Comparison of Head Movements and Gaze Distribution during Tracheal Intubation between Experts and Novices at Tracheal Intubation

Takanari Yoshikawa¹, Soichiro Inoue¹, Shoichiro Takehara², Toru Shimizu³, Kosuke Hamabe¹, Yoshisuke Naito¹, Miyuna Kimura¹, and Hirokiyo Nomura¹

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Abstract

Background: Video analysis of body and gaze movements has recently become widespread, mainly in the field of engineering, however, few medical studies have used motion capture and eye-tracking systems. The aim of this study was to test the hypothesis that head movements and gaze distribution during tracheal intubation differ between practitioners who are expert at tracheal intubation and those who are novice at tracheal intubation as a secondary analysis of our previous study.

Methods: Practitioners who were either novices or experts at tracheal intubation using Macintosh laryngoscopes were recruited. Head movement and gaze distribution during tracheal intubation into a mannequin were recorded using motion capture and eye-tracking systems and analyzed according to 3 phases: phase A (mouth opening), B (obtaining vocal cord view), and C (tracheal intubation). The values obtained were compared between novices and experts.

Results: Intra-group comparison showed significant differences in the height of the head and forward-backward head tilt during tracheal intubation in the experts and novices, respectively. Inter-group comparison showed significant differences at each phase except for the height of the head at phase A (height: 154.1 vs. 159.1 cm, p = 0.602 for Phase A; 150.6 vs. 141.3 cm, p < 0.001 for Phase B; 151.2 vs. 135.6 cm, p < 0.001 for Phase C; tilt: 2.9 vs. 6.4 cm, p < 0.001 for Phase A; 6.5 vs. 9.3 cm, p < 0.001 for Phase B; 6.2 vs. 8.4 cm, < 0.001 for Phase C). Gaze depth analysis indicated that the experts had a further gaze distance. While the experts continued looking down throughout the tracheal intubation, the novices looked up after the mouth opening phase until the accomplishment of intubation.

Conclusion: Posture and gaze distribution during tracheal intubation with a laryngoscope differed between novices and experts. The results of this study will help trainers develop a clear teaching policy and help trainees become aware of their posture during tracheal intubation training.

Key Words

Motion capture, eye-tracking, tracheal intubation, simulation

Introduction

Tracheal intubation with a rigid laryngoscope is a crucial medical skill, mainly in the setting of anesthesia, critical medicine, and emergency medicine. However, it is not an easy skill to master because it is a complex psychomotor skill that requires spatial hand-eye coordination to be exercised at a distance within a narrow space.

Careful clinical observations have suggested that the posture and form of the practitioner differ between expert and novice intubators. Based on precise
observations, Whitten has reported that novices crouch and assume an incorrect posture with their face close to the patient’s mouth and they move the laryngoscope incorrectly\(^1\). Some authors have shown the difference between experts and novices in a simulation setting by measuring the angles and distances between some body parts and a mannequin on still images and video images.\(^2\)–\(^8\) Despite these reports, most textbooks and clinical educators do not seem to focus on the practitioner’s posture, head position, gaze distribution, and whole left arm movement, though they often provide detailed instructions on the patient’s position, how to open the mouth, and how to use a laryngoscope blade.

Motion capture systems and eye-tracking systems are modern techniques for analyzing body motion and eye movement, respectively. They have been applied in various fields such as healthcare, manufacturing, marketing, sports, and entertainment\(^9\)–\(^11\). In healthcare, motion capture systems have been used primarily to observe patients; however, in recent years such systems have also been used to evaluate medical procedures performed by healthcare providers\(^12\)–\(^15\). We analyzed tracheal intubation using both a motion capture system and an eye-tracking system and reported that the novices handled the laryngoscope in a rattled way, defined as “jagged pattern”, they moved their head both parallel and perpendicular to the ground in a “lasso-like” trajectory. They and looked both upward and downward throughout the entire course of the tracheal intubation. In experts, however, neither the ‘jagged pattern’ nor ‘lasso-like’ loop was observed, and over 99% of their gaze points were directed downward\(^1\).

