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Ergonomic analysis of microlaryngoscopy

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Abstract

Objectives/Hypothesis—To apply ergonomic principles in analysis of three different operative positions used in laryngeal microsurgery.

Study Design—Prospective case-control study.

Methods—Laryngologists were studied in three different microlaryngeal operative positions: a supported position in a chair with articulated arm supports, a supported position with arms resting on a Mayo stand, and a position with arms unsupported. Operative positions were uniformly photographed in three dimensions. Full body postural data was collected and analyzed using the validated Rapid Upper Limb Assessment (RULA) tool to calculate a risk score indicative of potential musculoskeletal misuse in each position. Joint forces were calculated for the neck and shoulder, and compression forces were calculated for the L5/S1 disc space.

Results—Higher-risk postures were obtained with unfavorably adjusted eyepieces and lack of any arm support during microlaryngeal surgery. Support with a Mayo stand led to more neck flexion and strain. Using a chair with articulated arm supports leads to decreased neck strain, less shoulder torque, and decreased compressive forces on the L5/S1 disc space. Ideal postures during microlaryngoscopy place the surgeon with arms and feet supported, with shoulders in an unraised, neutral anatomic position, upper arms neutrally positioned 20° to 45° from torso, lower arms neutrally positioned 60° to 100° from torso, and wrists extended or flexed <15°.

Conclusions—RULA and biomechanical analyses have identified lower-risk surgeon positioning to be utilized during microlaryngeal surgery. Avoiding the identified high-risk operative postures and repetitive stress injury may lead to reduced occupationally related musculoskeletal pain and may improve microsurgical motor control. *Laryngoscope*, 2010

Keywords

ergonomics; microlaryngoscopy; laryngeal surgery; laryngeal surgical ergonomics; surgical ergonomics

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INTRODUCTION

To date, no reports exist on the number of otolaryngologists who perform microsurgery and experience musculoskeletal fatigue and/or injury in the upper extremities, wrists, neck, and back. In addition, actuarial data for otolaryngologists in the United States who file disability insurance claims or retire prematurely secondary to occupationally acquired musculoskeletal injury are unpublished. With these data lacking for otolaryngologists, we extrapolate from occupational risk assessment in dentistry, as otolaryngologists maintain somewhat similar static postures while performing microsurgical procedures. Work-related musculoskeletal disorders, particularly of the upper extremities and the neck, have been reported in dentists.¹ Such injuries have been implicated as the most common reason leading to premature retirement from the dental profession in a cohort of 393 dentists in the United Kingdom.² Given the restrictions in microlaryngeal surgery and the need for dexterity and fine motor control, we hypothesize that microlaryngeal surgeons may adopt suboptimal or inflexible working postures, which if maintained statically for an extended period of time, may lead to musculoskeletal disorders of the back, neck, or upper extremities. Thus, we have chosen to explore some of the basic ergonomic principles of microlaryngeal surgery.

Variables to be considered in the ergonomics of microlaryngoscopy include surgeon support, patient position, and microscope features. Available surgical chairs exist with variable ability to adjust seat height, adjust arm support height, with or without articulated forearm supports, and variable lower back support, depending on the type of chair. Some microlaryngeal surgeons operate with upper extremity support in the form of an adjustable Mayo stand, whereas others perform microlaryngeal surgery with no upper extremity support at all. Patient positioning and chair height may be adjusted to allow for variable degrees of foot support on the floor. Variance exists among adjustable features on operative microscopes as well. Many commercially available surgical microscopes have the ability to fine focus with focal lengths that may vary from the standard microlaryngeal surgical focal length of 400 mm. In addition, operative microscopes may have adjustable, articulated eyepieces that may be oriented for the comfort of the surgeon. Though each respective operative microscope has a fixed distance from the proximal eyepiece to the distal operative lens, this also varies among microscope manufacturers. With these variables in the performance of microlaryngeal surgery related to patient positioning, operative microscopes, and surgeon support, a host of surgical postures can be created without consideration to musculoskeletal health. Depending on the degree of support and the respective postures associated with obtaining good operative exposure, microlaryngeal surgeons may be placing themselves at substantive ergonomic risk for their musculoskeletal health. Data correlating microlaryngeal postures and operative precision are lacking, but one may hypothesize that operative precision may improve once the microsurgeon is optimally supported, with minimal muscle strain while operating. Lastly, most surgeons adopt operative positions based on their training and personal preferences and not incorporating ergonomically guided principles. We chose to analyze three operative postures that we feel represent a majority of those utilized for microlaryngeal surgeons: a supported position in a chair with articulated arm supports, a supported position with both arms resting on a Mayo stand, and a position with both arms unsupported. We hypothesize those fully supported operative positions, which place the

