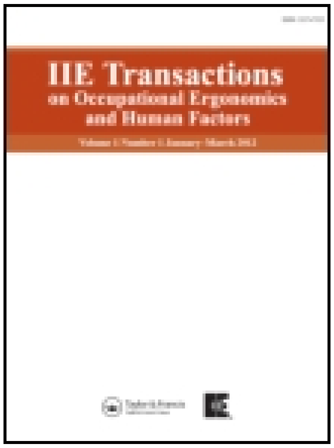

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Neck Postures and Cervical Spine Loading Among Microsurgeons Operating with Loupes and Headlamp

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ORIGINAL RESEARCH

Neck Postures and Cervical Spine Loading Among Microsurgeons Operating with Loupes and Headlamp

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OCCUPATIONAL APPLICATIONS Surgical tasks performed using loupes and headlamps were examined to identify exposures to physical risk factors for work-related musculoskeletal disorders in the neck among microsurgeons. Surgeons who use loupes and headlamps were found to spend extensive time periods working in non-neutral head–neck postures. These postures, and the use of loupes and headlamps, were found to be associated with an increased loading of the cervical spine, which might cumulatively contribute to occupational neck musculoskeletal disorders. To develop effective control strategies, future studies should focus on the impact of design features of loupes (e.g., mount angles, weight, and shape) on head–neck postures during surgical tasks.

TECHNICAL ABSTRACT ***Background:*** Work-related musculoskeletal disorders in the neck are common among microsurgeons who operate with loupes and headlamps. Published surveys indicate that microsurgeons across many subspecialties believe that loupes contribute to neck musculoskeletal disorders. However, objective data on head–neck posture and cervical loading during surgical tasks performed using loupes and headlamps are currently lacking. ***Purpose:*** This study will assess exposures to physical risk factors for neck musculoskeletal disorders during surgical tasks performed using loupes and headlamp. ***Methods:*** A field study was performed in operating rooms to measure the head–neck postures commonly used by three ophthalmic plastic surgeons; a subset of microsurgeons. Posture data were used as input to a biomechanical model to estimate cervical spine loading. ***Results:*** During nearly 85% of the time spent operating, surgeons adopted asymmetrical head–neck postures characterized by either bending or rotation of $>15^\circ$, coupled with flexion of $>15^\circ$. Postures consisting of flexion $\geq 45^\circ$, 15°–30° bending, and 15°–45° rotation produced significantly higher biomechanical loading of the cervical spine compared to near-neutral postures (i.e., flexion, bending and rotation between 0° and 15°). This loading was further exaggerated by the weight of loupes and headlamp. ***Conclusions:*** Non-neutral head–neck postures demanded by the

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dexterous operating tasks performed using loupes and headlamps could be important biomechanical risk factors for cervical musculoskeletal disorders among microsurgeons.

KEYWORDS Loupes, microsurgeon, neck musculoskeletal disorder, headlamp

INTRODUCTION

Musculoskeletal disorders (MSDs) of the neck are common. The Task Force of Bone and Joint Decade on Neck Pain reported an annual prevalence of 30%–50% in the general population (Hogg-Johnson et al., 2008), and work-related disabling neck pain occurs in 11%–14% of people (Côté et al., 2008). While exact costs associated with neck MSDs are not known, recent U.S. statistics report a median of 21 days of missed work due to neck and shoulder MSDs, which is three times that of low back pain (U.S. Bureau of Labor Statistics, 2010).

Contemporary studies demonstrate that surgeons are substantially affected by work-related neck MSDs. In 2009, Szeto et al. (2009), reported an 82.9%, 12-month prevalence of neck pain in Hong Kong public hospital surgeons, which is eight times that for the general working population. Similarly, a survey of European surgeons indicated that more than 80% ($n = 284$) had discomfort in the neck, shoulder, and back muscles associated with operating (Wauben et al., 2006). More recent reports have focused on identifying factors that may contribute to MSDs in surgeons. A number of studies have identified that laparoscopic surgeries are associated with relatively higher incidence rates of neck, hand, and other MSDs (Park et al., 2010; Sari et al., 2010; Stomberg et al., 2010). Very recently, Sivak-Callcott et al. (2011) reported that 72.5% of ophthalmic plastic surgeons ($n = 139$) experience pain (non-body part specific) during operating, with 58% localizing pain to the neck and 26% reported bulging or herniated cervical disc(s). More concerning, nearly 10% of the surgeons that participated in this study had to cease operating as a result of neck pain. This population, ophthalmic plastic surgeons, uses surgical loupes and headlamps to magnify and illuminate their field of view. Use of these devices can be hypothesized as contributing to the risk of neck MSDs.