The sequence of tracheal intubation can be divided into several phases: from opening the mouth to laryngoscope insertion, inserting a laryngoscope into the mouth to obtain vocal cord views, keeping the vocal cord view, intubating the trachea, and removing the laryngoscope\(^16\). Each phase has a different purpose and requires different maneuvers. However, in our previous study we only analyzed the total head and eye movements.

There has been no investigation regarding the difference in the posture and gaze pattern for each phase of tracheal intubation between experts and novices. We hypothesized that in each phase of tracheal intubation, head posture and gaze distribution differ between experts and novices. This study aims to test this hypothesis by re-analyzing our data set of our previous study\(^1\) exploring the body and eye movements of experts and novices in a simulation setting using both motion capture and eye-tracking systems.

**Methods**

This study is a secondary analysis of our data examining body and eye movements during tracheal intubation using a Macintosh laryngoscope. Participants for the study were recruited by means of recruitment and oral announcements to anesthesia residents and physicians from July to September 2018 at St. Marianna University Hospital. Novices were defined as individuals who had performed tracheal intubation less than 30 times using a Macintosh laryngoscope, while experts were defined as qualified anesthesiologists who had performed tracheal intubation more than one hundred times using a Macintosh laryngoscope.\(^1\)

**Motion capture system and eye-movement tracker**

All the sessions in this study were conducted in the simulation laboratory at the St. Marianna University School of Medicine. Information on the study aims was provided to each participant using a written informed consent form, and informed consent was obtained in writing.

Motion capture was performed using a system comprising ten Prime 13 and two Prime 13W cameras and retro-reflective markers (Acuity Inc., Tokyo, Japan). This system only identifies coordinates if one marker is consistently captured by two or more cameras. During this study, we used a camera arrangement with full coverage of all participants and the ability to capture all markers (Figure 1). The participants wore a body analysis outfit and cap fitted with 27 motion capture retroreflective markers (bilateral temporal regions, occipital regions, necks, shoulders, upper arms, forearms, back, and waist). The markers were attached to a tracheal intubation training mannequin (Kyoto Kagaku Co., Ltd., Kyoto, Japan) placed on a 70-cm-high table, and three markers were placed on the top of the handle of the Macintosh laryngoscope.

Tobii Pro Glasses (Tobii Technology Ltd., Danderyd, Sweden) were used to evaluate the gaze movement of the practitioner’s eyes, which were irradiated with near-infrared rays that traveled from the measuring device to the cornea, based on the corneal reflection method. The glasses were also used to evaluate the eyeball movement.
Figure 1. Experimental setup and setting of the YZ plane coordinates.
YZ plane: The Y axis runs vertically from the practitioner’s head to the abdomen before tracheal intubation and the Z axis at the feet runs parallel to the line running horizontally from the head of the mannequin in the supine position to the abdomen.

Measurement and analysis

Before each analysis, the participant wearing the outfit and cap for body analysis and the goggles for gaze analysis was asked to assume the T-pose to calibrate the motion capture system (Figure 2). Tracheal intubation was then performed on the mannequin using a Macintosh laryngoscope (Blade 3). The position of the mannequin’s head was adjusted at the discretion of the participant, and a towel or pillow was placed under the head to achieve the appropriate position. Each participant repeated the tracheal intubation 10 times.

The tracheal intubation series was divided into 3 phases based on the evaluation by Carlson et al.: A) mouth opening and laryngoscope insertion, B) the period from when the laryngoscope was inserted into the mouth to enable visualization of the vocal cords, and C) a constant hold of the vocal cord view during placement of the tracheal tube. These phases were defined by the fluctuation of the angle between the Y-axis and the long axis of the laryngoscope handle in our previous study.

