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Ergonomic Assessment of Septorhinoplasty Maneuvers During Simulated Pregnancy

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Abstract

Objective. Women represent an increasing proportion of the otolaryngology workforce. Work-related musculoskeletal disorders (WRMSD) are a little-studied yet important impediment to career completion. Scant attention has been directed to study the impact of pregnancy on surgeon posture and ergonomics. We piloted the use of a pregnancy simulation suit (Empathy Belly) to assess the risk of ergonomic compromise when performing open septorhinoplasty.

Study Design. Surgical simulation.

Setting. Single session, training simulation lab at academic medical center.

Methods. Medical students and surgical residents performed the initial steps of a rhinoplasty procedure without and with a pregnancy simulation suit and were filmed with an artificial intelligence-based video analysis app from Kinetica Labs that calculates joint angles and categorizes the ergonomic risk factors. Still images from videos were taken and analyzed using validated posture-based analysis rubrics. Participants were asked to complete a qualitative questionnaire after the session.

Results. Twelve medical students and surgical residents participated in the study. Posture-based analysis indicated increased ergonomics risk factors among trainees when performing a rhinoplasty while wearing the pregnancy suit. Video analysis indicated trends of worsening back angle and shoulder postures. Trainees reported experiencing pain in the neck, suprapubic area, and lower back. They acknowledged the importance of ergonomics in otolaryngology and desired further education about workplace injury risk mitigation.

Conclusion. Pregnancy impacts the ergonomics of performing septorhinoplasty and further investigation is required into interventions to reduce risk of WRMSDs.

Keywords

ergonomics, pregnancy, rhinoplasty, simulation

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Women make up 18.3% of registered otolaryngologists. However, 40.3% of otolaryngology head and neck surgery (OHNS) residents in the United States are women, a percentage which has risen from 27.5% in 2008.[1,2] While statistics may indicate that gender disparities such as pay, representation, and leadership are improving, there are many challenges uniquely faced by female surgeons. Women report feeling more dissonance regarding balancing career and family life.[3] Negative attitudes persist among male and other female surgeon colleagues surrounding the topic of pregnancy.[4] Many women in surgery delay childbearing until the completion of training and carry twice the risk of pregnancy loss compared to the general population.[5] In fact, female otolaryngologists have the highest rate of infertility (29%), when compared to other specialties.[6] Nevertheless, the rates of childbearing have increased from 7% in a cohort of female residents between 1976 and 1999 to 35% in a matched cohort between 2000 and 2009.[7] Given the increasing number of women pursuing surgical specialty training, it is imperative to foment both better understanding and education on the increased challenges and risks of pregnancy during training and/or practice. Pregnant surgeons encounter unique physiological and anatomical changes that may alter their practice each trimester. Fatigue, edema, altered center of gravity, poor sleep quality, hormonal changes, and pain can negatively impact stamina, focus, stability, and dexterity—all critical elements to performing

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surgery.[8-10] However, there is limited research on risk mitigation, highlighting the magnitude of this impact.

The study of human factors and ergonomics is a systems-based approach to examining the interaction between individuals and their physical, organizational, and cultural environment. This information can be used to design the fit between the workplace and the worker, which is of utmost importance in surgery to ensure that surgeons can perform their tasks effectively and efficiently while minimizing the risk of musculoskeletal disorders. Work-related musculoskeletal disorders (WRMSD) rates of up to 90% have been reported among health care professionals, including carpal tunnel syndrome, tendonitis, arthritis, and neuropraxia.[11-13] Among surgeons, this is due to the long periods of standing, postures requiring hyperflexion of the joints, repetitive movements, truncal twisting, and use of ergonomically compromising equipment such as loupes and headlights.[14-16] Within the field of otolaryngology, one survey found that 97% of respondents experienced some exacerbation of WRMSD in one or more regions of their body due to work.[14] Occupational injuries can also affect surgeon wellness such as work productivity and sleep quality and has been reported to lead to early retirement in certain instances.[15-20]

Currently, surgical residency programs prioritize clinical skills, medical knowledge, and surgical techniques needed for patient care, which may overshadow the need for learning personal well-being practices for career longevity. A study by Epstein et al found that only 1.5% of general surgery programs had formal education on ergonomics within their residency curriculums.[21] Given that symptoms of back and neck pain starts as early as the first 2 years of residency, this underscores a need for enhanced surgical ergonomics education at large.[22] With such limited exposure to ergonomics within surgical education, it comes as no surprise that there are limited studies in the literature quantifying risk of musculoskeletal disorders in pregnant trainees.

