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Mallampati Classification, an Estimate of Upper Airway Anatomical Balance, Can Change Rapidly during Labor

THE Mallampati classification is a rough estimate of the tongue size relative to the oral cavity.[1] Although the single usage of the Mallampati classification has limited discriminative power for difficult tracheal intubation,[2] it is a simple, reproducible, and reliable preanesthetic airway assessment method when performed properly. In addition to difficult tracheal intubation, Mallampati class 3 or 4 is an independent predictor for difficulty of mask ventilation during anesthesia induction and presence of obstructive sleep apnea.[3,4] Increase of the Mallampati class during labor and delivery reported in this issue of ANESTHESIOLOGY[5] provides insight for exploring and understanding the mechanisms of difficulty in perioperative airway management of pregnant women, particularly during or immediately after labor. In the article, the authors thoroughly discuss the clinical implications of their findings on difficult tracheal intubation; therefore, I would like to assess their data focusing on perioperative upper airway obstruction of pregnant women.

Clinical Significance of Upper Airway Changes during Pregnancy and Labor

Kodali *et al.*[5] did not directly test the clinical significance of the increased Mallampati class because none of the women underwent general anesthesia; however, careful interpretation of their data reveals noticeable features of the upper airway structures in pregnant women. First, Mallampati class 3 and 4 seem to be more prevalent in parturients at the beginning of labor (28%) than in the general adult population (7–17%), suggesting that tongue volume increases even during normal pregnancy as previously reported.[6] Increased tongue volume presumably due to fluid retention during pregnancy may be partly responsible for increasing both prevalence of obstructive sleep-disordered breathing in pregnant women and incidence of difficult tracheal intubation in obstetric anesthesia.[7]

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More surprisingly and significantly, half of the parturients demonstrated Mallampati class 3 or 4 by the end of labor, predicting a further increase in difficulty of airway management during labor or immediately after delivery upon medical interventions such as general anesthesia. The risk of emergency cesarean delivery and surgery for postpartum hemorrhage is particularly high in obese parturients, presumably because of their higher incidence of maternal complications and fetal growth retardation.[7–9] Hood *et al.*[8] reported that 48% of laboring morbidly obese parturients required emergency cesarean delivery compared with 9% of control laboring parturients. Considering the high prevalence of obstructive sleep apnea in obese subjects and the growing problem of obesity among industrial countries, the finding of Kodali *et al.* is not trivial and carries particular importance to practitioners when anesthetizing obese parturients. In fact, a recent survey of anesthesia-related maternal deaths in Michigan identified obesity and African-American race as common characteristics of these cases.[10] Noticeably, there were no deaths during anesthesia induction, and five of eight anesthesia-related deaths resulted from hypoventilation or airway obstruction during emergence, endotracheal extubation, or recovery. Although safety of airway management during anesthesia induction seems to have greatly improved as a result of development of the airway algorithm and various intubation devices, an unsolved and significant problem in obstetric anesthesia is how to assess and manage the upper airway upon emergence and endotracheal extubation. The data of Kodali *et al.* suggest the labor is a potential risk factor for perioperative airway catastrophe in parturients in addition to obesity, craniofacial abnormalities, and sleep-disordered breathing. Pregnancy and labor are inevitable and physiologic processes for human beings that significantly burden the respiratory system by decreasing lung volume and thoracic compliance and narrowing the upper airway. Labor potentially makes some parturients more susceptible to pathologic upper airway narrowing.

Upper Airway Anatomical Imbalance in Parturients

The pharyngeal airway is a collapsible tube whose patency is precisely regulated by upper airway dilating muscles such as the genioglossus. Increase in the dilating muscle activity acts to maintain the narrowed pharyngeal airway during wakefulness in patients with obstructive sleep apnea.[11] Similar neural mechanisms presumably compensate the progressive upper airway narrowing in parturients. Preservation of these neural regulatory mechanisms is, therefore, crucial for parturients with a high Mallampati class to maintain their breathing. Regional anesthetic techniques have only minimal influence on the neural mechanisms; however, the neural compensatory mechanisms become weaker during general anesthesia, sedation, and sleep with residual anesthetics. The pharyngeal airway patency entirely depends on its structural stability in parturients undergoing emergency cesarean delivery during general anesthesia.