The trajectories of motion capture sensors on the sagittal plane of the mannequin (YZ plane) were measured and analyzed for head movements. The YZ plane comprised two axes: the Y-axis, running vertically from the head to the abdomen of the practitioner before tracheal intubation, and the Z-axis, running horizontally from the head to the abdomen of the mannequin in the supine position (Figure 1).

Vertical head movement during tracheal intubation was assessed as the trajectory of the center of the quadrangle consisting of four markers placed on bilateral temporal regions and bilateral occipital regions on the YZ axis and expressed as the height from the floor ($Y = 0$ is the level of the floor).

The inclination of the head with respect to the direction of gravity (Y-axis) was assessed as the difference between the height (Y value) of markers between the occipital region and temporal region (i.e. positive value means the head is tilted forward) (Figure 3a).

Gaze movements on the sagittal plane of the subject (Y’Z’ plane) were measured and analyzed. The Y’Z’ plane was comprised of two axes: the Y’ axis, running vertically from the head to neck of the standing practitioner, and the Z’ axis, running horizontally from the ear to the eye of the practitioner. As shown in Figure 3b, a positive Y’ value indicated the gaze pointed upwards. The depth of the gaze point was expressed as the Z’ value, and a larger value indicated that the practitioner looked far away (the focus was placed far). The distribution of gaze points at the Y’Z’ plane during tracheal intubation was evaluated.

Statistical analysis

All statistical analyses were performed with
parametric unpaired two-tailed t-test was used to assess differences between groups (inter-group comparison). If the continuous data were not normally distributed, non-parametric tests were used: the Friedman test followed by post-hoc Bonferroni correction for repeated measures (intra-group comparison) and Mann-Whitney test for inter-group comparison. A value of $p < 0.05$ was considered statistically significant, and after adjusting for multiple comparisons with Bonferroni correction, $p < 0.0083$ (less than $0.05/6$) for the height of the head and $p < 0.016$ (less than $0.05/3$), respectively, were considered as statistically significant.

**Results**

The practitioners comprised 4 experts and 5 novice intubators. Data on 14 intubations by 4 experts and 19 by 5 novices were considered valid and used for the analysis of this study. The height at control point defined as the height of the head at the calibration was normally distributed, and the novices had a significantly high ($159.4 ± 8.2$ vs. $169.7 ± 6.4$ cm, $p < 0.01$). However, none of the other measured values were distributed normally. Thus, a non-parametric analysis was applied for both intra-group analysis (comparing the values at each phase in the same group) and inter-group (comparing the values at the same phase between the novices and experts) analysis.

The results of the median height of the head are presented in Table 1. The height at the control was significantly higher in the novices ($155.1$ cm vs. $170.0$ cm, $p < 0.01$). Figure 4 shows the typical trajectories of the vertical head movement in the novices and experts on the YZ plane. Intra-group comparisons demonstrated that the fluctuations of the median height of the head during tracheal intubation were significantly different in both expert and novice groups. A post-hoc test of intra-group comparison revealed that the median height in novices significantly decreased as the phase progressed. In experts, the height in phase B significantly decreased from phase A, but the height between the control and phase A and between phases B and C were not different. The inter-group comparison demonstrated that the median height of the head in Phases B and C was significantly lower in the novices.

Figure 5 shows the typical height differences between the occipital region and the temporal regions on the YZ plane in the novices and experts, and the median values are shown in Table 2. Intra-group
Table 1. Range of the Center of Head Height during Tracheal Intubation