Methods

We undertook a pilot study approved by the San Francisco General Hospital Panel (IRB #21-34124) to assess changes in ergonomics in surgical trainees performing critical steps of a rhinoplasty procedure prior to and while donning a pregnancy simulation suit. All participants in a surgical skills lab session for OHNS residents and fourth-year medical students on their OHNS subinternship were invited to participate. Written consent was obtained prior to study participation.

Using cadaveric heads positioned on surgical tables, participants performed septorhinoplasty maneuvers such as raising the nasal skin envelope as well as looking inside of the nostrils with and without wearing the suit, steps deemed appropriate by the facial plastic surgeon to be independently performed by residents. This step was identified by the ergonomics specialist during study conception to be one involving multiple joints and, therefore, possibly elevated ergonomic risk. Video recordings were captured for 45 seconds by 3 authors (R.M.B., K.L., A.M.P.) from the dominant arm side. To isolate effects of the simulation suit to just posture, we kept several variables constant by prohibiting table height changes, use of headlamps or loupes, and use of step stools or sitting stools.[23,24]

The "Empathy Belly" suit consisted of a pouch filled with 1.3 L of warm water simulating the weight and warmth of the pregnant woman's abdomen, suspended weights within the belly that mimic fetal limb movement, a rib belt to constrict lungs, a bladder pouch to simulate fetal head on the bladder, as well as added weight and volume in the chest. To allow for adjustment to the weight and change in center of gravity, participants were asked to wear the suit for 20 minutes prior to performing the procedure. After recording, medical students and residents were asked to give feedback about their physical experiences wearing the suit, takeaways from the study, and perceived barriers to ergonomics in surgical training (**Figure 1**).[25]

Data collected were analyzed using validated scoring systems, the Rapid Upper Limb Assessment (RULA) and Rapid Entire Body Assessment (REBA) which quantify exposure levels of risks to the musculoskeletal system due to stresses placed on the neck, trunk, upper limbs, and lower limbs with various frequency and duration (**Figure 2**).[26,27]

REBA scores range from 1 to 12, with 1 being negligible risk, 2 to 3 low risk, 4 to 7 medium risk, 8 to 10 high risk, and 11+ very high risk. RULA scores range from 1 to 7, with 1 to 2 deemed acceptable posture, 3 to 4 requiring further investigation, 5 to 6 requiring urgent investigation, and 7 requiring emergent investigation and immediate change.

Data analysis was performed by hand by authors R.M.B. and K.L and via the use of a smartphone application from Kinetica Labs (https://www.ehs.com/kineticalabs/). The app assesses the severity and frequency of ergonomically inappropriate positions using artificial-intelligence video content analysis and classifies joint angles in categories of "safe," "requiring caution," or "hazardous" based on criteria from the RULA and REBA (**Table 1**). Because the videos were taken from a sagittal point of view on the dominant side, analyses regarding the nondominant shoulder, elbow, and knee were not performed. For ease of analysis, we combined "requiring caution" and "hazardous" angles as a single category deemed "unsafe."

Angles are calculated at 15 frames per second. Therefore, a 45-second video captures roughly 675 data points per joint per trainee. From this, the app calculates the percentage of time spent in each joint angle within the timeframe of the video. Qualitative responses from the survey were collected and analyzed by author R.M.B. Differences in means of REBA and RULA scores pre- and post-suit as well as differences in means of incidence