surgeon with more neutral joint postures, are more ergonomically favorable, and as such, pose the least amount of global musculoskeletal risk to the microlaryngeal surgeon.

MATERIALS AND METHODS

Simulated Microlaryngoscopy

We investigated three operative positions in a simulated microlaryngoscopy model. These three operative positions included a supported position in a chair with articulated arm supports, a supported position with both arms resting on a Mayo stand, and a position with both arms unsupported.

Prior to modeling operative conditions, we measured various operative parameters for each respective surgeon to account for multiple variables in microlaryngoscopy. Over a 6-week period of time, each surgeon assumed a comfortable operative micro laryngoscopic position after laryngeal exposure, and microsurgical suspension was performed using the chair with articulated arms supports. Data was collected at the start of the procedure, which included the angulation of Trendelenburg tilt of the operative table, the angle of the laryngoscope in relation to the horizontal plane, the angle of the head of the operative bed in relation to the horizontal plane, the height of the operating table from the floor, the distance from the proximal end of the laryngoscope to the surgeon's anterior/superior iliac spine, and the focal length of the microscope in focus. This was subjectively deemed the most comfortable position in which to operate for each surgeon. Averages were calculated for each parameter. Table I summarizes these data for each respective surgeon.

Subjects in this study included three fellowship-trained laryngologists: subject 1, whose stature represents anthropometric male, 95th percentile for height; subject 2, female, 50th percentile for height; and subject 3, female, 5th percentile for height. The operative chair used (Zeiss, model 9999–10) may be adjusted for height, back support, upper extremity arm rests, and articulated forearm supports, which can be angulated in three planes (Fig. 1). Each subject was photographed in the operating room using all of our standardly utilized operative equipment and a laryngeal surgical simulator³ which holds a Zeitel's #6 laryngoscope (Universal Glottoscope System; Endocraft LLC, Boston, MA) (Fig. 2). A Leica F40 (Leica, Heidelberg, Germany) operative microscope was used, which is equipped with a variable focal length that can be adjusted with fine focus adjustments by the surgeon. The eyepieces on this microscope are articulated and may be positioned upright or upside down, depending on surgeon preference.

Photographs were then taken with each subject in the three study operative positions. Each subject was dressed in form-fitting clothing, and 27 reflective markers were placed on bony landmarks such that these structures were readily visible with the use of flash photography to allow for joint angle analysis. Photographs were taken in a standardized fashion from statically positioned tripod supports in the lateral view, a fixed-distance anterior view, and a fixed-distance aerial view to obtain a z axis. Examples of these photos can be seen in Figures 3a to 3c. The degree of neck flexion was calculated for all subjects in each of the operative positions, and these were compared with static modeling previously reported by Chaffin⁴ to correlate neck strain with maximal muscle contraction.

Rapid Upper Limb Assessment (RULA), a validated survey method to assess posture risk in ergonomic investigations in occupational settings,⁵ was utilized to score all photographs in each of the three posture frames.⁵ The RULA scores were generated for each posture, allowing conclusions to be drawn as to the estimated risk of injury due to the posture used. RULA scoring and correlating risk assessments are presented in Table II. RULA scores for the each set of photographs for all subjects are summarized in Table III.

