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Dynamic Interaction of Craniofacial Structures during Head Positioning and Direct Laryngoscopy in Anesthetized Patients with and without Difficult Laryngoscopy

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Background: **We lack fundamental knowledge of the mechanisms of difficult laryngoscopy despite its clinical significance. The aim of this study was to examine how head positioning and direct laryngoscopy alter arrangements of craniofacial structures.**

Methods: **Digital photographs of the lateral view of the head and neck were taken at each step of head positioning and direct laryngoscopy in age– and body mass index–matched patients with (n = 13) and without (n = 13) difficult laryngoscopy during general anesthesia with muscle paralysis. The images were used for measurements of various craniofacial dimensions.**

Results: **Both simple neck extension and the sniffing position produced a caudal shift of the mandible and a downward shift of the larynx, resulting in an increase of the submandibular space. Direct laryngoscopy during the sniffing position displaced the mandible and tongue base upward and caudally, and the larynx downward and caudally, increasing the submandibular space and facilitating vertical arrangement of the mandible, tongue base, and larynx to the facial line. These structural arrangements in response to direct laryngoscopy were not observed in patients with difficult laryngoscopy, whereas head positioning produced similar structural arrangements in patients with and without difficult laryngoscopy.**

Conclusion: **Increase in the submandibular space and a vertical arrangement of the mandible, tongue base, and larynx to the facial line seem to be important mechanisms for improving the laryngeal view during head positioning and direct laryngoscopy. Failure of these structural arrangements in response to direct laryngoscopy may result in difficult laryngoscopy.**

ESTABLISHMENT of clear glottic visualization is of great significance for successful tracheal intubation. A meta-analysis performed by Shiga *et al.* [1] indicates that direct laryngoscopy can be difficult in 5.8% of the general anesthesia population. Difficulty or failure in tracheal intubation by direct laryngoscopy is a major and life-threatening complication during anesthesia induction and emergency resuscitation.[2,3] Despite these clinical significances, overall fundamental knowledge of the mechanisms of difficult laryngoscopy is insufficient.

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The aim of direct laryngoscopy is to visualize the vocal cords through the originally curved, oral airway space. Proper head positioning and successful laryngoscopy shifts the craniofacial structure arrangements to make proper visualization of the vocal cords possible. Difficult laryngoscopy is, therefore, a possible resultant of incomplete structural arrangements during the process of head positioning and direct laryngoscopy. Accordingly, this controlled, nonrandomized, observational study was undertaken to examine how head positioning and direct laryngoscopy alter craniofacial arrangements and to compare the dynamic structural interactions during laryngoscopy between age– and body mass index–matched patients with and without difficult laryngoscopy.

Materials and Methods

The study was approved by our ethics committee (Graduate School of Medicine, Chiba University). The aim and potential risks associated with direct laryngoscopic procedure were fully explained, and written informed consent was obtained from each individual.

Subjects

The study consisted of 13 consecutive patients presenting for difficult laryngoscopy, defined as the best laryngeal view of Cormack and Lehane grade 3 without external laryngeal pressure during direct laryngoscopy (difficult laryngoscopy [DL] group), and 13 consecutive patients with easy laryngoscopy, defined as the best laryngeal view of Cormack and Lehane grade 1 without external laryngeal pressure (easy laryngoscopy [EL] group). We first recruited 15 patients with potentially difficult laryngoscopy indicated by multiple positive predictors such as Mallampati class 3 and 4, thyromental distance less than 65 mm, and small or receding mandible.[1] Laryngoscopy was difficult in 13 and easy in 2 patients, and these 2 patients were assigned to the EL group. An additional 11 patients without narrow submandibular space and small or receding mandible matching the age, sex, and body mass index of the DL group patients were recruited as candidates for the EL group, and laryngoscopy was easy in these patients, as expected. All were scheduled to undergo elective surgeries

Table 1. Anthropometric Characteristics and Results of Preoperative Airway Assessment for Patients with Difficult Laryngoscopy (DL Group) and without Difficult Laryngoscopy (EL Group)

	EL Group	DL Group
Age, yr	64 (32–70)	64 (38–69)
Sex, M/F	10/3	9/4
Height, m	1.63 (1.54–1.72)	1.67 (1.50–1.73)
Weight, kg	65.0 (53.7–68.2)	65.0 (46.9–72.6)
Body mass index, kg/m^2	23.1 (21.1–26.3)	23.3 (18.1–25.1)
Mallampati class	2 (1–3)	3 (2–3)
Interincisor distance, mm	50 (44–60)	45 (39–57)*
Thyromental distance, mm	85 (62–95)	70 (60–80)*
Cormack and Lehane grade	1	3

Values are median (10th–90th percentiles).

* $P < 0.05$ *vs.* EL group.

during general anesthesia by tracheal intubation. Patients with craniofacial anomaly and limitation of head extension were excluded from this study. Anthropometric characteristics and preoperative airway assessments for each group are presented in table 1.