1. Could you describe the location, quality, and severity of pain wearing the simulation suit?
2. Could you describe challenges you faced while operating with the simulation suit?
3. Could you rank your symptoms from 1 being most bothersome to 12 being least bothersome?
    a. Breathing/Chest Constriction/Shallow Breathing/Shortness of Breath
    b. Increased Body Temperature
    c. Bladder Pressure
    d. Fatigue
    e. Lower Back Discomfort
    f. Weight Gain of ~30 Pounds
    g. Shift in Center of Gravity
    h. Increased BP or Pulse
    i. Difficulty Bending at Waist
    j. Poor Balance
    k. Awkwardness in Body Movements
    l. "Fetal kicks" or movements
4. In what ways has today's session impacted your perception on the importance of surgical ergonomics?
5. What, if any, additional sessions on surgical ergonomics would you hope to see throughout your training?
6. What barriers do you foresee in integrating today's session on surgical ergonomics best practices into your everyday practice?

Figure 1. Post-intervention survey. Qualitative survey assessing study participants' experience using the pregnancy simulation suit and their perception of ergonomics.

of safe joint angles were assessed. Paired samples 2-tailed *t*-test was employed with significance set at $P < .05$.

Results

Ten postgraduate surgical residents (PGY) and 2 medical students participated in the study. There were 3 PGY-5s (3/12, 25%), 4 PGY-4s (4/12, 33%), 2 PGY-3s (2/12, 17%), 1 PGY-2 (1/12, 8%), and 2 MS4s (2/12, 17%). Trainees varied in age from 27 to 33 (median 29.5, interquartile range 29, 32); the majority were male (7/12, 58%). All trainees were right-hand dominant (100%). None of the trainees are or have ever been pregnant. Demographics and measurements are listed in **Table 2**.

Mean REBA score for pre-suit group was 5.17 (range: 2-11) while REBA score for post-suit group was 7.33 (range: 4-10) with $P < .006$. Mean RULA score for pre-suit group was 6.00 (range: 4-7) while RULA score for post-suit group was 6.67 (range: 6-7) with $P < .039$.

Based on the REBA and RULA rubrics (**Figure 2**), mean REBA score for pre-suit fell into the category of "medium risk, further investigation, change soon" while the post-suit group score fell into the category of "high risk, investigate and implement change." The mean RULA score for pre-suit fell into the category of "further investigation, change soon" while the post-suit group fell into the category of "immediate investigate and implement change."

Table 3 illustrates the percentage of time spent in "safe" and "unsafe" positions among trainees' joint angles of the neck, right shoulder, right elbow, right knee, and back. Videos captured for one resident were not available for analysis. In the pre-intervention assessment, more than 50% of time spent in joint angles considered to be "safe" were in the back, right shoulder, and right knee, while those considered "unsafe" were in the neck and right elbow. In comparison, ergonomically "safe" positions in the assessments while wearing the pregnancy suit included the back, right shoulder, right elbow, and right knee, while the only "unsafe" category was in the neck (**Figures 3** and **4**).

Between the pre- and post-suit groups, there was no statistically significant difference in safety among any of the joint angles: neck (3% vs 12%, $P = .11$), back (83% vs 74%, $P = .44$), right shoulder (73% vs 71%, $P = .83$), right elbow (35% vs 57%, $P = .09$), and right knee (98% vs 100%, $P = .34$) (**Table 3**). Combining pre- and post-suit groups together, the time spent in "safe" positions across all joints was 62% when performing the rhinoplasty procedure. Further analysis of the "unsafe" category was performed and divided into sub-categories of "requiring caution" and "hazardous" (**Table 4**). Among these "unsafe" neck angles measured, 92% were hazardous in the presuit group versus 78% in the postsuit group. Based on RULA and REBA criteria, right elbow angles that fall under $0° < 60°$ flexion or $100° < 180°$ flexion are automatically deemed "hazardous" and therefore made up 100% of "unsafe" angles in pre- and post-suit groups.

Of the 12 trainees, 8 responded to the postsimulation survey (66% response rate). Common locations of pain during the simulation included lower back, suprapubic region, and neck. Challenges in performing surgery included difficulty bending forward, twisting their torso to optimize viewing angles, and discomfort with shoulder abduction attributed to extended working distance between the "patient" and their body.