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Phase A</th>
<th>Phase B</th>
<th>Phase C</th>
<th>p value 1) (intra-group comparison)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experts (cm)</td>
<td>155.1‡</td>
<td>154.1‡</td>
<td>150.6‡†‡</td>
<td>151.2‡†‡</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td></td>
<td>[154.0—165.3]</td>
<td>[153.6—163.5]</td>
<td>[149.8—154.2]</td>
<td>[150.7—151.7]</td>
<td></td>
</tr>
<tr>
<td>Novices (cm)</td>
<td>170.0‡‡</td>
<td>159.1‡†‡</td>
<td>141.3‡†‡</td>
<td>135.6‡†‡</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td></td>
<td>[169.6—171.3]</td>
<td>[156.7—161.0]</td>
<td>[139.1—143.3]</td>
<td>[135.0—137.0]</td>
<td></td>
</tr>
</tbody>
</table>

p value 2) (inter-group comparison)

<0.01 0.602 <0.001 <0.001

Values are median and inter-quartile range.

1) compared with Friedman and Post-hoc test
2) p < 0.002 compared with control, † p < 0.001 compared with Phase A, ‡ p < 0.001 compared with Phase B
3) compared with Mann - Whitney U test

Figure 4. Typical trajectories of the head height change in the YZ plane by the novice and expert practitioners performing simulated intubation.

The head height of the novices began to lower from Phase A, and became even lower in B and C with fine vertical movements. The head height of the experts went down slightly, but there was no big change.

comparisons demonstrated that the median values were significantly different in both experts and novices, and the post-hoc test revealed that the median values significantly increased as the phase progressed. The inter-group comparison demonstrated that the median values in all phases were significantly higher in the novices. Furthermore, the differences between the maximum and minimum height of the head were significantly higher in novices in all the phases compared with those of experts.

The typical distribution of the gaze points of the subjects on the Y'Z' plane is shown in Figure 6. At all phases, the gaze points of the experts were significantly distant compared with those of the novices in...
**Figure 5.** Typical trajectories of the head tilt change in the YZ plane by the novice and expert practitioners performing simulated intubation. Both the novices and experts tilted their heads forward when intubating. However, the degree was large for the novices, and further shows a rattling movement.

**Table 2.** Range of the Difference of the Height of Markers between the Occipital Region and Temporal Region during Tracheal Intubation

<table>
<thead>
<tr>
<th></th>
<th>Phase A</th>
<th>Phase B</th>
<th>Phase C</th>
<th>p value (^1) (intra-group comparison)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experts (cm)</td>
<td>2.9(^1)</td>
<td>6.5(^*)</td>
<td>6.1(^*)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>[1.6 – 3.8]</td>
<td>[5.5 – 7.4]</td>
<td>[5.2 – 7.6]</td>
<td></td>
</tr>
<tr>
<td>Novices (cm)</td>
<td>6.4(^1)</td>
<td>9.3(^*)</td>
<td>8.4(^*)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>[5.9 – 6.7]</td>
<td>[8.9 – 10.3]</td>
<td>[8.1 – 9.7]</td>
<td></td>
</tr>
</tbody>
</table>

Values are median and inter-quartile range. Positive value means tilting the head forward.

\(^1\)compared with Friedman and Post-hoc test. \(^*\)p < 0.01 compared with Phase A, \(^\dagger\)p < 0.01 compared with Phase B

\(^\ddagger\)compared with Mann-Whitney U test

the Z’ axis (Z’: 55.2 vs. 40.3 cm, p < 0.001 for Phase A, 45.3 vs. 38.9 cm, p < 0.001 for Phase B, 46.0 vs. 44.3 cm, p < 0.001 for Phase C) (**Table 3**). The gaze points of the experts were significantly lower than those of the novices; the differences were particularly remarkable in Phases B and C (Y’: -13.0 vs. -6.0 cm, p < 0.001 for Phase A, -12.0 vs. -2.2 cm, p < 0.01 for Phase B, -12.9 vs. 7.5 cm, p < 0.01 for Phase C) (**Table 3**).