In addition to ophthalmic plastic surgery, many other surgical subspecialties use loupes and headlamps, including neurosurgery, otolaryngology, plastic, and vascular surgery. Over 90,000 U.S. surgeons use loupes in their practice (National Center for Health Care Statistics, 2009). Surgical loupes consist of magnifying lenses mounted on glasses. The magnification provided enhances vision, allowing appreciation of subtle tissue differences and optimal instrument placement (Baker & Meals, 1997). Previous studies have supported the usefulness of loupes in surgical tasks (Ross et al., 2003; Kono et al., 2010).

Survey and observational studies have established that loupe and headlamp use contributes to work-related neck MSDs (Babar-Craig et al., 2003; Hobbs, 2004; Dhimitri et al., 2005). Despite this knowledge, the specific contributing physical risk factors responsible have not been well studied or quantified. Therefore, the purpose of this study was to evaluate physical exposures during surgery with loupes and headlamps by measuring head–neck postures assumed by microsurgeons while operating "in the field." Furthermore, and to assess how these postures affect the musculoskeletal loading of the cervical spine, biomechanical modeling analysis was performed. It was hypothesized that surgeons adopt/maintain non-neutral neck postures for sustained durations while operating using surgical loupes and headlamp and that these postures cause increased cervical spine loading.

METHODS

Approach

A field study was performed in the operating room while surgeons performed surgery on actual patients. Local institutional review board approval was obtained, and all surgeons and patients gave informed consent to participate. Three-dimensional (3D) posture data were recorded using an inertia-based, marker-free kinematic system. Based on this data, the effect of predominant postures on cervical spine loading was computed using a 3D biomechanical model of the cervical spine.

Field Study

Participants and Surgeries

Data were collected from three ophthalmic plastic surgeons, two males and one female.

Anthropometric measurements of each surgeon, including height, weight, trunk length, shoulder width, and head–neck length, were recorded using standard procedures as described by Wickens et al. (2004). Respective ranges of the measures were 150.4–175.3 cm, 48–73 kg, 49–57 cm, 35–43 cm, and 23–36 cm. For each surgeon, data were recorded during a total of 16 surgeries. Prior to each surgery, informed consent was obtained from the patient undergoing the surgery during the data collection. All the surgeons were consented at the beginning of the study. These surgeries were classified into two groups: superficial (eyelid) and deep (orbit). During superficial surgeries, surgeons mainly operate on the surface, whereas deep surgeries involve operating inside the eye orbit. The durations of superficial and deep surgeries were 45 to 60 and 60 to 90 minutes, respectively. For each surgeon, data for 12 superficial and 4 deep surgeries were recorded. Total duration of superficial surgery data was 30.5 hours, with approximately 8 to 12 hours for each surgeon. Total duration of deep surgery data was 20.1 hours, with approximately 6 to 8 hours for each surgeon.

Data Collection

The Functional Assessment of Biomechanics (FAB; BIOSYN, Canada) system is a 3D kinematic system. Segmental kinematics are recorded by using small lightweight sensors (4 × 7 × 2.4 cm). Each sensor has a triad of accelerometers, gyrometer, and magnetometer that allows real-time detection of angular displacement within biomechanical bodies. This system transmits 3D posture data to a host computer using a dedicated wireless network. Posture data were acquired here at 100 Hz. Anthropometric parameters were input into the FAB software, forming a real-time humanoid, allowing precise computation of 3D kinematic trajectories between biomechanical bodies.