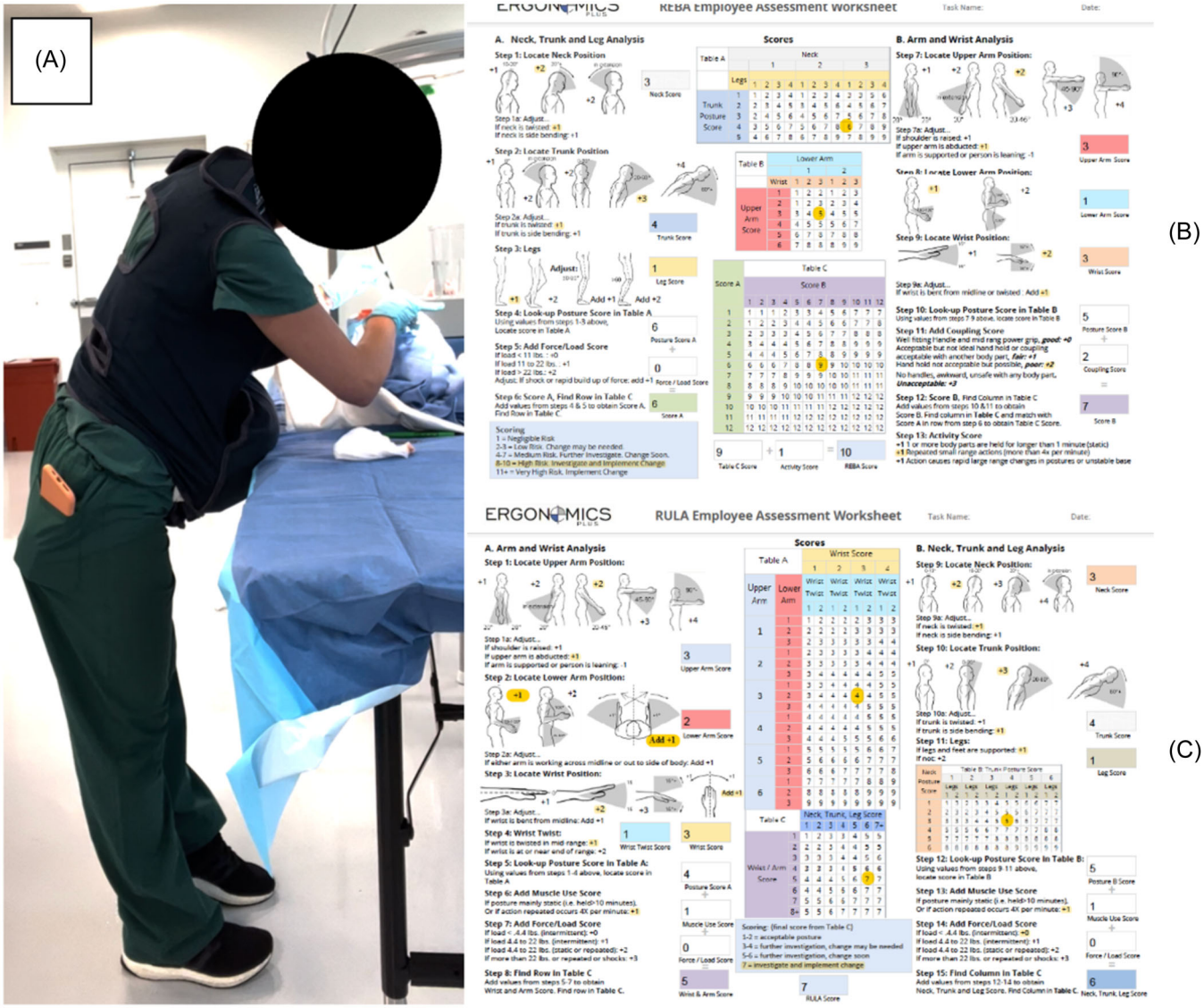

Figure 2. Ergonomic analysis of a study participant. (A) (Left) is an image captured of a participant performing septorhinoplasty. (B, C) (Right) are examples of completed Rapid Entire Body Assessment and Rapid Upper Limb Assessment worksheets used to score participants taken from https://ergo-plus.com/.

