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Neck incision planning for total laryngectomy: A finite element analysis

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ABSTRACT

Post-operative complications can be attributed to technical aspects of surgery, yet no studies have investigated the mechanics behind commonly used incisions for total laryngopharyngectomies (TLP). This procedure, seen in head and neck cancer patients, necessitates free tissue transfer to construct a neo-pharynx, creating an inherently greater risk of complications. We sought to investigate the impact of neck incision location on these post-operative complications for TLP using finite element analysis (FEA). A nonlinear hyperelastic 2-D finite element model was used to evaluate the stress and strain along the incision line of two separate neck incision models commonly used for TLP: low-neck apron (LNA) incisions that incorporate the patient's tracheostoma and mid-neck apron (MNA) incisions that do not communicate with the tracheostoma. A constant displacement was applied to the incision to simulate normal neck extension experienced during the post-operative phase. Each neck incision was also modeled at varying strain energy densities to simulate various stages of wound healing. For a constant displacement of 40 mm, the principal von Mises stress of the LNA incision varied between 5.87 and 6.41 MPa, depending on the hyperelastic properties of the healing incision. This stress was concentrated at the junction of the incision and the fixed tracheostomal edge. The MNA model demonstrated a principal von Mises stress that varied between 0.558 and 0.711 MPa and was concentrated along the midline of the neck incision. MNA incisions for TL patients result in principal von Mises stresses which are up to 11 times lower than those seen in LNA incisions. These results coincided with clinical observations from a concurrent study that showed a decrease in rate of wound dehiscence for patients undergoing TLP with an MNA incision.

1. Introduction

Of the 55,000 newly diagnosed cases of head and neck cancer each year in the United States, 25% are laryngeal cancers (Siegel et al., 2014; Maddox and Davies, 2012). Depending on the extent of the tumor, a total laryngectomy (TL) – the complete removal of the patient's larynx – may be necessary to provide potential cure for advanced stage primary disease or recurrent cancer. A total laryngopharyngectomy (TLP) requires the additional ablation and reconstruction of the pharynx via free tissue transfer. These surgeries have been successfully performed for decades, being first performed by Billroth in 1873 (Agrawal and Goldenberg, 2008; Absolon and Keshishian, 1974; Weir, 1973). They continue to play an important role in management of laryngeal cancer with over 3400 TLs being performed in the United States in 2008 (Maddox and Davies, 2012).

All cause complications for these surgeries approaches 40% Ganly et al. (2005). Wound infection, pharyngocutaneous fistula, stomal stenosis, and wound dehiscence are among the more common complications for both primary and salvage procedures (Ganly et al., 2005). Causes are largely multifactorial, but wound dehiscence is known to depend specifically on technical aspects of surgery, including incisional design (Flint et al., 2010). This becomes especially relevant for TLP procedures, as the increased tissue bulk and edema from the free tissue transfer increases the opening pressure along the incisional line. Despite this increased propensity for complications, important technical aspects like neck incision placement remain without a universally accepted standard. Two commonly utilized approaches differ in the location of the neck incision and their relation to the trachestoma. A low-neck apron (LNA) incision incorporates the tracheostoma into the central aspect of the incision. A mid-neck apron (MNA) incision

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separates the two. There are proponents for each approach and the decision for either incision relies mostly on surgeon preference. No formal analysis looking at wound complications has been conducted.

Finite element analysis (FEA) has been widely used to describe the biomechanics of biological materials like human skin and has also been used to elucidate other problems within otolaryngology (Lovald et al., 2013; Topp et al., 2014; Groves et al., 2013; Lapeer et al., 2010). It is a numerical technique that is able to determine the stress, strain, and overall deformation of a static or dynamic geometry for given boundary conditions, material properties and loading conditions. This makes it well suited for elucidating the structural aspects of multifaceted clinical problems. Furthermore, comparing surgical methods using FEA provides the clinician with a sound theoretical basis to justify a particular surgical approach which may minimize post-operative complications and may ultimately help guide the clinician's surgical practice. This study contrasts the biomechanical stresses applied to the LNA and MNA neck incisions for TLP using FEA. The maximal von Mises stress experienced in the LNA model is an order of magnitude larger than that seen in the MNA model – a finding that correlates with a significantly lower rate of wound dehiscence in MNA models.

2. Materials and methods

2.1. Geometry

Two models were created to compare the most commonly utilized neck incisions for TLP: one with a stoma incorporated into a LNA incision and one with a separate MNA incision and stoma. For both simplified models, the neck was approximated using a 2-D planar geometry in ANSYS 14.5. Fig. 1 demonstrates the geometry of both LNA and MNA models. The dimensions of the neck were held constant with a vertical length (l) of 170 mm, horizontal width (w) of 240 mm and skin thickness of 2 mm. These measurements were approximated from anthropomorphic data. (Choi et al., 2011; Ben-Noun et al., 2001) The diameter and location of the stoma were also constant. Both models had a diameter (d) of 30 mm, centered at a height (h) of 60 mm from the inferior border of the model. For both models, the incision extended horizontally across the entire width of the neck with a thickness (t) of 2 mm. In the LNA model, the incision incorporates the stoma and is centered at $\alpha=45°$ from the stoma's vertical midline. In the MNA model, the incision is located at a vertical distance (b) of 30 mm above the superior edge of the stoma.