Three FAB sensors were used to record the head–neck posture with respect to the trunk: (1) a pelvis sensor mounted at the level of L5-S1; (2) a trunk sensor mounted at the level of T10-11; and (3) a head sensor mounted over the occipital bone. Pelvis and trunk sensors were mounted using adjustable nylon buckle straps. Both these sensors are provided with side (stopper) plates to minimize their motion with respect to the body (Fig. 1(a)). A self-adhesive elastic band was used for mounting the head sensor. The width and length of this band provide sufficient overlapping area for a tight (self) adhesion. Additionally, a section of Velcro^{TM} at the end of this band allowed for the tight mounting of this sensor on the head.

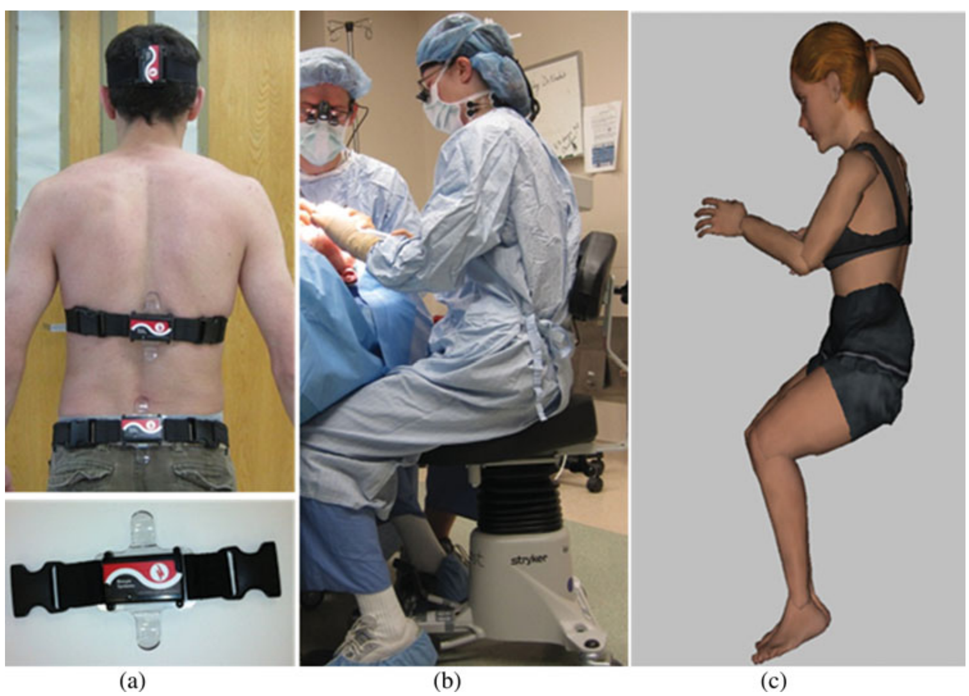

FIGURE 1 **(a) FAB sensors and their locations for recording head-neck kinematics, (b) a surgeon performing surgery, and (c) real-time humanoid displayed by FAB system. To generate this humanoid, all 13 FAB sensors were used during pilot data collection (color figure available online).**

The FAB system was calibrated before each surgery and was done with the surgeon standing in an anatomically neutral posture: feet pointing straight ahead, shoulder-width apart; knees locked; back straight; hands at the sides with thumbs pointing forward and palms against the legs; and head straight. This neutral posture was held for 30 seconds while the FAB software set cervical flexion, lateral bending, and rotation angles to zero. The basic functionality of the FAB system and the calibration process are explained elsewhere (Nimbarte et al., 2013). Based on the manufacturer's recommendation, to minimize the effect of local magnetic fields on kinematic computation, each calibration was performed in the operating room at the surgeon's workstation. Immediately after FAB calibration, the surgeon began operating, and 3D kinematic data were recorded continuously during all the surgeries. Figures 1(b) and 1(c) show a picture of a surgeon performing surgery and the real-time humanoid displayed by the FAB system.

The commonly adopted postures that resulted from combined flexion, bending, and rotation were identified using the following procedure.