Table 1. Joint Angles Grouped by Degrees of Safety

	Safe	Requiring caution	Hazardous
Neck	0 < 10° flexion	10 < 20° flexion	20 < 180° flexion
Back	0 < 20° flexion	20 < 60° flexion	60 < 180° flexion
Shoulder	0 < 45° flexion	45 < 90° flexion	90 < 180° flexion
Elbow	60 < 100° flexion	N/A	0 < 60° flexion or 100 < 180° flexion
Knee	0 < 30° flexion	30 < 60° flexion	60 < 180° flexion

Angles of neck, back, shoulder, elbow, and knee corresponding to varying degrees of safety (safe, requiring caution, and hazardous) based on RULA and REBA criteria.
Abbreviations: REBA, Rapid Entire Body Assessment; RULA, Rapid Upper Limb Assessment.

In response to the questions on the significance of ergonomics, residents commented on their revitalized appreciation for the subject. Male residents discussed how increased central obesity may impact ergonomics in their own careers and expressed desire to see a study where this could be explored. Female residents expressed concern about how pregnancy might affect their colleagues' and their own lives. All participants commented on the need

Table 2. Demographics and Measurements of the Study Participants

	Sex	Age	Training level	Height, feet	Elbow height to ground (cm)	Acromion to 3rd digit arm length, cm	Abdominal girth w/o suit, cm	Abdominal girth with suit, cm
Trainee 1	M	30	PGY-4	5′9″	43.25	27	33.25	46.25
Trainee 2	F	29	PGY-5	5′5″	42	28.5	28.75	43
Trainee 3	M	29	PGY-3	5′9″	43.75	30	31.25	44.5
Trainee 4	F	31	PGY-4	5′8″	41.5	29.75	27	45
Trainee 5	M	27	MS4	5′9″	43	30	37	55
Trainee 6	F	29	PGY-2	5′5″	41	26	29	44
Trainee 7	M	32	PGY-4	5′9″	42.5	29	32.75	45.75
Trainee 8	F	32	PGY-5	5′7″	40.75	31.5	36	49.75
Trainee 9	M	33	PGY-5	5′7″	41	25	29	42
Trainee 10*	F	29	PGY-3	5′6″	37	30.5	26	46
Trainee 11	M	32	PGY-4	6′0″	44.75	28	40.75	56.25
Trainee 12	M	28	MS4	6′3″	48	32	36	48

Sex, age, level of training, height, elbow height from ground, wingspan, and body circumference are listed for each study participant.
Abbreviation: PGY, postgraduate surgical residents.
*Videos captured for Trainee 10 were not available at time of analysis.

Table 3. Incidences of Ergonomically "Safe" and "Unsafe" Positions Observed Among Participants Separated by Joint Angle

Category	Safety level/joint angle	Pre-suit (% of time spent)	Post-suit (% of time spent)	*P* value
Neck	Safe/0-10°	3	12	.11
	Unsafe/10-180°	97	88	
Back	Safe/0-20°	83	74	.45
	Unsafe/20-180°	17	26	
Right shoulder	Safe/0-45°	73	71	.83
	Unsafe/45-180°	27	29	
Right elbow	Safe/60-100°	35	57	.09
	Unsafe/0-60 or 100-180°	65	43	
Right knee	Safe/0-30°	98	100	.34
	Unsafe/30-180°	2	0	
Total	Safe	61	64	.54
	Unsafe	39	36	

"Unsafe" positions were defined as angles within "requiring caution" and "hazardous" columns from **Table 1**. Values are reported as percentages.