Structurally, the pharyngeal airway is surrounded by soft tissues such as the tongue and soft palate, which are enclosed by bony structures such as the mandible and spine. Size of the airway space is determined by the balance between the bony enclosure size and soft tissue volume (anatomical balance) when pharyngeal muscles are inactivated by general anesthetics and muscle relaxants.[12] Pharyngeal edema, presumably due to fluid retention during pregnancy, and pharyngeal swelling acutely developed during labor increase the soft tissue volume surrounding the airway, narrowing the pharyngeal airway in parturients. Recent extensive research on the pathophysiology of upper airway obstruction revealed a significant role of the lung volume reduction in pharyngeal narrowing. Tagaito *et al.*[13] demonstrated that lung volume dependence of pharyngeal airway patency is more pronounced in obese patients. Accordingly, obese parturients, a high-risk group for perioperative airway catastrophe, are prone to develop progressively narrower pharyngeal airways due to increase of soft tissue volume surrounding the pharyngeal airway and decrease of lung volume during pregnancy. Lung volume reduction during general anesthesia is known to be more prominent and prolonged in obese patients. General anesthesia for emergency cesarean delivery in obese parturients during or immediately after labor may tend to exaggerate upper airway swelling and lung volume dependence, in addition to impairment of neural compensatory mechanisms, and is, therefore, a worst-case scenario for upper airway maintenance. Application of positive end expiratory pressure during anesthesia and full consciousness at endotracheal extubation are strongly recommended for these patients.

Mallampati Classification for Assessment of Upper Airway Anatomical Balance

Kodali *et al.* demonstrated a decrease in upper airway volume of approximately 10 ml during labor and delivery. Although they did not simultaneously assess changes in Mallampati class in this group of parturients, it is of interest how much reduction of the upper airway volume, *i.e.*, how much increases in the tongue volume, leads to a 1-point increase in Mallampati class. Assuming similar changes of the Mallampati class in both study groups, *e.g.*, a 26-point increase of the Mallampati class in 61 subjects leads to a 10-ml reduction of upper airway volume on average, it can be roughly estimated that a 1-point increase of the Mallampati class approximately corresponds to a 20-ml increase of the tongue volume in women with Mallampati class 3 or 4 before labor. Upper airway volume differed between patients with and without difficult tracheal intubation by 30–40 ml.[14] Tongue volume was significantly larger in patients with obstructive sleep apnea, by approximately 20–25 ml, than in nonapneic persons.[15] For every 1-point increase of the Mallampati class, the relative risk of obstructive sleep apnea doubles and apnea hypopnea index increases by 5 h^{-1}.[4] Accordingly, a 20-ml increase of the tongue volume during labor potentially results in difficult tracheal intubation and upper airway obstruction under influence of general anesthetics and sedatives.

The Mallampati classification allows us to instantaneously identify such small but significant increases in the tongue volume at the bedside without using sophisticated apparatuses. The Mallampati classification originated in our specialty, and recently, clinicians and researchers in other specialties have recognized its usefulness for assessment of upper airway anatomical balance. We anesthesiologists should be proud of the Mallampati classification and are encouraged to use this classification to assess the upper airway anatomical balance with it before every general anesthesia induction. The article by Kodali *et al.*[5] reminds us that the Mallampati classification is not static, but can change over hours with processes such as labor, and we should assess it just before instrumentation, rather than relying on an assessment even a few hours earlier.