Preparation of the Subjects

Each subject was initially premedicated with 0.5 mg atropine intramuscularly. The study was performed with the subjects in a supine position, on an operating table. General anesthesia was induced with intravenous administration of 3–4 mg/kg thiopental sodium. Intravenous administration of muscle relaxant (0.2 mg/kg vecuronium) induced complete paralysis throughout the experiment. Anesthesia was maintained by inhalation of 2–4% sevoflurane while positive-pressure mask ventilation using an anesthetic machine was performed. Oxygen saturation, electrical activity of the heart, and blood pressure were continuously monitored.

Experimental Procedures and Measurements

Digital photographs of the lateral view of the head and neck of the subject (COOLPIX4500; Nikon, Tokyo, Japan) were taken under the following five conditions:

1. Neutral position: No pillow was placed under the head, with the face straight up.
2. Simple neck extension: The head was maximally extended, without a pillow under the head.
3. Sniffing position: Three pillows were placed under the head, with the head straight up or slightly extended.
4. L3: A laryngoscope blade (Macintosh No. 3) was inserted and placed to first achieve Cormack and Lehane grade 3 laryngeal view.
5. Lmax: Maximum arm force was applied to achieve best laryngeal view.

Conditions 1–3 (head positions) and conditions 4–5 (laryngoscopic procedures with Macintosh No. 3) were separately performed during 2–3 min of apneas. Positive-pressure ventilation was resumed immediately after conditions 3 and 5. All measurements were completed within 10 min before surgery. Measurements were terminated when oxygen saturation decreased to 97%. The height of the camera lens was adjusted at the level of the ear canal in the control position. Staff anesthesiologists in our department with experience of more than 500 direct laryngoscopies and anesthesia practice of more than 3 yr positioned the head and performed laryngoscopy without any previous knowledge of the purposes of this study. The thyroid notch was identified (fig. 1, L) and pointed at with an indicator by one of the authors for each condition.

Measurements of Craniofacial Dimensions

Figure 1 presents an example of the lateral photograph during laryngoscopy to first achieve Cormack and Lehane grade 3 view (L3 condition) in a subject of the EL group. Anatomical landmarks were identified and connected for the purpose of angle and distance measurements as illustrated in figure 1. Three lines were drawn for assessment of lower neck flexion on the chest (α:

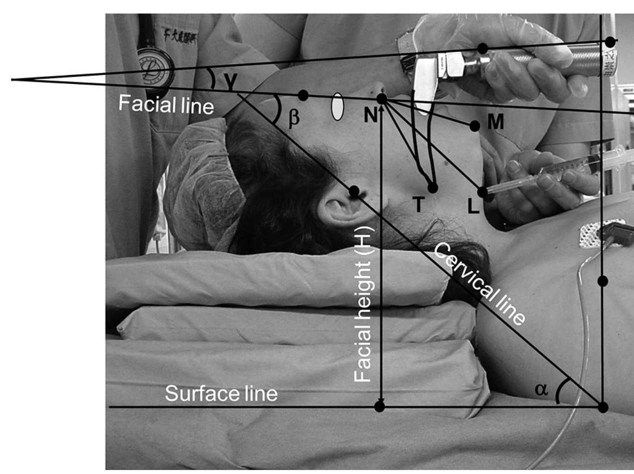

Fig. 1. An example of lateral photograph during direct laryngoscopy presenting anatomical landmarks and definitions of craniofacial dimensions. Definitions of the three lines: cervical line = line that connects the earlobe and a point of intersection between the surface of the operating table and a perpendicular line through the armpit; facial line = line that connects the stem of the ala nasi (N) and the eyebrow; surface line = surface of the operating table. Definitions of the angles formed by the lines: lower neck flexion angle (α) = angle between the cervical line and the surface line; upper neck extension angle (β) = angle between the cervical line and the facial line. Laryngoscope angle (γ) = angle between the facial line and the axial line of the laryngoscope handle. Facial height = distance between the point N and the surface line. Definitions of the landmarks: point L = thyroid notch; point M = mandibular mentum; point N = stem of ala nasi; point T = tip of the laryngoscope blade corresponding to the base of the tongue. Craniofacial dimensions determining location of the anatomical landmarks: angle L = angle between the facial line and NL line; angle M = angle between the facial line and NM line; angle T = angle between the facial line and NT line, distances between points N and M, L and T. Distance ML is considered to be a two-dimensional estimate of the submandibular space.