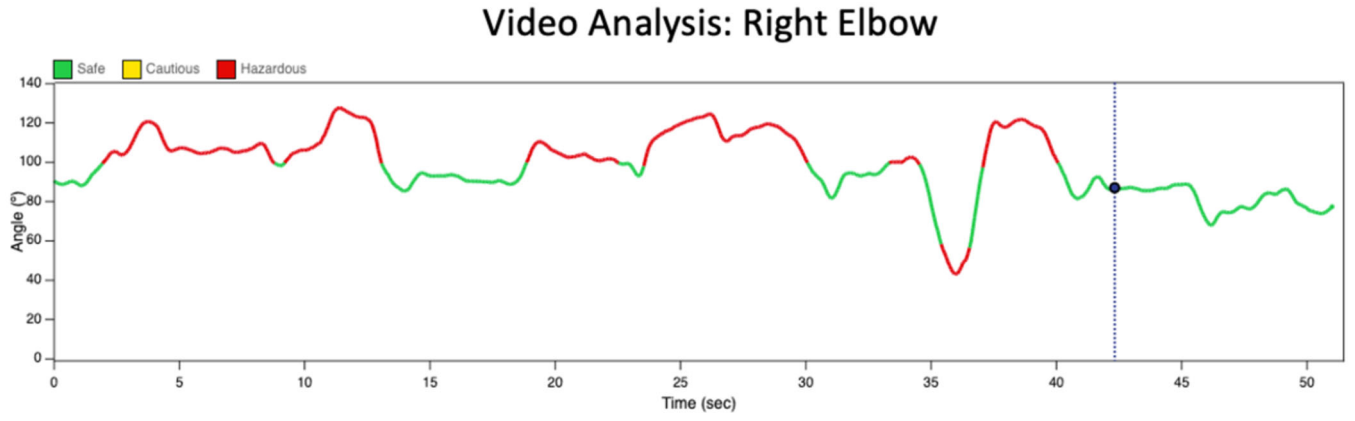

Figure 3. Video artificial intelligence-analysis data pertaining to the right elbow joint of 1 participant. Green line indicates elbow moving through "safe" angles, while red line represents "hazardous" joint angles.

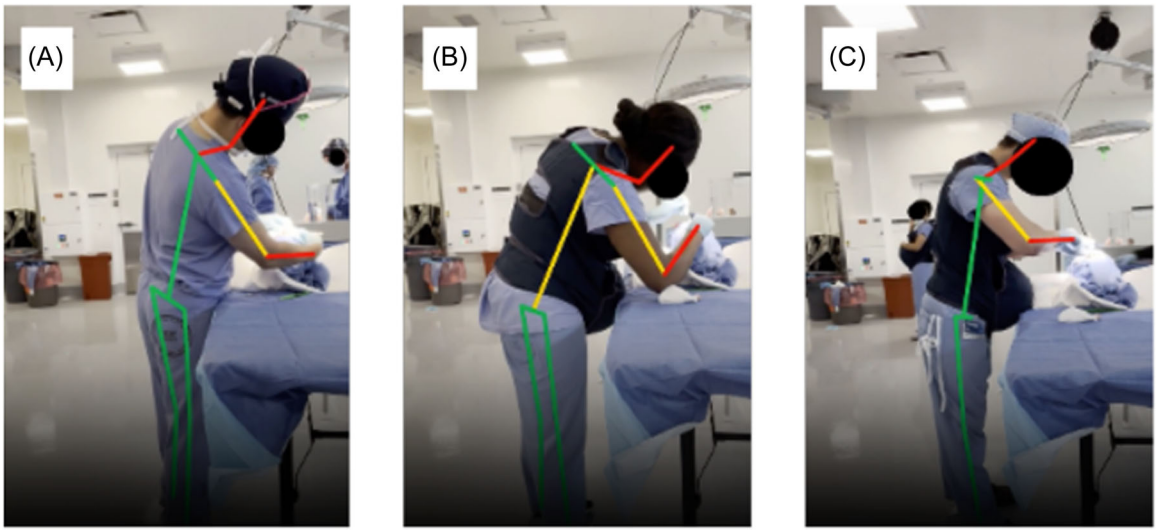

Figure 4. Three images (A-C) captured of participants taken from the video artificial intelligence-analysis app. Green joint angles represent safe positioning, yellow joint angles represent "requiring caution" positioning, and red joint angles represent hazardous positioning.

