard injection materials on two fresh cadavers using the transnasal approach with the robot. Methylene blue was used to mark target injection sites on the vocal cords of fresh cadavers. A zero degree Hopkins rod was inserted into the larynx via a lateral transcervical incision at the level of the hyoid to enable external recording. An 8 mm nasopharyngeal airway tube (Smiths Medical) was inserted in the cadaver nostril to protect the tip of the fiberoptic camera from debris during insertion. (Figure 1) The robotic arm was manually inserted through one nostril down to the level of the larynx. The robot controller actively bent the robot’s tip to facilitate insertion by using the active compliance algorithm described by Goldman [6,7]. The robotic telemanipulation controls were used to guide the robot to the injection sites. A 25 gauge needle tip modified by soldering it to a hollow superelastic nickel-titanium (NiTi) tube of the same diameter was passed through one port of the robotic arm. Both Cymetra™ and Radiesse™ were injected through the needle into the true cords at the marked injection sites in standard injection laryngoplasty technique. (Figure 2)

Results:
Insertion times for the TNRS averaged 5.05 seconds (range 3.8 - 10.4 seconds). Average insertion times for the flexible fiberoptic laryngoscope was 14.6 seconds, (range 8.4 - 28.1 seconds). Figure 2

Insertion forces for the TNRS averaged 2.06 Newtons (range 1.56 - 5.55 Newtons). Insertion forces for the flexible fiberoptic laryngoscope averaged 1.25 Newtons (range 0.37 - 3.57 Newtons). Figure 3

A total of seven injection sites on three vocal cords in two cadaveric larynxes were marked and injected. One cadaveric vocal cord was deemed unsuitable for injection due to anatomic abnormalities. In 2 out of 9 sites marked we were unable to access the vocal cord due tongue base collapse that obscured the posterior airway, making it difficult to manipulate the robot to our goal site. The seven successful injection sites were injected with either Radiesse™ or Cymetra™.

Conclusion
Our trials showed comparable insertion times and forces, between the two insertions, with no evidence of trauma to the cadaveric tissues with the use of the TNRS. The TNRS robot is able to effectively access the larynx, although in a supine model may be somewhat limited by tongue base collapse. Continued development of flexible robotic arms will enhance our ability to perform robotic surgery of the larynx.

References