Motion Capture—Simulated Microlaryngoscopy

In addition, subject 1 was placed in all three operative postures with the same operative chair, an operative microscope, and a stretcher bed in a fully equipped three-dimensional motion analysis laboratory at the University of Pittsburgh. The same laryngoscope model was utilized for all data gathering. To determine the seated posture and joint and body angles, the subject was outfitted in form-fitting spandex and 66 reflective markers placed on known bony landmarks, which are standardly used for precise ergonomic joint angle analysis. Eight high-speed, fixed, passive, full-body motion capture video cameras (VICON Peak 612; Oxford Metrics Ltd., Oxford, UK) were used to capture static position of the reflective markers and the subject. The laboratory measurement space is illuminated by infrared strobe lights mounted on each camera, from which output is invisible to the human eye. The reflective markers receive this light and reflect it back to the cameras to determine their location within the room. Illumination and video data collection was synchronized and controlled by the VICON Peak 612 motion analysis system. This analysis system is a precision measurement instrument designed to locate and track reflective markers moving in a calibrated measurement space. Images were acquired in this fashion for all three operating postures, and motion was captured for each. Postcollection processing was performed with in the VICON Peak 612 motion analysis system software, and marker positions were exported as position data. A graphic example of this data collection system is seen in Figure 4. Using geometric equations and MATLAB R2008a (The MathWorks, Inc., Natick, MA) software, the position relationships of the markers were analyzed and converted to angles, creating angular positioning of the body in each posture.

Using 3-Dimensional Static Strength Prediction Program Analysis (3D-SSPP 6.0; University of Michigan Office of Technology Transfer, Ann Arbor, MI), the obtained angles for each posture were input into the software to generate the surgeon's three-dimensional profile. The 3D-SSPP software was also used to model the subject in the operative chair and hold a 0.1 N load to mimic the surgical position and a microlaryngeal instrument in each hand used. As previously noted, two of the postures were seated with arms supported. To account for this support, a pressure pad was used to obtain the force generated by the forearms when rested on an armrest. This vertical force was then normalized to the subject's body weight to mimic the force exerted from the chair arm supports and the Mayo stand on the elbow in the 3D-SSPP model. With the aforementioned vertical force applied to the elbow to account for arm support, the forces and moments at the shoulder joint were calculated and are summarized in Figure 5a. The difference in sign convention for the respective shoulder moments is due to the fact that no force is exerted on the elbow in an unsupported position.

RESULTS

RULA Risk Assessment

RULA scores for each operative posture for all subjects are presented in Table III. The angles of neck flexion for each subject in respective operative positions are listed in Table IV. RULA scores were higher, in general, for all subjects when no upper extremity support was used, and as such, unsupported postures were identified by RULA as being high risk for potential musculoskeletal injury.

Inverse Dynamics: Static Modeling

A graphic example of the VICON Peak 612 motion analysis system is seen in Figure 4. With the 66 reflective markers on standard bony landmarks, very precise angle measurements were obtained for each joint using the aforementioned motion capture system. An example of the laboratory setting for subject 1 correlating to the respective 3D-SSPP 6.0 model can be seen in Figure 6a and 6b. The program delineates right-sided joints and left-sided joints with different colors, so the figure has been demarcated accordingly. When comparing supported positions versus an unsupported position, a difference in torque of greater than 40 Nm was calculated. In addition, the compressive forces at the L5/S1 junction were modeled and are reported in Figure 5b. Our data demonstrate that an unsupported microlaryngeal surgical position causes a nearly four-fold increase in the compressive force on this disc space when compared to our most supported operative condition.

DISCUSSION

Musculoskeletal injury is an important component in disability compensation claims in several industries, being the most common work-related reason for both days missed from productive work and premature retirement due to substantial worker injury.⁴ These injuries are often caused by static postures or repetitive movements in various vocations.⁴ Data to account for the proportion of physicians, or specifically otolaryngologists, suffering from occupationally acquired musculoskeletal disorders is lacking as actuarial data for disability insurance claims and retirement demographics are unobtainable. The ergonomics of microlaryngeal surgery place otolaryngologists at risk for potential injury when accounting for the amount of neck flexion or extension performed, the amount of shoulder girdle adduction or abduction used, and stability of the upper extremities during surgery, all of which are maintained in a prolonged static posture and performed with variable degrees of surgeon support. This may lead to muscle and joint fatigue, pain, and eventual musculoskeletal injury. Furthermore, these issues may impact surgical accuracy.