(1) 3D head–neck motion trajectories were divided into segments based on the head–neck flexion angles (0° to 15°, 15° to 30°, 30° to 45°, and 45° to 60°).
(2) For each 15° of head–neck flexion, the kinematic trajectories were further divided into separate segments using 15° of rotation (0° to 15°, 15° to 30°, 30° to 45°, and 45° to 60°).
(3) For each 15° of rotation, kinematic trajectories were further divided based on 15° of head–neck bending (0° to 15°, 15° to 30°, and 30° to 45°).

The above procedure divided the continuous kinematic data into 48 different postures. The durations of individual postures were quantified by adding the data across the three surgeons. To compare the postures between the two types of surgeries, kinematic trajectories for head–neck flexion, bending, and rotation were divided into 15° segments of joint rotation (e.g., 0°–15°, 15°–30°, 30°–45°, and 45°–60°), and the corresponding durations were calculated as a percent of total time for each surgery.

Biomechanical Modeling

The effect of the head–neck postures assumed by the surgeons on the loading of the cervical spine was evaluated using a biomechanical model of the cervical spine in the public domain AnyScript™ Model Repository (AnyBody Technology, 2011). This model is based on the physiological parameters provided by van der Horst (2002) and consists of nine rigid segments (head segment, seven vertebrae, and thoracic segment) with properties corresponding to bone mass and the contribution of soft tissue attributed to each bone. The joints between T1 and C2 vertebrae are 3-degree-of-freedom spherical joints, while C2 to the head is a 1-degree-of-freedom universal joint. This model includes 136 force/moment actuators (i.e., muscles). The basic cervical spine model was modified by mounting loupes and headlamp on it for the purpose of this study. 3D images of the loupes and headlamp were created in .stl format. The .stl format is typically used when surface geometry of a 3D object is of primary importance without any representation of color, texture, or other common CAD model attributes, as most of these features can be modeled in the AnyBody™ modeling platform. These images were attached to the cervical spine model so that the mass of the loupes was applied at the mid-point between the eyebrows and the mass of the headlamp was applied at its center of mass (approximately 0.05 m above the center of mass of the surgical loupes), as shown in Fig. 2. The combined mass of commercially available loupes and headlamps varies from 5 to 12 N. In this analysis, the masses of loupes and the headlamp were set to 5 N each. The modeling analysis was performed under two conditions: (1) without loupes and headlamp and (2) with loupes and headlamp.

In the AnyBody™ Modeling System, the muscle forces required to generate motion or sustain body posture are computed using inverse-dynamic methods by solving a multi-body dynamics problem. The muscle recruitment in the inverse dynamics process is solved using a min/max optimization procedure (Rasmussen et al., 2001), within which the objective function is to minimize the maximum normalized muscle force, subject to equilibrium constraints and lower bounds on force (i.e., all forces must be in the "pull" direction). The model output consists of estimated loading of cervical spine in terms of various muscle and joint reaction forces. To quantify the loading of the cervical spine during the surgical tasks, 18 postures with varying levels of head–neck flexion, bending, and rotation were evaluated (Table 1). These postures were based on the same segments of 15° of joint rotation used in the posture analysis. To run the model for different postures, head–neck flexion, bending, and rotation data recorded

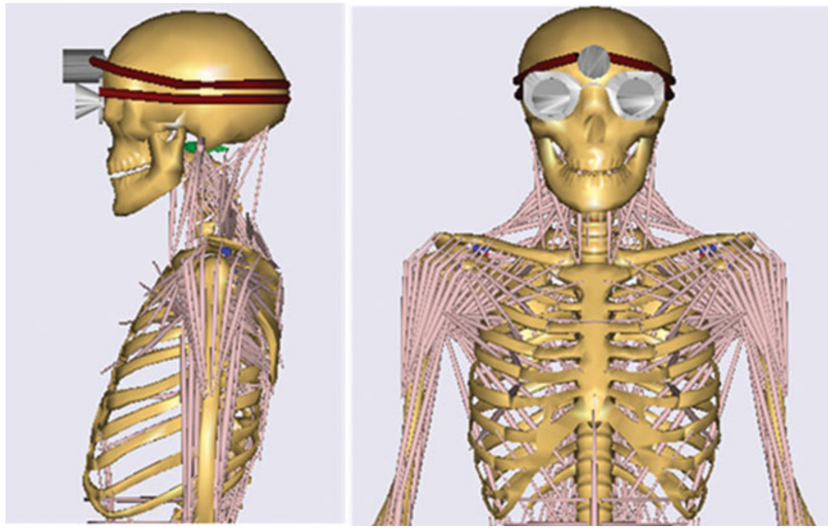

FIGURE 2 Graphical representation of the AnyBody™ model (color figure available online).