Table 4. Incidences of Ergonomically "Unsafe" Positions Divided Into "Requiring Caution" and "Hazardous" Groups

Category	Safety level/joint angle	Pre-suit (% of time spent in "unsafe" angles)	Post-suit (% of time spent in "unsafe" angles)
Neck	Requiring caution/10° < 20°	8	21
	Hazardous/20-180°	92	78
Back	Requiring caution/20 < 60°	16	26
	Hazardous/60° < 180°	0	0
Right shoulder	Requiring caution/45° < 90°	97	29
	Hazardous/90° < 180°	3	0
Right elbow	Requiring caution/N/A	0	0
	Hazardous/0-60° or 100-180°	100	100
Right knee	Requiring caution/30° < 60°	2	0
	Hazardous/60° < 180°	0	0

"Unsafe" joint angles were split into medium-risk "requiring caution" category and high-risk "hazardous" categories that were observed among the study participants. Values are reported as percentages.

for a standardized curriculum on ergonomics, suggestions on stretches to offset the long-term effects of poor ergonomics and the need for frequent reminders to enforce ergonomic concepts into everyday practice. Barriers to incorporating ergonomics included lack of time to integrate ergonomics into daily routine and an implicit hierarchy within the surgical culture where they feel obligated to defer positioning to attendings, especially in cases involving body habitus mismatches.

Discussion

As more women join the surgical workforce, understanding their unique ergonomic needs during surgical training, which may coincide with their childbearing years, is crucial to prevent injuries. Work-related ergonomic stressors on pregnant health care workers were shown to lead to deleterious outcomes such as spontaneous abortions, preterm delivery, low birth weight babies, and infertility.[28] At present, there is a paucity of literature regarding the risk of WRMSDs among pregnant surgeons. To that end, we seek to bridge this gap through this pilot study.

Herein, we used an "Empathy Belly" to simulate the effects of pregnancy in surgical trainees and quantify postural areas of concern during rhinoplasty procedures using established ergonomic evaluative scoring rubrics and motion tracking software. Medical students and residents were recruited because childbearing years tend to occur at a time when women in OHNS would usually be in training. Moreover, early trainees within the first 2 years of residency were shown to be a higher-risk group for WRMSD but may have the potential for learning ergonomics best practices correctly if emphasized.[22] While this study focused on trainees with limited experience in operating and may have impacted the REBA and RULA

averages, we cannot assume that more experienced attending surgeons would have lower scores without further study given that OHNS attendings report exacerbations of WRMSDs as well.[14]

REBA and RULA were chosen as the ergonomic standard tools because of ease of use, cost-effectiveness, practicality as a multiple joint analysis method, and integration already within health care settings.[29] Overall, both REBA and RULA analyses indicated a need for further investigation into specific ergonomic risk factors for all surgeons who perform rhinoplasty. When comparing pre- and post-suit RULA and REBA scores, there was a significant difference in population means, indicating an even higher risk of injury with pregnancy.

Examining data collected from the Kinetica app, the incidence of inappropriate back angles due to excessive hip flexion showed a net increase from pre- to post-suit groups, although, both groups still met the criteria of "safe." Among the percentage of back angles deemed "unsafe," data for both pre- and post-suit groups never fell within a "hazardous" range within the 45-second videos taken.

On the other hand, the incidence of inappropriate neck angle position decreased with simulated pregnancy although neither neck nor back angle results were statistically significant. It is still important to acknowledge, however, that most of the neck angles captured in both pre- and post-suit groups were determined to be in "hazardous" range. Therefore, this represents an urgent need for intervention among all rhinoplasty surgeons, regardless of pregnancy status. Our results are consistent with the fact that neck strain is among the most commonly reported WRMSD in surgical fields.[22,30-33]

With regard to upper limbs, 65% of right elbow angles captured were "unsafe" and "hazardous" in the presuit group, highlighting another urgent need for intervention among all rhinoplasty surgeons. Comparing pre- and postsuit groups, however, right shoulder results only slightly decreased in safety and right elbow results showed nonsignificant trends of improvement. These results seem to contradict the residents' reported experiences of sore arms with increased working distance and "awkward" shoulder movements after wearing the suit. Given that the REBA scoring rubric considers extensive upper arm abduction an ergonomically unsafe posture, it is possible that the software erroneously captured angles from the nondominant shoulder despite recording from the dominant sagittal side and possibly other nondominant joints if participants had some truncal twisting toward the camera. Not being able to erase irrelevant nondominant side data points captured represents a major limitation with the artificial intelligence app used for analysis that may have affected statistical significance.