**Discussion**

We found that there were significant differences in the head movements and gaze distribution during tracheal intubation in the three phases (intra-group)...
Figure 6. Gaze distribution for each phase in the Y’Z’ plane by the novice and expert practitioners performing simulated intubation. The gaze of the experts was downward with little variation in all phases. In contrast, the gaze of the novices was dispersed and upward in Phases B and C.

and in both the experts and novices (inter-group) by using both motion capture system and eye-tracking system. To the best of our knowledge, this is the first study to analyze gaze distribution and head posture at the same time in each phase of tracheal intubation.

The changes in head height during tracheal intubation were statistically significant in the experts. However, the differences were very small, within 5 cm. The changes in the height differences between the occipital and temporal regions were also statisti-
Table 3. Distribution of Gaze Point of Novice and Expert Intubation Practitioners on Y’ Axis and Z’ Axis

<table>
<thead>
<tr>
<th>Phase</th>
<th>Y’ axis</th>
<th>Z’ axis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Experts (cm)</td>
<td>Novices (cm)</td>
</tr>
<tr>
<td></td>
<td>-13.0 [20.5−6.3]</td>
<td>-12.9 [19.0−8.4]</td>
</tr>
<tr>
<td></td>
<td>-12.0 [15.1−8.8]</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>-12.9 [19.0−8.4]</td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td>-6.0</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>2.2</td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td>7.5</td>
<td>12.2</td>
</tr>
</tbody>
</table>

Values are median and inter-quartile range. Positive value means tilting the head forward.

1)compared with Mann-Whitney U test

This course indicates that the experts tilted their head slightly forward during mouth opening to see the face of the mannequin (Phase A), leaned a little more during the manipulation of the Macintosh laryngoscope to see the vocal cords (Phase B), and then kept their head position until tracheal intubation was completed (Phase C). It is natural to look down at the beginning of tracheal intubation because the patient (mannequin) is lying on a bed lower than the practitioner’s head and to look down a little more to see deeper, the oral cavity and the vocal cords during Phases B and C. It can be said that experts move their head after opening the patient’s mouth, but thereafter perform tracheal intubation in a substantially constant posture.

Similar to the experts, there were statistically significant differences in the fluctuations of both the height of the head and the height differences between the occipital region and the temporal regions during tracheal intubation in the novices. However, the degrees and patterns were quite different. The novices lowered their head and turned their face down much more than the experts as the phases progressed. The novices lowered their head approximately 10 cm from the control to Phase A.

However, this result should be carefully considered, since the height of the head of the novices was significantly higher in the control, but not different in Phase A. Thus the head movement at the beginning of tracheal intubation in the novices can be considered in two ways. First: 1) the novices moved down their head more down during mouth opening, and 2) the taller novices lowered their heads to a level similar to the experts’ head. Therefore, it is difficult to draw an assertive conclusion in this phase. After mouth opening, the novices continued to lower their heads and face downward; that is, they were keeping their faces close to that of the mannequin.

As described above, it can be said that the experts maintained a substantially constant posture, but the novices continued to lower their heads and faces during tracheal intubation. Our previous analysis with the same dataset indicated that the novices showed rattling of the laryngoscope, which was defined as the “jagged pattern”, during tracheal intubation1). Therefore, we assume that the immature hand skill of novices is a possible reason behind the difference in the postures during tracheal intubation. Differences in height between the experts and novices and the fixed height of the table could affect these head dynamics. However, we think that the fixed height of the table might mitigate the difference in the influence of the height of head. In a skilled laryngoscopic maneuver by an expert, the field of view of the vocal cords is constant in a cer-
tain space before the practitioner, and the practitioner places the head within this space to see the vocal cords regardless of their own height and the height of table. Therefore, the height of head from the ground in the experts was within a narrow range.