during the surgical tasks were used to drive the T1-C7 joint. The orientation of thoracic segment with respect to the global reference frame was maintained at neutral. Rhythm drivers were used to drive the other cervical joints based on the kinematics of T1-C7 joint. Joint loading, in terms of resultant of compression, anterior-posterior and medio-lateral shear forces acting at eight vertebral levels (T1-C7 to C1-head), was computed for the specific postures indicated in Table 1.

Statistical Analysis

A two-way general linear ANOVA model was used to evaluate the effect of type of surgery on the durations of different posture segments. Type of surgery had two fixed levels (superficial and deep), posture segments had four fixed levels (0°–15°, 15°–30°, 30°–45°, and 45°–60°), and the dependent variable was the duration of posture segment (percent of time). The effect of posture and the presence of loupes and headlamp on the loading of cervical spine at T1-C7 to C1-head cervical levels were also evaluated using a two-way general linear ANOVA model. Posture had 18 fixed levels (Table 1), and loupes and a headlamp had 2 fixed levels (with and without). Individual surgeons were treated as a random variable. The biomechanical modeling analysis was performed for the 50th percentile male and female, in addition to the three surgeons from the field study, to increase the power of the statistical test. Dependent variables were the total forces acting at eight vertebral levels (T1-C7 to C1-head). Minitab 16 statistical analysis software (Minitab Inc., PA, USA) was used to perform these analyses. Adequacy of these parametric models was confirmed, based on normal probability plots of the residuals. Significant (i.e., $p < 0.05$) main and/or interaction effects were further evaluated using Tukey's honestly significant difference (HSD) all-pairwise comparison test.

TABLE 1 Flexion (Flx), bending (Bend), and rotation (Rot) angles for different postures (Pos) evaluated using the biomechanical model

		Rot 15°	Rot 30°	Rot 45°
Flx 15°	Bend 15°	Pos 1	Pos 2	Pos 3
	Bend 30°	Pos 4	Pos 5	Pos 6
Flx 30°	Bend 15°	Pos 7	Pos 8	Pos 9
	Bend 30°	Pos 10	Pos 11	Pos 12
Flx 45°	Bend 15°	Pos 13	Pos 14	Pos 15
	Bend 30°	Pos 16	Pos 17	Pos 18

RESULTS

Head–Neck Posture

Near-neutral postures (i.e., flexion, bending and rotation of 0° to 15°) were only seen during 16.4% of superficial operating time ($T = 30.5$ hours) and 13.8% of deep operating time ($T = 20.1$ hours). All other postures had flexion, bending, and rotation angles, individually or in combination, greater than 15°. Postures with flexion and bending of 0°–15° and rotations of 15°–30°, 30°–45°, and 45°–60° were maintained for durations of 5.5%, 4.8%, and 2.1%, respectively, during superficial surgery. The corresponding durations during deep

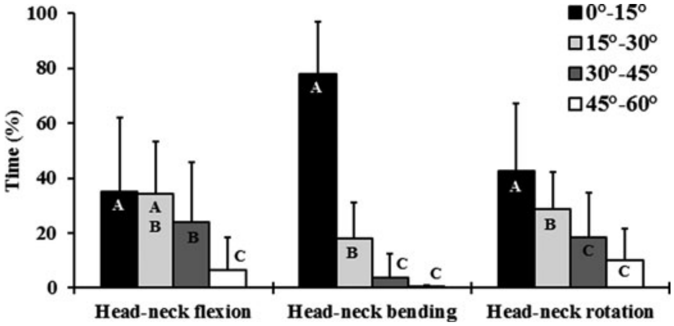

FIGURE 3 Comparison of different posture segments of head–neck flexion, bending, and rotation. Values of one type of motion that do not share a letter are significantly different (error bars represent one *SD*).