angle between the surface line and cervical line) and upper neck extension (β: angle between the cervical line and facial line). We chose the mandibular mentum (point M) and thyroid notch (point L) as significant landmarks for assessment of their original locations and dynamic movements during head positioning and direct laryngoscopy because the distance of these structures (*i.e.*, thyromental distance) is significantly associated with difficult tracheal intubation. Distance ML was considered to be a two-dimensional estimate of the submandibular space. Rotation of the laryngoscope during direct laryngoscopy was assessed by the angle (γ) between the facial line and the axial line of the laryngoscope handle. The location of the tip of the laryngoscope blade (point T) was determined by the size of laryngoscope blade and angle of the laryngoscope handle. We considered that point T corresponds to the tongue base, which can interfere with the laryngeal view during direct laryngoscopy. Relative movements of these anatomical landmarks were plotted on the two-dimensional coordinates defined by the stem of the ala nasi (point N) as the origin and the facial line as an axis (fig. 2). Anatomical landmarks were located on the coordinates using median values of the distances from the nose and the angles from the facial line. Movements parallel to the facial line denote cranial or caudal movement, and vertical movements to the facial line denote upward or downward movement. Laryngoscope size was used to obtain absolute distance values, and ear length was used as a conversion factor for the head positioning photographs.

Statistical Analyses

To determine the sample size for this clinical study, data from the similar structural measurement study performed by Adnet *et al.*[4] were used. Angular changes between craniofacial structures in response to head positioning varied from 18° to 24° with a maximum SD of 13°. The sample size was determined assuming $\alpha = 0.05$ and 80% power, and an expected angle difference of 18° with an expected SD of 13° (SigmaStat 3.1; Systat Software Inc., Point Richmond, CA). We calculated that nine or more patients were required to detect the difference. To minimize type I error and increase the effect size, all variables were compared between two distinct patient groups based on the laryngeal view during direct laryngoscopy (grades 1 and 3) without including patients with grade 2.

Statistical differences among the head positions were assessed by repeated-measures analysis of variance on ranks, and a multiple comparison was performed through the Tukey test (SigmaStat 3.1). Statistical differences between L3 and Lmax during direct laryngoscopy were assessed by Wilcoxon signed rank test. Differences between the groups were assessed by Mann–Whitney rank sum test. Spearman correlation analyses were performed between preoperative airway assessments for predicting difficult intubation such as Mallampati classification, interincisor distance, and thyromental distance and craniofacial dimensions at Lmax during laryngoscopy. Nonparametric statistics were used because of violation of normality in some variables. $P < 0.05$ was considered to be significant. All variables are presented as median (10th–90th percentiles).

Results

Anthropometric characteristics and results of preoperative airway assessment are presented in table 1 for each

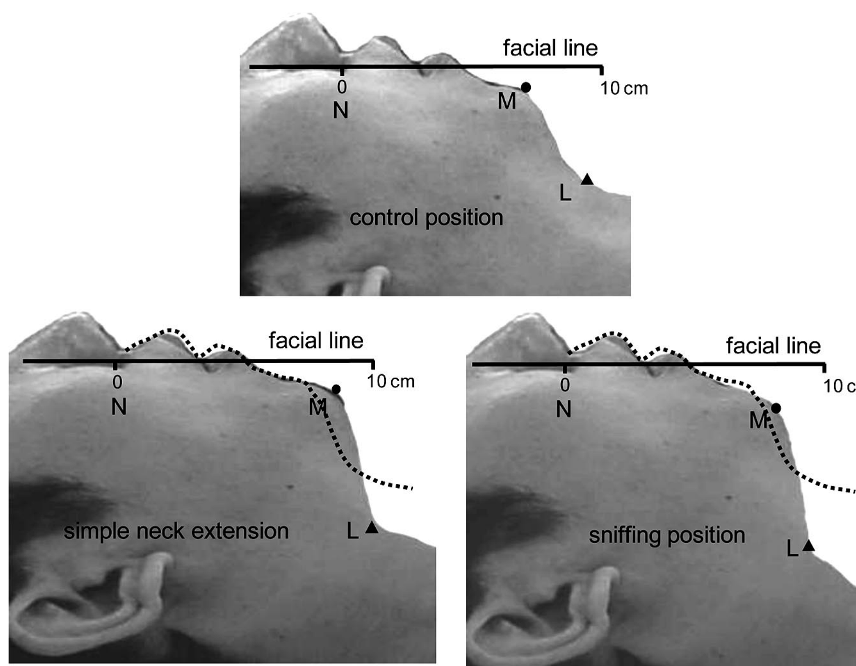

Fig. 2. Relative positions of the mandible (M; *closed circles*) and larynx (L; *closed triangles*) to the nose (N: zero) and the facial line in neutral, simple neck extension, and sniffing positions in patients without difficult laryngoscopy. Background profiles were artificially produced by graphic software (Adobe Photoshop CS2; Adobe Systems Inc., San Jose, CA) so that three anatomical landmarks were on the profiles. *Dotted lines* represent the profile during the neutral position.