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Impact of Analgesia on Bone Fracture Healing

BONE fractures are painful and, in general, temporarily disabling injuries that occur after trauma or as an end result of various pathologic conditions, such as osteoporosis or bone invading cancer (pathologic fracture). It is common practice for acute pain services to be heavily involved in the treatment of orthopedic patients, and although it is usually understood that fractures are very painful, few studies have directly attempted to measure or define the nature of the pain after a fracture. In addition, controversy exists regarding the effects of analgesics, including opioids and nonsteroidal antiinflammatory drugs, on skeletal tissue healing. In this issue of Anesthesiology, reports from Freeman *et al.*[1] and Minville *et al.*[2] show that commonly used fracture healing models also can be used to assess pain quantitatively and therefore to assess analgesic efficacy. Because bone is a highly innervated tissue, these models also can be applied to define the mechanism of pain transmission after fracture. Furthermore, and of even greater clinical importance, these fracture pain models lend themselves to studying the effects of pharmacologic interventions on bone healing.

Bone fractures are treated by restoring the anatomy of the broken bone (reduction) and immobilizing the bone pieces (fixation) while regeneration proceeds. Commonly, fracture fixation is done by casting the broken bone. This also can be achieved surgically by use of intramedullary rods or external fixators that use percutaneous pins or rods to hold the bone fragments in correct anatomical alignment. In these cases, the fracture site is not significantly disturbed and the fractures heal by bone regeneration. Initially, the fracture causes localized tissue hypoxia and hematoma formation and is soon followed by a robust inflammatory response. Next, mesenchymal cells migrate and proliferate at the fracture site to form a callus. Concomitantly, osteoblasts in the periosteum near the fracture site begin to proliferate. At the interface with the periosteal osteoblasts, the mesenchymal cells differentiate into chondrocytes and elaborate a cartilage matrix. Eventually, the chondrocytes undergo hypertrophy and mineralize the cartilage matrix, which then acts as a substratum for osteoblast bone formation. This process is reiterated from the periphery of the fracture site toward the center until the fracture is bridged with newly formed bone and is dependent on angiogenesis. Subsequently, the bony callus is remodeled to restore the mechanical properties of the bone. This is the normal endochondral ossification pathway of fracture healing and is often referred to as secondary fracture healing. In contrast, primary fracture healing occurs only after surgical fixation of the fracture in which the fracture callus is removed, and the bone ends are closely abutted and rigidly fixed in place, usually with a plate. In this case, the fractures heal slowly *via* normal bone remodeling mechanisms while the metal plate stabilizes the fracture and provides for any weight-bearing functions.

Pharmacologic treatments that can affect the molecular and cellular processes of bone regeneration can have a significant impact on healing. For example, fracture healing is severely impaired in rats treated with TNP-470, an antiangiogenic compound.[3] More important in terms of pain management, nonsteroidal antiinflammatory drugs and cyclooxygenase-2 inhibitors, such as celecoxib, impair fracture healing in animal models.[4,5] Eight weeks after fracture, twice the normal bridging time in rats, femur fracture healing had failed in approximately one third of female rats treated with celecoxib (4 mg/kg daily) for 5 days after fracture. However, celecoxib therapy before fracture or celecoxib therapy initiated 2 weeks after fracture had no significant effect on healing in rats. Limited retrospective data also indicate that these effects may translate to humans.[6] Among acetabular fracture patients treated with indomethacin or localized radiation to prevent heterotopic ossification, 29% of those patients treated with indomethacin experienced a non-

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Airway Changes during Labor and Delivery

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Background: **There are no prospective studies that evaluated airway changes during labor. The purpose of this study was to evaluate airway changes in women undergoing labor and delivery.**

Methods: **Two studies were undertaken to evaluate airway changes during labor. The first study used the conventional Samsoon modification of the Mallampati airway class. The airway was photographed at the onset and the end of labor. Women with class 4 airways were excluded from initial participation. In the second study, upper airway volumes were measured using acoustic reflectometry at the onset and the conclusion of labor. Acoustic reflectometry software computed the values for the components of upper airway, oral volume, and pharyngeal volume.**