surgery were 7.9%, 4.0%, and 2.9%, respectively. Moderately non-neutral postures, consisting of flexion and rotation between 15° and 30° and bending between 0° and 15°, were maintained for 8.5% and 6.4% during the superficial and deep surgeries, respectively. Durations of postures with similar levels of bending and rotation but greater flexion (30°–45°) were 6.4% and 3.0%, respectively. Extremely non-neutral postures, with either flexion or rotation greater than 30° and bending between 0° and 15° and 15° and 30°, occurred 0.2% to 4.4% of the time in superficial surgery and 0.4% to 2.5% of the time in deep surgery. The most extreme postures, consisting of flexion and rotation of 45° to 60° and bending greater than 15°, were seen 0.5% and 4.1% of the time in superficial and deep surgeries, respectively.

Type of surgery had no effect on the durations of different posture segments, but the durations were found to be significantly different between the posture segments of head–neck flexion, bending, and rotation (All p values < 0.0001). Head–neck flexion of 0°–15° and 15°–30° was maintained for the similar amount of time (Fig. 3). The mean duration of head–neck flexion of 30°–45° was lower but statistically not different than the mean duration of head–neck flexion of 15°–30°. The mean duration of head–neck bending and rotation of 0°–15° was significantly higher than the rest of the posture segments. Head–neck rotation of 30°–45° and 45°–60° was maintained for similar amount of time.

Biomechanical Loading of Cervical Spine

The effect of posture on loading of the cervical spine was significant at every cervical level (all p-values $<$ 0.0001). Three general patterns were evident as follows: (1) increasing bending from 15°–30°, significantly increased cervical load in postures consisting of flexion between 15° and 30° and rotation between 15° and 45°; (2) increasing flexion from 30°–45°, significantly increased cervical load in postures consisting of bending of 15° and rotation between 15° and 45°; and (3) increasing rotation from 15° to 30° to 45° did not significantly increase cervical load in postures consisting of flexion between 15° and 45° and bending of 15° and 30°. Based on these trends, the relationship between posture and loading of the cervical spine was further summarized using low, medium, and high loading zones based on tri-planar postural deviations (Fig. 4). The postures in different zones generated significantly different loading of the cervical spine, whereas loading of the cervical spine for all postures within a zone was not statistically different.

The main effect of loupes and headlamp on cervical spine loading was significant at every cervical level (all p-values < 0.0001; Fig. 5). A significant interaction effect was observed between posture and the presence of loupes and headlamp on cervical loading. For postures consisting of 45° flexion, 15°–30° bending, and 15°–45° rotation, the effect of loupes and headlamp was consistently significant across all cervical levels. At higher cervical levels (C5-C4 to C1-head), this effect was significant for most of the postures, but at the lower cervical levels (T1-C7 to C5-C4), the effect of loupes and lamp was significant for postures with either flexion or bending of 30°.

DISCUSSION

The occupational risk of cervical MSDs in surgeons is well established, but the pathophysiologic mechanisms of injury have not been comparably well defined or objectively studied (Babar-Craig et al., 2003; Hobbs, 2004; Dhimitri et al., 2005). The majority of surgeons use loupe magnification and headlamp illumination. As a first step toward decreasing this work-related hazard, the head–neck postures adopted by ophthalmic plastic surgeons, a subset of microsurgeons, were measured as they operated on actual patients. Although the number of surgeons was small, 3D posture data were collected for over 50 hours of surgery. Of note, the current system has been used in other studies, which reported good precision and test–retest validity (Hamameh, 2010; Murgia et al., 2010; Nimbarte et al.,