Table 2. Influences of Head Positioning and Direct Laryngoscopy on Craniofacial Dimensions in Patients with Difficult Laryngoscopy (DL Group) and without Difficult Laryngoscopy (EL Group)

Parameter	Group	Neutral Position	Simple Neck Extension	Sniffing Position	L3	Lmax
Angle M,°	EL	6 (−5 to 12)	7 (−7 to 19)	12 (3–21)*	10 (2–20)*	6 (−2 to 19)
	DL	6 (−5 to 14)	13 (1–18)	11 (5–20)*	11 (5–22)*	12 (7–21)*
Submandibular space: ML, cm	EL	4.4 (3.6–6.2)	6.2 (5.6–7.9)*	5.7 (4.8–7.5)*	6.6 (5.8–7.0)*	7.5 (5.9–8.2)*†
	DL	4.3 (3.7–5.7)	5.9 (5.0–9.3)*	5.7 (4.7–7.6)*	5.9 (5.1–7.5)*	6.6 (5.1–8.0)*
Angle T,°	EL	NA	NA	NA	49 (46–53)	43 (42–46)†
	DL	NA	NA	NA	54 (52–57)‡	51 (48–58)†‡
Laryngoscope angle: γ,°	EL	NA	NA	NA	18 (12–22)	24 (19–29)†
	DL	NA	NA	NA	10 (7–14)‡	13 (11–16)†‡

Definitions of craniofacial dimensions are presented in figure 1. Values are median (10th–90th percentiles).

* $P < 0.05$ *vs.* neutral position. † $P < 0.05$ *vs.* L3. ‡ $P < 0.05$ *vs.* EL group.

L3 = time during direct laryngoscopy when Cormack and Lehane grade 3 laryngeal view was first achieved; Lmax = time during direct laryngoscopy when the maximum arm force was applied to the laryngoscope blade; NA = not applicable.

group. Age, sex, and body mass index did not differ between the groups. Patients with difficult laryngoscopy had shorter thyromental and interincisor distances compared with those without difficult laryngoscopy.

Influences of Head Positions on Craniofacial Dimensions in the EL Group

Placement of three cushions under head produced 7 cm of head elevation, 35° of lower neck flexion on the chest (α), and 32° of upper neck extension (β) during the sniffing position (appendix 1). Simple neck extension produced 44° of upper neck extension (β) without changing the lower neck flexion angle (α). The mandible moved downward during the sniffing position (angle M), whereas positions of the mandible (angle M and NM) and larynx (angle L and NL) relative to the facial line and nose did not differ between simple neck extension and the sniffing position (table 2 and appendix 1). As illustrated in figure 2, arrangement of the mandible and larynx became more vertical to the facial line during both simple neck extension and the sniffing position, increasing the submandibular space (ML) compared with the neutral position.

Influences of Direct Laryngoscopy on Craniofacial Dimensions in the EL Group

Successful direct laryngoscopy during the sniffing position significantly increased both the upper neck extension angle (β) and the lower neck flexion angle (α), further augmenting head and neck arrangement produced by the sniffing position (appendix 2). As clearly illustrated in figure 3 (left), direct laryngoscopy shifted the mandible (angle M and NM) and tongue base (angle T and NT) upward and caudally, whereas the larynx (angle L and NL) was displaced downward and caudally (table 2 and appendix 2). As a result, the vertical arrange-

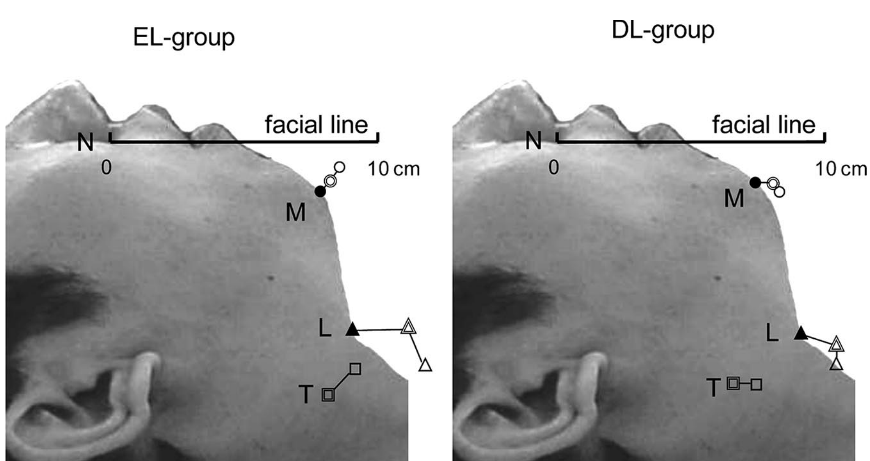

Fig. 3. Relative positions of the mandible (M; *circles*), larynx (L; *triangles*), and tongue base (T; *squares*) to the nose (N: zero) and the facial line during direct laryngoscopy in patients without difficult laryngoscopy (EL group; *left*) and patients with difficult laryngoscopy (DL group; *right*). *Closed symbols* represent positions during sniffing position before direct laryngoscopy. *Symbols with double lines* represent positions at L3 (time during direct laryngoscopy when Cormack and Lehane grade 3 laryngeal view was first achieved). *Open symbols* represent positions at Lmax (time during direct laryngoscopy when the maximum arm force was applied to the laryngoscope blade). Background profiles were artificially produced by graphic software (Adobe Photoshop CS2; Adobe Systems Inc., San Jose, CA) so that three anatomical landmarks (M, L, and N) during the sniffing position were on the profiles.

ment of the structures such as the mandible, tongue base, and larynx to the facial line was facilitated during laryngoscopy, further increasing the submandibular space (ML) (table 2 and fig. 3).