Results: **In study 1 (n = 61), there was a significant increase in airway class from prelabor to postlabor (P < 0.001). The airway increased one grade higher in 20 (33%) and two grades higher in 3 (5%) after labor. At the end of labor, there were 8 parturients with airway class 4 (P < 0.01) and 30 parturients with airway class 3 or class 4 (P < 0.001). In study 2 (n = 21), there were significant decreases in oral volume (n = 21; P < 0.05), and pharyngeal area (P < 0.05) and volume (P < 0.001) after labor and delivery. No correlation was observed between airway changes during labor and duration of labor, or fluids administered during labor in either study.**

Conclusion: **Airways can change during labor. Therefore, a careful airway evaluation is essential just before administering anesthesia during labor rather than obtaining this information from prelabor data.**

THE incidence of failed tracheal intubation in the pregnant population is perhaps eight times higher than in the nonpregnant population.[1] Difficult or failed intubation after induction of general anesthesia for cesarean delivery remains the major contributing factor to anesthesia-related maternal complications.[2,3] The first national study of anesthesia-related maternal mortality in the United States revealed that 52% of the deaths resulted from complications of general anesthesia predominantly related to airway management problems.[4] Despite decreases in the number of obstetric general anesthetics and better awareness of obstetric airway difficulties, a recent survey has shown that the incidence of difficult intubation and subsequent complications have not diminished with time.[5] Furthermore, a critical evaluation of anesthesia-related maternal deaths in Michigan, 1985–2003, showed that airway obstruction or hypoventilation during emergence and extubation were the cause of five maternal deaths.[6] Obvious factors such as enlarged breasts have been implicated, but simple maneuvers for dealing with these problems did not seem to decrease the incidence of difficult intubation.[5,7,8] There is no known bone or joint abnormalities in pregnancy that could pose difficulties during intubation. However, soft tissue changes such as airway edema are an invariable association of pregnancy, and this may contribute to difficult intubation.[8] Pilkington *et al.*[8] demonstrated that airway edema can increase during the course of pregnancy and result in increases in Mallampati score. There is speculation and an anecdotal report that airways can also change during labor and delivery.[9] There is no comprehensive study that has prospectively evaluated airway changes in pregnant women undergoing labor and delivery. To evaluate airway changes associated with labor and delivery, we undertook two studies that used two different approaches of airway evaluation. In the first study, we used the conventional Samsoon modification of the Mallampati score to evaluate airway changes, and in the other, we used acoustic reflectometry to objectively analyze airway changes. Acoustic reflectometry offers a distinct advantage of studying the concealed portion of the upper airway extending from the uvula to the glottis (pharyngeal volume), in addition to the visible portion (oral volume). The Samsoon modification of the Mallampati airway classification is based on the visibility of the soft palate, faucial pillars, and uvula.[1,10] The visibility of structures is dependent on the relative capacity of the oropharyngeal cavity and the volume of the base of the tongue.[10] If the base of the tongue is disproportionately large, it can mask the visibility of faucial pillars and the uvula (increasing airway class) by encroaching into the oropharyngeal cavity.[10] This leads to a relative decrease in the oropharyngeal volumes. Therefore, the outcomes of the two studies, airway evaluation by the Samsoon modification of the Mallampati airway classifi-

◇ This article is featured in "This Month in Anesthesiology." Please see this issue of ANESTHESIOLOGY, page 5A.

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cation and airway volume determinations by acoustic reflectometry, can complement each other in determining changes in the airway during labor.

Materials and Methods

There are no previous studies to determine sample size. These studies were undertaken as exploratory feasibility studies to build an appropriately powered trial in the future. The studies were approved by the Partners Human Research Committee, Brigham and Women's Hospital, Boston, Massachusetts.