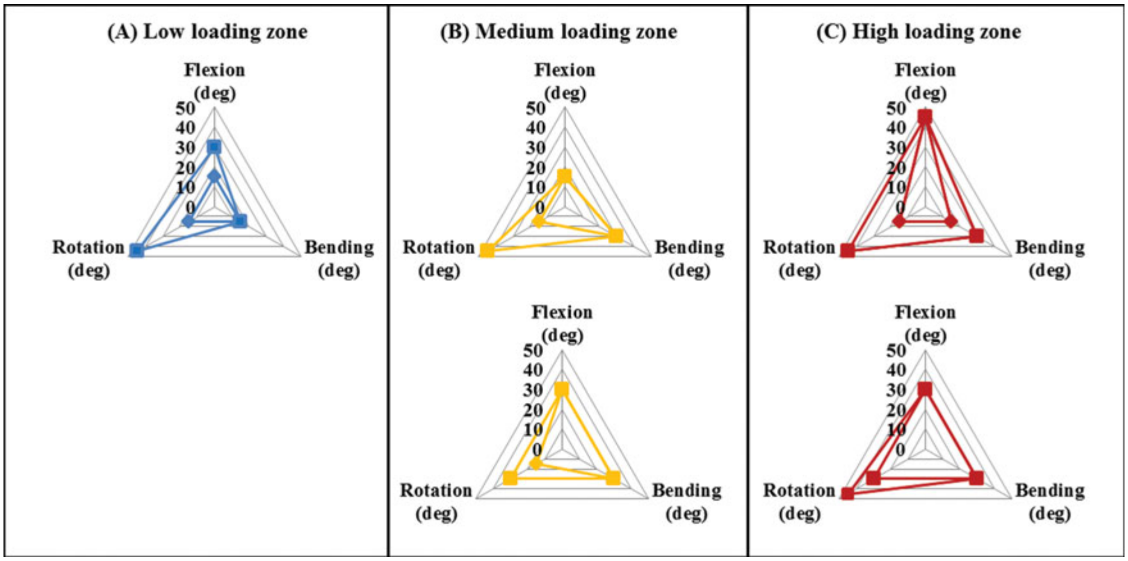

FIGURE 4 Low, medium, and high loading zones of the cervical spine based on tri-planar postural deviations. Postures between the two triangles generate similar loading of cervical spine. For example, a low loading zone is formed by two triangles: small triangles with vertices at 15° of flexion, 15° of bending, and 15° of rotation; big triangles with vertices at 30° of flexion, 15° of bending, and 45° of rotation. Thus, low loading of the cervical spine was observed for all postures with 15° to 30° of flexion, 15° of bending, and 15° to 45° of rotation. Note that two non-overlapping zones with medium and high loading were identified, and these are illustrated separately (color figure available online).

2013). The system was well tolerated by the surgeons here, with no adverse indications.

In general, the surgeons operated with non-neutral head–neck postures characterized by motions in flexion, bending, and rotation planes. Several previous studies have reported a positive relationship between neck flexion and self-reported symptoms of neck pain for various working populations (Kilbom et al., 1986; Dartigues et al., 1988; Ignatius et al., 1993; Yu & Wong, 1996; Szeto et al., 2002).

Compared to these previous studies, in which the working postures were mostly symmetrical with deviation primarily in the flexion/extension plane, postures adopted by the surgeons here were more complex and with deviations from neutral in all three planes. Such postures with increased deviation from neutral generate a higher moment at the cervical joints compared to near-neutral postures. Higher moments require greater force generation by the neck muscles and thus increased loading of the cervical spine, as indicated by the results of biomechanical modeling analysis. For nearly 85% of the operating time, the surgeons adopted asymmetrical postures characterized by either bending or rotation angles higher than 15°, coupled with flexion higher than 15°. Additionally, the surgeons assumed rather extreme non-neutral and asymmetrical postures with high flexion (>45°), rotation (>45°), and bending (>30°) for about 26% of the time operating. As a whole, the results of this study suggest that the asymmetry and the duration of the postures used by the surgeons may put substantial stress on the cervical spine due to increased biomechanical loading.