Differences of Structural Movements between the Groups

All craniofacial dimensions presented in table 2 and appendix 1 did not differ between the EL and DL groups in response to simple neck extension and sniffing position. Both head positions increased submandibular space (ML) and facilitated vertical arrangement of the mandible and larynx.

As indicated by significantly greater angles T in DL patients, the tongue base located more cranially in DL patients than in EL patients when Cormack and Lehane grade 3 laryngeal view was first achieved (L3 condition). The laryngoscope handle was more parallel to the facial line at L3 in DL patients as indicated by significant group difference of γ angle. As illustrated in figure 3, structural movements during direct laryngoscopy were less obvious in DL patients than in EL patients. Direction of the laryngeal movements (angle L and NL) were essentially the same between the groups, whereas upward movements of the mandible (angle M) and tongue base (angle T) were not observed in the DL group. As a result, the submandibular space (ML) did not increase, and the vertical arrangement of structures such as the mandible, tongue base, and larynx to the facial line was not facilitated during direct laryngoscopy in DL patients. The tongue base remained more cranially and the laryngoscope handle remained more parallel to the facial line at Lmax in DL patients, as indicated by significant group differences of angles T and γ.

Association between Preoperative Airway Assessments and Dynamic Craniofacial Dimensions during Direct Laryngoscopy

Table 3 presents results of the correlation analyses between clinically established preoperative airway assessments for predicting difficult intubation and craniofacial dimensions at Lmax during direct laryngoscopy. It is of particular interest that short thyromental distance was significantly associated with narrow submandibular space (ML) produced during laryngoscopy, and less movement of the mandible (angle M) and tongue base (angle T).

Table 3. Results of Spearman Correlation Analyses between Clinically Established Preoperative Airway Assessments (Mallampati Classification and Others) and Our Craniofacial Dimensions during Direct Laryngoscopy

Craniofacial Dimension at Lmax	Mallampati	IID	TMD
Angle M	0.478*	−0.383	−0.475*
Submandibular space: ML	0.206	0.114	0.443*
Angle T	0.199	−0.303	−0.583*
Laryngoscope angle: γ	−0.133	0.501*	0.533*

Definitions of craniofacial dimensions are presented in figure 1. Values are correlation coefficients.

* $P < 0.05$.

IID = interincisor distance; Lmax = time during direct laryngoscopy when the maximum arm forces were applied to the laryngoscope blade; TMD = thyromental distance.

Discussion

Dynamic interaction between craniofacial structures during head positioning and direct laryngoscopy was investigated in age– and body mass index–matched patients with and without difficult laryngoscopy. Head positioning and direct laryngoscopy facilitated vertical arrangement of the mandible, tongue base, and larynx increasing submandibular space. Relative positions of these structures did not differ between simple neck extension and the sniffing position in both DL and EL patients. Tongue base was located more cranially in DL patients than in EL patients. In response to direct laryngoscopy, upward movements were not observed in the mandible and tongue base in DL patients unlike movements in EL patients, impairing vertical arrangement of the structures and increase of submandibular space.

Roles of Head Positioning in Direct Laryngoscopy

Numerous previous studies evidenced improvement of laryngeal view during direct laryngoscopy by proper head positioning.[5–7] Nevertheless, few studies systematically assessed structural changes due to head positioning.[4,8] These studies limited measurements of head and neck angles and did not evaluate positions of the mandible and larynx. This study was conducted under the belief that dynamic movements of craniofacial structures during head positioning and direct laryngoscopy will improve our understanding of the mechanisms of direct laryngoscopy. "Obstacle theory," proposed by Isono,[9] suggests that two groups of obstacles between our eyes and the vocal cords can impair the laryngeal view during direct laryngoscopy: obstacles located posterior to the oral airway (upper teeth, maxilla, nose, head, and others) and obstacles located anterior to the oral airway (tongue, epiglottis, mandible, and others) (fig. 4). Proper head positioning should, therefore, displace these obstacles out of the operator's view. Caudal movement of the mandible observed in this study increases the distance between anterior and posterior obstacles. Caudal movement of the mandible and downward movement of the larynx facilitate the vertical arrangement of anterior obstacles and the larynx to the facial line and increase the submandibular space. Only a small difference in the relative arrangements of the obstacles and the larynx was found between simple neck extension and sniffing position. This may account for the finding of Adnet *et al.*,[10] which states that laryngeal view and performance