The National Institute of Occupational Safety and Health (NIOSH) recommendations for workstation design include avoidance of static loads, fixed work postures, and job requirements in which operators must for long periods lean to the front or to the side, hold a limb in a bent or extended position, or tilt the head forward more than 15°. ⁶ Nearly all of these recommendations are unavoidable during microlaryngeal surgery. Though the actual weight of the microsurgical instruments is minimal, the postures maintained during operative procedures may vary based on the operative chair used, the operative microscope,

patient positioning, and surgeon preferences. Proper chair positioning and surgeon support can minimize the angulation of the surgeon's head, and upper extremity support alleviates the limb from remaining in an unsupported, bent position. By using support for the upper extremities, shoulder moments decreased such that from our biomechanical model, we infer that less shoulder girdle muscular activity is utilized in maintaining the needed microsurgical operative postures.

NIOSH reports that there is strong evidence that working groups with high levels of static contraction, prolonged static loads, or extreme working postures involving the neck/shoulder muscles are at increased risk for neck and shoulder musculoskeletal disorders.⁷ Unfortunately, normative data for force loads to the cervical spine or neck moments have not been calculated for at-risk worker populations other than the recommendation that maintaining an extension neck posture of neck flexion greater than 15° to 20° for a prolonged period of time is an at-risk posture.^{5, 7} In an experiment of static postures maintained in healthy volunteers, cervical disc compression was nominal for those maintaining their head in a neutral position (0°) for 1 hour when compared to those maintaining flexed neck positions (20° and 40° neck flexion), and with the higher degree of neck flexion, a larger amount of cervical disc compression was noted.⁸ These authors postulate that individuals would increase muscular tension in the levator anguli scapulae and other muscles involved in raising the head to compensate for this cervical compression, and that this would increase pressure on the cervical discs.⁸ Prolonged neck flexion has been associated with cervical musculoskeletal complaints and trapezius muscle pain.⁹ In a group of 93 dentists, prolonged neck flexion was an indicator of neck pain.¹⁰ Workers who have a visually demanding job, such as computer workers, experience neck pain with increasing neck flexion, and workers who use laptop computers use more neck flexion, as the screen is at a fixed distance from the keyboard, and begin experiencing discomfort in as little as 20 minutes.^{4, 11} Industrial hygienists standardly recommend that positioning of visually demanding work be done as to minimize neck flexion angles.⁴

As stated by Chaffin, a relationship between muscle strength and strain has been developed based on the understanding of muscle contractile strength.^{4, 15} Muscle strength is the maximum force that a group of muscles can develop under prescribed conditions. With this, Chaffin has noted that maintaining the neck a static 10° flexion utilizes maximal contraction strength of 5% to 7%.⁴ When maintaining these contractile forces and necessitating continuous and increasing muscle strength, the neck musculature is strained as increased and constant forces require continuous contraction, leading to prolonged fatigue and eventual injury risk. When comparing each of our tested operative positions, neck flexion was the least for all subjects in the position with articulated arm supports. Though the upper extremities are also supported in the Mayo stand-supported position, each subject had a neck flexion angle of greater than 20°. With this higher angle of neck flexion, each subject uses a maximal contractile force of at least twice that for the position with the articulated arms supports. With the understanding that continuous muscle contraction leads to eventual musculoskeletal injury risk, the Mayo stand-supported position poses the microlaryngeal surgeon at risk for greater neck strain.

With regard to occupational risk assessment, RULA is a validated survey method originally developed to assess posture in ergonomic investigations in occupational settings in which work-related upper limb disorders are reported, such as in visual display unit operators and other manufacturing tasks.⁵ In surveying the literature and reviewing workplace risk assessment tools, RULA is the most applicable ergonomic assessment tool for the analysis of the working posture of microlaryngeal surgeons because microlaryngeal surgeons work in a prolonged static sitting position, which resembles some manufacturing tasks. The major benefit of RULA is in its ease of use in risk assessment and its ability to identify occupational conditions that warrant ergonomic investigation. The major limitation of RULA is that it is an instrument of risk prediction, cumulative of all the joints involved in upper extremity movement, and it cannot delineate specific joint angles that are at high risk or help with recommendations for optimizing working postures. For more involved analysis of individual joints, biomechanical calculations and analyses are needed, as described above.