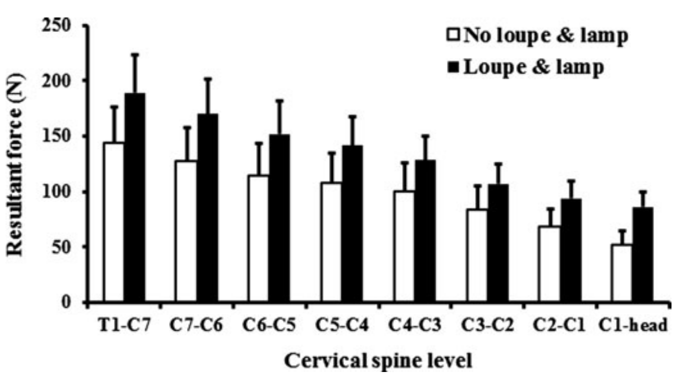

FIGURE 5 Effect of loupe and headlamp on loading of cervical spine at all cervical spine levels. Differences due to loupe and headlamp were significant at all levels (error bars represent one *SD*).

Although type of surgery had no effect on the durations of posture segments, some interesting differences were observed between the surgeries with respect to the time spent in different loading zones. In general, the surgeons spent nearly 65% of the total operating time in a low loading zone (see Fig. 4) and the other 35% in medium and high loading zones. Nearly 27% of superficial surgery and 19% of deep surgery were performed in the medium loading zone. The corresponding durations in the high loading zone were 9% and 14%, respectively. These outcomes suggest that the deep surgeries may be more stressful to the cervical spine than superficial surgeries.

Most microsurgeons require magnification and illumination to improve visualization and accuracy. In some subspecialties, loupes and headlamp use is the standard of care (Ilie et al., 2011). Using the biomechanical model, it was determined that these devices significantly increase the loading of cervical spine. Across the postures evaluated, use of loupes and headlamp increased the mean cervical loading by 34 N or 40% overall. The effect of loupes and headlamp was more pronounced in postures consisting of flexion $\geq 45^\circ$ and bending of 15°–30°. In these postures, greater muscle forces are required to support the weight of the head alone, and this force is further increased by wearing loupes and headlamp. An increase in rotation had minimal effect on the cervical spine loading. However, rotated head–neck postures can cause contralateral increases in the activity of anterior neck muscles, especially the sternocleidomastoid muscle (Nimbarte et al., 2013). Further, the surgeons were found here to work in asymmetrical postures with rotation $>15^\circ$ for 55% and 63% of time during the superficial (eyelid) and deep (orbit) surgeries, respectively. Sustained activation of anterior neck muscles during such postures may cause neuromuscular fatigue. Future research should evaluate the activation of neck muscles during surgical tasks to identify potential muscle fatigue.

Several factors may influence the postures assumed by the microsurgeons while operating. Microsurgeons generally operate on very small, irregular surfaces, often looking into a deep hole where visualization is difficult and performing tasks that require extensive dexterity. In this study, head–neck postures used by the ophthalmic plastic surgeons were studied, and the resulting loading of cervical spine was quantified using biomechanical modeling analysis. In order to have a more focused understanding of the effect of different head–neck postures (a total of 18 postures were analyzed) on the cervical spine loading, the position of thoracic segment was fixed to neutral in the biomechanical modeling analysis. This assumption was also based on observations in the operating room, where surgeons were found to use upright trunk postures for most of the time during operating. Other microsurgeons may adopt non-neutral trunk postures while operating, and these postures may further affect the loading of cervical as well as the lumbar spine. Anthropometry and group dynamics can also affect the postures used by the microsurgeons. Depending on the surgical subspecialty, surgeons usually operate in groups of two to four. In this study, two surgeons worked simultaneously while operating. Differences in the anthropometry of the surgeons working together may influence the postural demands. Furthermore, individual surgeons, based on their preferences, used different styles of loupes, which might affect the postures and the corresponding loading of the cervical spine. All these factors must be considered before generalizing the findings of the current study to other surgical subspecialties. Future studies should focus on the aforementioned factors, especially the impact of loupe design features (e.g., mount angles, weight, and style) on the head–neck postures during surgical tasks, for improved understanding of MSD risk factors among microsurgeons and development of effective control strategies.

CONCLUSION

Most microsurgeons require magnification and illumination to improve visualization and accuracy. This study shows that surgeons who use loupes and headlamps spend extensive time over the course of their career working in asymmetrical, non-neutral head–neck postures. These postures, coupled with the weight of loupes and headlamps, are associated with increased forces on the cervical spine and may contribute to occupational cervical MSD with cumulative exposure.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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