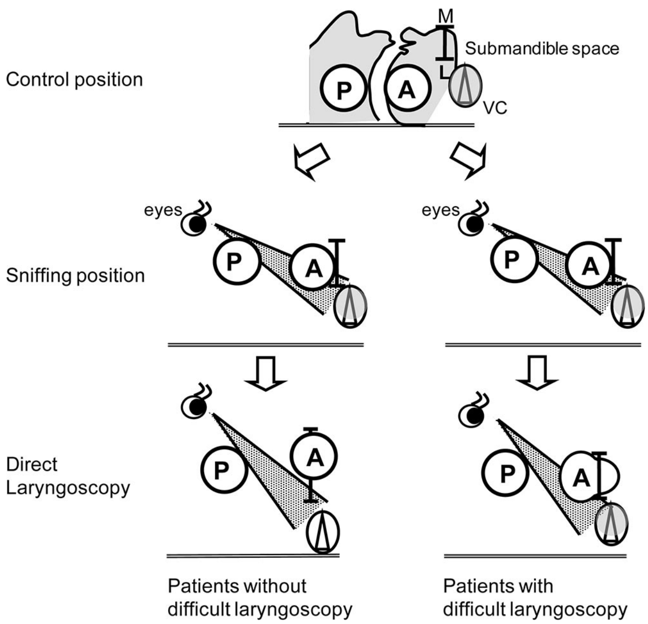

Fig. 4. Schematic explanation of dynamic changes of structural arrangements during head positioning and direct laryngoscopy in patients without difficult laryngoscopy and in patients with difficult laryngoscopy. A = structures anterior to the oral airway (anterior obstacles: tongue, epiglottis, mandible, and others); L = larynx; M = mandible; P = structures posterior to the oral airway (posterior obstacles: upper teeth, maxilla, head, and others); VC = vocal cords. Submandibular space defined as space between M and L is shown by the *vertical line*. The *double lines* on the bottom of each figure are parallel to the facial line. Note that the sniffing position produces vertical arrangement of the anterior obstacles and vocal cords to the facial line and increases in the submandibular space in patients with and without difficult laryngoscopy. Further increase in the submandibular space during direct laryngoscopy allows displacement of the anterior obstacles through it in patients without difficult laryngoscopy. However, failure of the further increase in the submandibular space during direct laryngoscopy impedes displacement of the anterior obstacles through it and the operator's view to the glottis in patients with difficult laryngoscopy.

of direct laryngoscopy do not differ between head positions. We achieved 7 cm of head elevation and 35° of neck flexion on the chest during the sniffing position in this study, in accord with the endpoint for the sniffing position.[11] Although these results indicate comparable effectiveness between simple neck extension and the sniffing position, it is possible that the sniffing position with the head maximally elevated further facilitates vertical arrangement of the anterior obstacles and larynx and is advantageous over simple neck extension for improvement of the laryngeal view, as recently demonstrated in patients with difficult laryngoscopy.[12]

Action of Direct Laryngoscopy

The results of this study are in accord with those reported by Horton *et al.*[8,13] They demonstrated increases in upper neck extension and lower neck flexion during laryngoscopy, using an "angle finder," in anesthetized adult persons.[8] They further observed caudal and downward movement of the hyoid body on lateral neck radiograph during direct laryngoscopy in awake adults.[13] The mandible was displaced to the direction of pull on the laryngoscope handle, suggesting that caudal and upward movement of the mandible as was observed in this study. We confirmed their findings and clarified dynamic interactions among the craniofacial structures during direct laryngoscopy. Caudal and upward movements of the mandible and tongue base increase the distance between anterior and posterior obstacles (fig. 3). Diverging movements of the larynx and mandible further facilitate the vertical arrangement of the anterior obstacles and the larynx, bringing the vocal cords into the operator's view. Accordingly, an increase of the submandibular space may be essential for caudal movements of anterior obstacles, allowing vertical arrangement of the anterior obstacles and larynx.

Mechanisms of Difficult Laryngoscopy

Responses to head positioning did not differ between DL and EL patients, indicating that mechanisms of difficult laryngoscopy unlikely relate to head positioning, whereas it is a necessity for obtaining a better laryngeal view in both patient groups. Our results indicate inadequate movements of the anterior obstacles during direct laryngoscopy in DL patients. Direction of the mandible movement was similar to the laryngeal movement, and no diverging movement was observed (fig. 3). The mechanisms of incomplete arrangements of craniofacial structures may be multifactorial and were not addressed in this study. It is, however, notable that no increase of submandibular space was observed in DL patients, which may result in limiting movements of the anterior obstacles through the submandibular space (fig. 4). Because of incompressibility of the anterior obstacles within the mandibular enclosure, the obstacles impede the operator's view to the glottis. Significant association between the submandibular space during direct laryngoscopy and thyromental distance may support this speculation. Alternatively, unfavorable structural arrangements as indicated by cranially located tongue base and/or reduced mobility of the craniofacial structures may be involved in the mechanisms. Clearly, future studies must be designed to assess structural properties and interaction during direct laryngoscopy in more detail.