Although RULA was an important metric for understanding the need for further investigation into the three operative postures, the biomechanical analysis, performed through modeling within 3D-SSPP, allowed for specific identification of major contributors to potential harms of musculoskeletal health. As previously mentioned, 3D-SSPP utilizes biomechanical modeling to create a simulated environment for complete postural analysis and interpretation. Within the software, calculations known as inverse dynamics, are performed to determine the impact of body postures and external loads on specific joints and anatomical landmarks. From inverse dynamics, further conclusions can be drawn and proposed alterations can be generated to improve surgeon safety through posture adjustments.

Specifically, inverse dynamics determine net force and moment occurring at specific joints of interest. Force is simply internal forces experienced by muscles, ligaments, and bone occurring at the joint due to external loads and gravity. Joint moment, or torque, is the net result of the muscular, ligamentous, and friction forces acting to alter the angular rotation of a joint. Moments help define which muscle groups must be active and to what relative magnitude each muscle group must contract to describe the amount of force required to perform an action or maintain a posture. By knowing the external forces occurring at each body segment and joint of interest (i.e., segmental mass, gravity), subject anthropometry, and subject position (i.e., joint angles), these forces and moments can be determined using Newton's laws and basic physics concepts. Although this can be performed analytically, we were able to extrapolate this data using 3D-SSPP and develop a biomechanical model through the software. This is a three-dimensional strength prediction program developed by the Center for Ergonomics at the University of Michigan College of Engineering.^{4, 12} This program has been validated to predict static strength requirements for tasks, such as lifting, pressing, pushing, and pulling with variable weight loads.^{4, 12} 3D-SSPP provides an approximate occupational simulation that includes force parameters, posture data, and accounts for gender-based anthropometry variance.^{4, 12}

As with any modeling or calculated analysis, there are several assumptions and limitations. With 3D-SSPP in particular, we were limited in the chair characteristics and external force application. Using this modeling program, we were unable to generate a chair that was

exactly identical to that used in the operative condition. The chair height and back were limited along with support of the feet in our modeling program. With regard to external forces, all external forces must be applied at a specific joint rather than appropriately proportioned along a segment. With this, the force of the forearm support acted strictly at the elbow rather than being distributed along the forearm. Additionally, the external force on the elbow in the seated condition was measured separately using a force plate and was applied to the model for inverse dynamic calculation.

The calculated shoulder moments are described in Figure 5a. The difference between the chair-supported position and a Mayo stand-supported position is small and based on slightly different angles about the shoulder in the two positions. The difference in supported positions versus a nonsupported position revealed a difference in torque of greater than 40 Nm. Though this difference is not a large amount of torque in one moment in time, when a static posture is maintained for a prolonged period of time, this larger shoulder moment will likely manifest in musculoskeletal pain in the upper back and shoulder. Surface electromyography may be useful to quantify muscle strain in the upper back and shoulder in these positions.

The lower back is the most injured and frequently treated for occupational injuries according to NIOSH.⁷ Because the L5/S1 disc space is the most occupationally injured, it is considered meaningful for ergonomic calculations in workplace risk assessment for activities that may involve the lower back. NIOSH guidelines have been issued for compressive loading forces for the lumbar spine (L5/S1 disc space) as an action limit of 3400 N and a maximal permissible limit of 6400 N based on lifting experiments¹³ in hopes of minimizing these injuries in the workplace. When calculating compressive forces of this disc space, anthropometric norms for this region of the spine are used in quantitative inverse dynamic calculations. These calculations, however, accounted for repetitive lifting maneuvers and did not account for statically maintained postures. No standard currently exists for workers maintaining static postures and the cumulative forces on the L5-S1 disc space with regard for recommendations for back support and lower limb angulations in a seated position. Though within the safety limits set by NIOSH for compressive forces on L5/S1 disc space, our data demonstrate that an unsupported microlaryngeal surgical position causes a nearly four-fold increase in the compressive force on this disc space when compared to our most supported operative condition. When an unsupported microlaryngeal posture is maintained for an hour or longer, the cumulative lower back compressive forces may pose substantial risk to the lower back.