2.2. Boundary and loading conditions

In both models, the inferior border of the skin was held fixed. The superior border was displaced vertically by 40 mm through 10 sub-steps to simulate the stress applied to the incision in the post-operative period by various factors including wound edema, neck extension, and edema of a free flap used for pharyngeal reconstruction if necessary. Both lateral edges were free to prevent distortion of the stress throughout the rest of the model. Similarly, the model width was 8 times the width of the stoma diameter to prevent reaction forces from distorting the stress at the stoma as per St Venant's principle (de Saint-Venant, 1855).

In the LNA model the portion of the tracheostoma above the LNA incision (corresponding to the membranous trachea) is free while the portion below the LNA incision is held fixed (corresponding to the cartilaginous trachea). For the MNA model, all borders of the tracheostoma are fixed to adjacent tissue. These boundary conditions mimic typical *in vivo* conditions for each surgery. However, the MNA model was also analyzed with a free superior edge in order to mimic the tracheostomal formation seen in LNA incisions. Detailed boundary conditions for LNA and MNA models are shown in Fig. 1.

2.3. Elements

Models were meshed using quadrilateral 8-node PLANE 183 elements in plane stress with constant thickness. PLANE 183 elements were chosen because of their ability to handle isotropic hyperelastic materials, like skin, undergoing large deflections. Plane stress conditions are also appropriate for thin materials like human skin (Danielson, 1973; Tong and Fung 1976; Evans 2009). The element size was adjusted in order to approximately double the number of nodes through

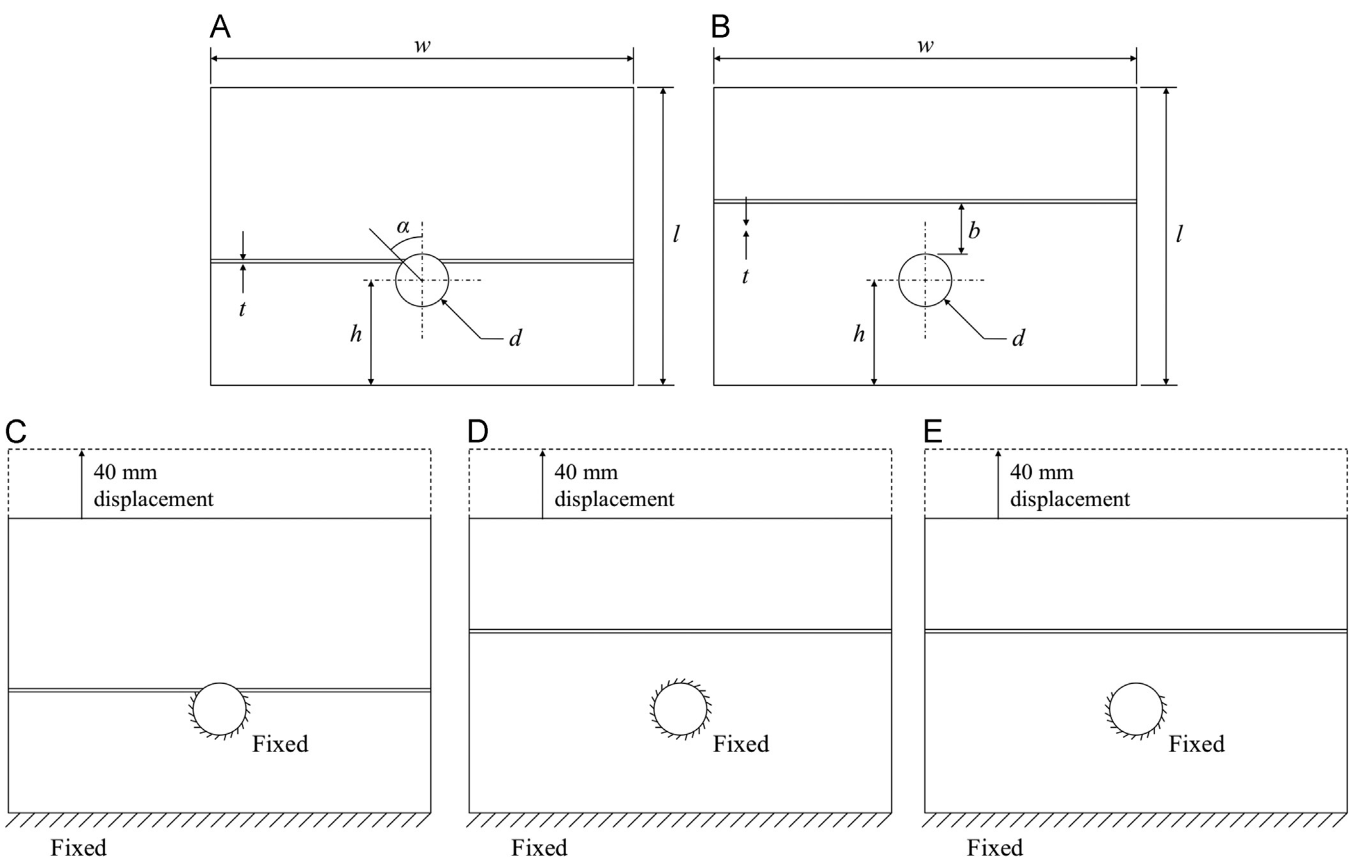

Fig. 1. The geometry of LNA (A) and MNA (B) models are depicted. Boundary conditions for LNA (C), MNA (D), and modified MNA (E). A 40 mm superior displacement is applied to all models. Numerical values of the corresponding dimensions are: $l=170$ mm, $w=240$ mm, $d=30$ mm, $h=60$ mm, $t=2$ mm, $b=30$ mm, and $\alpha=45°$.