Clinical Implications of the Findings

The vertical arrangement of anterior obstacles and the larynx to the facial line with submandibular space increase seems to be the fundamental structural arrangement necessary for improving the laryngeal view during direct laryngoscopy. Both simple neck extension and the sniffing position are equally effective for structural arrangements in accordance with the magnetic resonance imaging study performed by Adnet *et al.*[4] To our knowledge, no study has demonstrated any disadvantages of the sniffing position as a head position for induction of general anesthesia; rather, an advantage of the sniffing position over simple neck extension has been reported in obese persons and persons with limited neck movement.[10] Successful mask ventilation is required to oxygenate before intubation, and our previous investigations of pharyngeal collapsibility in anesthetized patients with obstructive sleep apnea indicated that the sniffing position decreased pharyngeal collapsibility more than simple neck extension.[14,15] Accordingly, we believe that the sniffing position is an optimal standard head position during induction of general anesthesia.

Our results suggest that any maneuvers that produce vertical arrangement of anterior obstacles and larynx with increasing submandibular space can improve the laryngeal view during direct laryngoscopy. In fact, laryngeal manipulations such as the BURP (backward, upward, rightward pressure) maneuver of the larynx,[16] OLEM (optimal external laryngeal manipulation),[17] and cephalad displacement of the larynx[18,19] shift the larynx downward and cranially, thus improving the laryngeal view. Recently, Tamura *et al.*[20] reported improvement of the laryngeal view by advancing the mandible upward.

Short thyromental distance is a well-established predictor for difficult tracheal intubation.[21] However, surprisingly, there have been no studies investigating the mechanisms of contribution of short thyromental distance to difficult tracheal intubation. Our results suggest that short thyromental distance limits expansion of submandibular space and disturbs the vertical arrangement of the anterior obstacles and vocal cords during direct laryngoscopy. Longer thyromental distance was also associated with difficult tracheal intubation,[22,23] which may be due to the failure of obtaining the vertical arrangement of anterior obstacles and vocal cords rather than to a narrow submandibular space.

Limitations of the Study

This was an observational, prospective study of the ease of direct laryngoscopy and identification of the vocal cords in patients whose airways were predetermined to be potentially difficult or easy using clinical determinants. Accordingly, patient selection may have introduced bias into the study design.

We recently reported that systemic evaluation of facial appearance by use of digital photographs revealed significant difference between patients with and without difficult intubation,[24] suggesting potential usefulness of photographs for analyzing and detecting dynamic changes of head and neck structures during direct laryngoscopy as a first step for understanding mechanisms of difficult laryngoscopy. However, analysis was limited because the photographs captured only two dimensions of the three-dimensional craniofacial structures, and measurements that were restricted to the skin surface did not account for underlying bony and soft tissue differences. Based on the results of this study, future studies should be directed to precisely assess movements of the mandible, tongue base, and larynx and interaction of these key structures with head and neck movements during direct laryngoscopy and tracheal intubation. Magnetic resonance imaging or lateral neck fluoroscopy may be appropriate for this purpose.[25]

Forces applied to the laryngoscope were not measured and controlled in this study, whereas the forces may vary depending on the head positions[26] and among the operators.[27] Furthermore, the results might have differed with different laryngoscope blade sizes (Macintosh No. 2 or 4) and types (Miller).[28,29] In addition to the technical limitations, it should be also noted that the mechanisms of difficult tracheal intubation including process of endotracheal tube insertion were not examined in this study. Although it was beyond the scope of this study to test and control these confounding factors, we examined the most common problem such as impaired laryngeal view during direct laryngoscopy with the most commonly used size and type of Macintosh blade in this clinical study.

In conclusion, increase in submandibular space and a vertical arrangement of the mandible, tongue base, and larynx to the facial line seem to be a significant mechanism for improvement of laryngeal view during head positioning and direct laryngoscopy. Failure of these structural arrangements in response to direct laryngoscopy may result in difficult laryngoscopy.