Proper patient positioning is integral to adequate operative exposure and for the surgeon to be positioned in an ergonomically favorable posture. In microsuspension laryngoscopy, the laryngoscope angle within the patient is relatively out of individual control, and the distance between surgeon and the patient is limited by instrument access and the surgeon's lower extremities coming into contact with the operative table. Characteristics of microsuspension laryngoscopy, which can be adjusted, include the height of proximal port of the laryngoscope, the chair position, the microscope position, and surgeon posture (body, arm, foot position). In addition, some microscopes have adjustable eyepieces such that they can be placed upside down or upright. We noted in our initial assessment that in some

individuals, placing the eyepieces upside down can cause neck extension, which is very ergonomically unfavorable.⁵ As such, we recommend assessing the position of the microscope eyepieces such that neck extension is avoided.

Trendelenburg table positioning combined with flexion of the head of the operative table properly extends the patients neck.¹⁴ Placing the patient's head of bed in flexion elevates the proximal part of the laryngoscope, and utilizing Trendelenburg bed tilt effectively lowers the patient's head. This position allows a view of the patient's larynx that is coaxial with the view through the operative microscope eyepieces with minimal surgeon neck flexion. With the limitations of laryngoscopy being a statically maintained posture, we have found that the posture with articulated arm supports to be the most favorable of our studied conditions, especially given that this position leads to the lowest degree of neck strain and least amount of compressive forces on the lower back.

When considering the anthropometric variance in our study subjects, there was a trend that the surgeon's height inversely correlated to greater risk for each of the three postures tested. From NIOSH assessment of workstation safety, assessment of the adequacy of a given work space should consist of considering the physical makeup of the worker population, the specific body parts involved in particular tasks, and whether the workstation features are fixed or adjustable.⁶ As with the population of workers in most any setting, surgeons differ widely in height, weight, and other body dimensions. Workstation features, as in the case of microlaryngoscopy, should then account for variable chair heights, variable operating room table heights, and adequate body supports that can comfortably fit the range of body sizes, regardless of gender. Of note, our smallest subject scored better on the RULA scale in an unsupported position, likely because she was able to get closer to the operative table. This, however, would likely be a worse operative position overall for this individual given the data on problematic lower back compressive forces and neck flexion. As with all surgeons, smaller individuals should be conscious to position themselves more favorably and adjust chair height, chair arms supports, operative table angulation and height, and microscope eyepiece position to accommodate more ergonomically favorable postures.

Limitations exist with this current study. Though this study's intent is to investigate the concept that microlaryngeal surgery can be analyzed ergonomically, the number of subjects in this study is small. Due to limited access to motion capture laboratory space and the inability to retransport operative equipment to this offsite laboratory, we performed biomechanical modeling on subject 1, and further study should examine multiple subjects in different operative postures in this setting. Biomechanical modeling is a quantitative assessment, but it is modeling nonetheless. Additional quantitative analysis via surface electromyography of at-risk muscle groups to calculate frequency analysis for fatigability, could further assess muscle fatigue during prolonged postures. Further determinations of optimal postures would be assessed via validated surveys of subjects in different operative positions.

Nonetheless, the calculation of moments about any given joint can lead to extrapolations of muscle strain and fatigue. Based on our findings, the position with articulated arm supports allowed the surgeons to assume a more globally neutral, and thus, more ergonomically

favorable posture. This position allowed for a decreased shoulder moment, the least amount of neck flexion, and the lowest amount of compressive forces applied to the lower back. Relating the postures assumed with the experimental conditions and taking into account recommendations for workers who maintain static postures with high visual demands,^{1, 2, 4, 5, 7, 10-2} the lowest risk position a microlaryngeal surgeon can assume includes having the surgeon with both lower extremities well supported, with the neck minimally flexed from 0° to 10° from the vertical plane. The patient should be positioned such that the laryngoscope is low enough that both shoulders are unraised in a neutral anatomic position, with upper arms in a neutral position, ergonomically defined as 20° to 45° from torso in the sagittal plane, lower arms supported and neutral, ergonomically defined as 60° to 100° from torso in the sagittal plane, and wrists neutral or minimally extended or flexed, ergonomically defined as <15° from the horizontal plane.⁵

CONCLUSION

RULA has identified higher-risk surgeon positioning that is used in microlaryngeal surgery. Higher-risk ergonomic postures are associated with unfavorably adjusted eyepieces and lack of arm support during microlaryngeal surgery. Neck extension leads to higher risk scores and increased neck moments, and any neck extension should be avoided in a prolonged posture during microlaryngeal surgery. Correlating our analysis, especially with regard to neck flexion and low back compressive forces in our studied operative postures, with those reported in the ergonomic literature for workers maintaining static postures, such as dentists, we recommend parameters of microlaryngoscopy that place the surgeon in an ergonomically favorable, well-supported, neutral anatomic position. Avoiding the identified high-risk operative postures may lead to reduced occupationally related musculoskeletal fatigue and pain and may improve microsurgical motor control.