There are other limitations to our study. Data collection was performed by 3 study personnel (R.M.B., K.L, A.M.P.) and occurred in a single session with a small number of residents. The focus of this study was to assess the impact of increased abdominal girth in pregnancy on posture. Trainees were recorded for 45 seconds performing the same step of the rhinoplasty procedure, but the consistent number of frames may not have captured the full range of ergonomic changes. We acknowledge that sustained posture and fatigue could result in worsening ergonomics over time, and we anticipate performing a much larger study in the future to capture the full range of ergonomic changes throughout an entire rhinoplasty procedure which can last anywhere from 1.5 to 4 hours.

Results may also have been affected by the time participants had to get accustomed to the Empathy Belly. Pregnancy is a 9-month course that involves progressive weight gain, build-up of edema, and fatigue over time, as well as compensatory muscle strength and conditioning, an experience which may not be replicable wearing a pregnancy suit for 20 minutes. Finally, for our pilot study, 1 primary evaluator (R.M.B.) and a trained ergonomic specialist (K.L.) verified the results. Still, intra-, and inter-rater variability issues may be present and cannot be fully assessed.

At present, we cannot be sure if rhinoplasty procedures can even be accomplished with minimal ergonomic risk without further study. However, within other surgical specialties, research into the development of resident ergonomics training sessions, incorporation of "targeted" stretching microbreaks into surgical theaters, and design of equipment intentioned to improve ergonomics is underway and may be worth adapting to otolaryngology procedural settings. Certain equipment interventions have already been shown to improve posture in otolaryngological surgery such as surgical stools, foot mats, and table height adjustments.[34,35] Cultural interventions have also been studied in other specialties; in a multicenter cohort study, incorporation of 1.5 to 2 minute multijoint stretching breaks at 20 to 40 minute intervals during surgical cases demonstrated improvements in postprocedure pain, mental focus, and physical performance.[36] None of these studies have used validated ergonomic tools such as REBA or RULA. Given that hip flexion seemed to be an ergonomically risky position in our study, it may be beneficial for pregnant otolaryngologists to emphasize psoas-lengthening stretches while strengthening the core and opposing hip extensor muscles for balance and support. For all rhinoplasty surgeons, movement breaks prior to and during surgery and a regular routine of neck stretching and upper arm resistance training exercises may be beneficial as well. Future studies will be necessary to examine if such recommendations significantly reduce risk of WRMSD and improve quality of life among pregnant OHNS surgeons and OHNS surgeons at large.

Conclusion

In this study, we characterized the ergonomic risks among OHNS trainees performing septorhinoplasty while using a simulation suit to mimic the physiological changes that

occur in pregnancy. To identify ergonomic risk, we used a multimodal approach of hand-scored posture-based analysis as well as an artificial intelligence-powered video assessment software that tracks time spent in ergonomically compromising joint angles. From our results, we conclude that rhinoplasty does carry moderate ergonomic risk and simulated pregnancy results in even further risk of WRMSD. Data trends show that incidence of unsafe neck flexion was high in both groups and incidence of unsafe hip flexion increased with the pregnancy suit on. Results from our postsession survey were consistent with the common sources of musculoskeletal discomfort for all surgeons, particularly neck and back pain. Trainees agreed on the need for further intervention such as a curriculum that highlights common ergonomic pitfalls in procedures and stretches to mitigate effects of long-term poor posture. Additional studies are needed to further characterize how pregnancy affects female surgeons and ways to reduce ergonomic risk.

Author Contributions

Rohith M. Bhethanabotla, study conception, study conduct, study design, data analysis, manuscript drafting and revision, final approval; **Kaye Ledgister**, study design, data collection, data analysis, manuscript revision, final approval; **Ian S. Soriano**, study conception, study conduct, manuscript revision, final approval; **Patricia O'Sullivan**, study conception, study conduct, manuscript revision, final approval; **Elaine Bigelow**, data analysis, manuscript revision, final approval; **Philip Daniel Knott**, study conception, study conduct, manuscript revision, final approval; **Andrea M. Park**, study conception, study conduct, study design, manuscript revision, final approval.

Disclosures

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