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Appendix 1: Influences of Head Positions on Craniofacial Dimensions in Patients with Difficult Laryngoscopy (DL Group) and without Difficult Laryngoscopy (EL Group)

Parameter	Group	Neutral Position	Simple Neck Extension	Sniffing Position
Lower neck flexion angle: α,°	EL	20 (13–24)	23 (16–26)	35 (30–38)*†
	DL	20 (14–25)	22 (11–27)	38 (30–41)*†
Upper neck extension angle: β,°	EL	29 (21–35)	44 (37–59)*	32 (25–40)†
	DL	22 (18–31)	49 (27–54)*	31 (28–35)*†
Facial height, cm	EL	20 (15–22)	21 (15–25)	27 (23–31)*†
	DL	20 (15–22)	19 (16–23)	26 (22–31)*†
Ala nasi to mandible distance: NM, cm	EL	7.0 (5.8–8.6)	8.5 (6.9–10.2)*	8.1 (6.6–9.2)*
	DL	6.8 (6.1–8.0)	7.6 (7.1–9.2)*	7.6 (6.6–8.4)*
Ala nasi to larynx distance: NL, cm	EL	10.4 (8.6–12.2)	11.7 (10.6–14.4)*	11.6 (9.9–14.0)*
	DL	10.1 (9.2–12.8)	12.6 (11.0–16.0)*	11.7 (10.2–13.5)*†
Submandibular space: ML, cm	EL	4.4 (3.6–6.2)	6.2 (5.6–7.9)*	5.7 (4.8–7.5)*
	DL	4.3 (3.7–5.7)	5.9 (5.0–9.3)*	5.7 (4.7–7.6)*
Angle M,°	EL	6 (−5 to 12)	7 (−7 to 19)	12 (3–21)*
	DL	6 (−5 to 14)	13 (1–18)	11 (5–20)*
Angle L,°	EL	25 (21–33)	34 (28–42)*	37 (29–45)*
	DL	24 (12–32)	38 (28–42)*	38 (30–42)*

Definitions of craniofacial dimensions are presented in figure 1. Values are median (10th–90th percentiles).

* $P < 0.05$ *vs.* neutral position. † $P < 0.05$ *vs.* simple neck extension.

Appendix 2: Influences of Direct Laryngoscopy on Craniofacial Dimensions in Patients with Difficult Laryngoscopy (DL Group) and without Difficult Laryngoscopy (EL Group)

Parameter	Group	Sniffing Position	L3	Lmax
Lower neck flexion angle: α,°	EL	35 (30–38)	37 (29–41)	40 (30–43)*
	DL	38 (30–41)	35 (33–41)	37 (30–42)
Upper neck extension angle: β,°	EL	32 (25–40)	32 (22–41)	40 (24–49)*†
	DL	31 (28–35)	34 (29–39)	41 (33–44)*
Laryngoscope angle: γ,°	EL	NA	18 (12–22)	24 (19–29)†
	DL	NA	10 (7–14)‡	13 (11–16)†‡
Facial height, cm	EL	27 (23–31)	27 (24–31)	28 (25–33)*
	DL	26 (22–31)	26 (25–29)	27 (24–29)
Ala nasi to mandible distance: NM, cm	EL	8.1 (6.6–9.2)	8.4 (7.4–10.3)	8.8 (7.5–10.4)*
	DL	7.6 (6.6–8.4)	8.4 (7.8–9.5)*	8.6 (8.0–9.4)*
Ala nasi to larynx distance: NL, cm	EL	11.6 (9.9–14.0)	13.2 (11.5–14.6)*	14.5 (11.7–16.0)*†
	DL	11.7 (10.2–13.5)	13.0 (12.1–15.2)*	13.4 (11.6–15.3)*†
Submandibular space: ML, cm	EL	5.7 (4.8–7.5)	6.6 (5.8–7.0)	7.5 (5.9–8.2)*†
	DL	5.7 (4.7–7.6)	5.9 (5.1–7.5)	6.6 (5.1–8.0)
Ala nasi to tongue base distance: NT, cm	EL	NA	12.4 (11.3–13.0)	12.6 (11.3–13.3)
	DL	NA	11.3 (11.0–11.8)	11.8 (11.6–12.6)†
Mandible to tongue base distance: MT, cm	EL	NA	7.9 (7.5–8.1)	7.3 (6.9–8.0)
	DL	NA	7.7 (7.1–8.3)	7.7 (7.4–7.8)
Larynx to tongue base distance: LT, cm	EL	NA	3.8 (2.6–4.5)	2.7 (1.9–3.9)†
	DL	NA	4.2 (4.1–5.0)	3.8 (3.0–4.4)†‡
Angle M,°	EL	12 (3–21)	10 (2–20)	6 (−2 to 19)*
	DL	11 (5–20)	11 (5–22)	12 (7–21)
Angle L,°	EL	37 (29–45)	32 (25–40)*	35 (29–41)
	DL	38 (30–42)	36 (30–42)	38 (30–44)
Angle T,°	EL	NA	49 (46–53)	43 (42–46)†
	DL	NA	54 (52–57)‡	51 (48–58)†‡

Definitions of craniofacial dimensions are presented in figure 1. Values are median (10th–90th percentiles).

* $P < 0.05$ *vs.* sniffing position. † $P < 0.05$ *vs.* L3. ‡ $P < 0.05$ *vs.* EL group.

L3 = time during direct laryngoscopy when Cormack and Lehane grade 3 laryngeal view was first achieved; Lmax = time during direct laryngoscopy when the maximum arm force was applied to the laryngoscope blade; NA = not applicable.