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Figure 1. Operative chair utilized by subjects in this study, manufactured by Zeiss (model no. 9999-10). The chair height, back support, arm rest height, and the angulation and lateral tilt of the articulated arm supports are all adjustable.

Figure 2.
Laryngoscope holder 3 with Zeitel's #6 laryngoscope (Universal Glottoscope System;
Endocraft LLC, Boston, MA) in place on an operative table.

Figure 3.

Subject 2 photographed from lateral view is in operative position. Note the reflective markers on bony landmarks. (a) Positioned with full support from adjustable chair with articulated arm supports. (b) Subject positioned with upper extremities supported with a Mayo stand. (c) Subject with no upper extremity support.

Figure 4.

A graphic example of the video data collection was synchronized and controlled by the VICON Peak 612 motion analysis system (Oxford Metrics Ltd., Oxford, UK), obtained from eight high-speed, fixed, passive, full-body motion capture video cameras, sampled at 120 Hz.

Figure 5.

(a) 3D-SSPP 6.0 (University of Michigan Office of Technology Transfer, Ann Arbor, MI) image, which models the subject in the supported operative chair, with respective forces applied to the elbows from the chair support, and holding a 0.1 N load in each hand to mimic the surgical position in which a microlaryngeal instrument is used. (b) An example of the laboratory setting correlating to the 3D-SSPP 6.0 model with subject in operative position with arms supported with articulated chair supports. Note the 66 reflective markers on bony landmarks.

Figure 6.

(a) With the vertical force applied to the elbow to account for arm support from either a chair or the Mayo stand, the moments at the shoulder joint are reported for each operative posture. (b) The compressive forces at the L5/S1 junction were modeled and are reported for each operative posture.

Table 1

Subject	OR Bed Trendelenburg Angle (°)	Laryngoscope Angle (°)	Head of Bed Angle (°)	Laryngoscope Height (cm)	Laryngoscope From Spine (cm)	Microscope Focal Length (mm)
1	-12	39	26	93	59	367
2	-11	39	19	90	54	387
3	-7	46	22	89	60	388

Summarizes average operative data for each subject with their Trendelenburg bed angle, laryngoscope angle, angle of head of bed, laryngoscope height, distance from proximal end of laryngoscope and iliac spine, and the focal length.

OR = operating room.

Table II

RULA Scores

RULA Score	Workplace Recommendations
1–2	Working under the optimal ergonomic posture with no risk
3–4	A potential risk to injury from the posture, which should be investigated further and corrected if possible
5–6	Poor posture with increased risk, thus necessitating changes in the near future
7–8	A posture threatening immediate risk, thus requiring investigation and changes immediately to the posture to prevent injury

As per the validated metric, Rapid Upper Limb Assessment (RULA) scores are listed for each risk stratification group.⁵

Table III

RULA Scores After Standardization of Trendelenburg Bed Angle, Laryngoscope Angle, Angle of Head of Bed, Laryngoscope Height, Distance From Proximal End of Laryngoscope and Iliac Spine, and the Focal Length for Each Respective Subject Was Performed

Subject	Operative Support	RULA Score (Right)	RULA Score (Left)
1	Chair	2	2
2	Chair	3	3
3	Chair	4	4
1	Mayo	3	3
2	Mayo	3	3
3	Mayo	5	5
1	No support	4	4
2	No support	4	4
3	No support	4	5

RULA = Rapid Upper Limb Assessment.

Table IV

Demonstrates Angles of Neck Flexion for Each Subject in Respective Operative Positions

Subject	Neck Flexion		
	Chair with Arms Supported (°)	Mayo Stand- Supported (°)	No Arm Support (°)
1	0–10	>20	>20
2	0–10	>20	10–20
3	0–10	>20	10–20

Regardless of anthropometric variance, neck flexion was increased in the Mayo stand-supported position and the position lacking arm support.