Our findings are in accordance with intubation instructional textbooks and the results of studies using other methods. Based on the consideration of clinical observation, Whitten reported that the typical novices mistakenly hunch close to the patient, bend their elbow completely, and place their right eye practically in the patient’s mouth. Grundgeiger et al. measured the angles of body parts of novices and experts during tracheal intubation of a training mannequin and reported that novices showed significantly more deflection for the trunk (19° vs. 5°) and neck (39° vs. 30°), and more extended upper arms (38° vs. 19°) than experts. Matthews and colleagues filmed novices and experts intubating the trachea of a training mannequin and found that the median distance from the nose of a subject to the chin of mannequin in the experts was significantly greater (43 cm vs. 35 cm), that is, the novices tended to crouch, with their head closer to the mouth, and the experts stood back during tracheal intubation. Using a motion capture system, Sakakura et al. reported that the novices potentially exhibited significantly higher acceleration values at the head and the left hand compared to the expert practitioners who commanded smoother motions with both the head and left hand using a 3-axis digital gyroscope, accelerometer, and magnetometer.

Here, the gaze distributions were completely different between the novices and experts. Gaze depth analysis indicated that the experts saw significantly further on the Z’ axis, and the differences were significant. This gaze distribution could be closely related to the result that the novices crouched and brought their face close to the mannequin. Analysis of vertical gaze distribution revealed that the novices turned the vertical gaze direction after mouth opening and looked up the Y’ axis. In contrast, the experts kept looking below the Y’ axis during tracheal intubation. The differences in the gaze are considered to be due to the influence of their postures. It might be natural that the novices were obliged to look upward after mouth opening because they crouched and brought their face closer to the mannequin when they started to use the Macintosh laryngoscope. In experts, the results that they kept looking downward during tracheal intubation can be thought to reflect the fact that they intubated without lowering their heads and the face too much. Walker measured photographs during intubation training with a mannequin and demonstrated that a lower line of sight caused by the levering laryngoscope, in turn, requires a reduction in height on the part of the practitioner, and the less experienced group compensated with their upper body, by stooping and bringing their face closer to the patient. Although there are differences between photographs and our video analysis, this result is consistent with ours.

The results of this study will be beneficial for both trainers and trainees in tracheal intubation training. Most textbooks do not mention the practitioner’s posture, head position, and eye movements, and senior doctors tend to teach according to their sense in the actual scene. We believe that the observed differences in the head movement must be a key for a trainer in developing a teaching policy that does not rely on feeling alone and for a trainee to be aware of their posture and head position in tracheal intubation training. Then, keeping a constant head height without lowering the head too much results in a downward gaze of the eyes.

Our study had several limitations. First, the sample size was relatively small, and whether the results can be generalized remains unclear. In addition, we defined practitioners with a certain amount of experience as experts, but there is no proof that their tracheal intubation posture or gaze distribution is excellent. Second, taller control heights of novices may affect the head height, but this time it was not possible to control for their height. However, despite the taller control height, the heads of novices were much lower in Phases B and C, which emphasized the change in posture. Third, our experiments were conducted in a simulated environment using a mannequin. Simulation studies differ from the environment in the actual operating room and may have affected the practitioners’ performance, especially for the novice practitioners. Implementation of the approach in patients under general anesthesia in the operating room is required to clinically validate the current results. Fourth, the experiments were conducted on a table with a fixed height, which may have affected the head movement. But, because it is not always possible to select the height at the time of intubation in clinical practice, especially outside the operating room, we think that the non-optimal height of the table is not far from the clinical practice. Finally, the movements were analyzed only in the YZ or Y’Z’ plane; tracheal intubation is a three-dimensional movement, and movements in the other planes may
affect the results. Further studies are needed to analyze the movement pattern in three dimensions.

In conclusion, during intubation, novices move their head and their gaze is in the upward direction; in contrast, experts hardly move their head, and their gaze is almost constant in the downward direction. If these differences are indicators of skill in tracheal intubation, it may be useful to teach posture and gaze direction during tracheal intubation education in clinical settings. Analysis using motion capture systems and eye-tracking systems will play an important role in future medical education.

Acknowledgments

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Conflicts of Interest

The authors have nothing to disclose.

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