Study 1

After obtaining written informed consent, we studied airway changes in 70 healthy pregnant women who were admitted to the labor and delivery suite (early active labor; cervical dilatation 2–3 cm). Initial airway examination was graded according to the Samsoon modification of the Mallampati classification. The parturients were trained to understand our perspective of airway evaluation so that they could open their mouth as wide as permissible without phonation. Women with a class 4 airway were omitted from enrollment because there is no further description of an airway class higher than 4 in visual airway classification. Airway photographs were obtained using a Polaroid Macro 5 SLR camera (Polaroid Corporation, Bedford, MA), with parturients in the sitting position. The head was in the neutral position, and the camera was held horizontal to the ground at the level of the uvula of the pregnant women. A unique feature of the camera enabled the distance from the camera lens to the uvula, or soft palate (if uvula was not visible), to be exactly 10 inches in all exposures. This was achieved *via* two red light beams from the camera that converged precisely at 10 inches from the lens, thus enabling us to obtain pictures without artifacts arising as a result of distance and angular variations. Airway photographs were also obtained at 20 min after the completion of stage 3 of labor, and at 36–48 h in the postpartum period in the sitting position. The photographs were given numerical coded numbers. A senior anesthesiologist, who was blinded to the origin of the photographs, analyzed and graded the airway into four classes (Samsoon modification of Mallampati airway class). Parturient characteristics, as well as labor and delivery variables, which included duration of stages of labor (stage 1 = onset of uterine contractions to full cervical dilatation; stage 2 = full cervical dilatation to delivery of the neonate; stage 3 = delivery of the neonate to delivery of the placenta; total duration of labor includes stages 1, 2, and 3), fluids administered during labor, and type of labor analgesia, were recorded.

Study 2

After obtaining informed written consent, 28 healthy pregnant women who were admitted to the labor and delivery suite (early active labor; cervical dilatation 2–3 cm) were recruited into the study. Acoustic reflectometry was used to study length *versus* cross-sectional area map of the airway. The acoustic reflection device (E. Benson Hood Laboratories, Pembroke, MA) consists of two microphones, and one horn driver mounted on a 30-cm-long, 1.89-cm-ID wave tube.[11] The operating principle of the acoustic device is that sound pulses driven by a horn driver loudspeaker are transmitted through a tube into the airway. The reflectometer impulse, 2 ms in duration, is characterized by a flat spectral range from 0 to 5,000 kHz (low-pass filter) and is repeated at the rate of 5 pulses per second. Expansions and constrictions along the airway reflect incident sound (pressure) waves. Incident and reflected waves are recorded by microphones mounted within the tube. The amplitude and phase of the reflected sound are determined by the airway local area, whereas the timing of arrival of the reflected sound is a function of the distance the sound has traveled. Therefore, pressure–time relations are converted to cross-sectional areas–*versus*–length relations. The digital-to-analog and analog-to-digital converters and software of the device displayed acoustic waveforms on the computer screen as shown in figure 1. The software of the system also computes and displays values for oral volume, mean oral area, pharyngeal volume, mean pharyngeal area, and total airway volume. Other data it can provide include the distances of the uvula and glottis from the incisor teeth. The parturients, seated comfortably, breathed room air *via* a mouthpiece attached to the wave tube without phonation. The computer screen of the device displayed the processed acoustic waveforms. When steady waveforms were obtained, the waveforms were saved to compute airway variables (oral volume, pharyngeal volume, mean oral and pharyngeal areas). The airway acoustic reflection measurements were also made at 20 min after labor and delivery. Physical characteristics of women, and labor and delivery variables were recorded.

A precondition for both studies was to include only those pregnant women who had spontaneous vaginal delivery for data evaluation. Women who underwent cesarean delivery were omitted from the studies.

Statistical Analysis

Means, SDs, medians, and interquartile ranges are presented as descriptive statistics for both studies. In study 1, the Wilcoxon signed rank test was used to compare prelabor and postlabor airway class, and ordinal classifications taken on the same patient. For analyses of individual airway classes prelabor and postlabor, the McNemar test was used. The Wilcoxon rank sum test was used to determine whether a significant number of women in

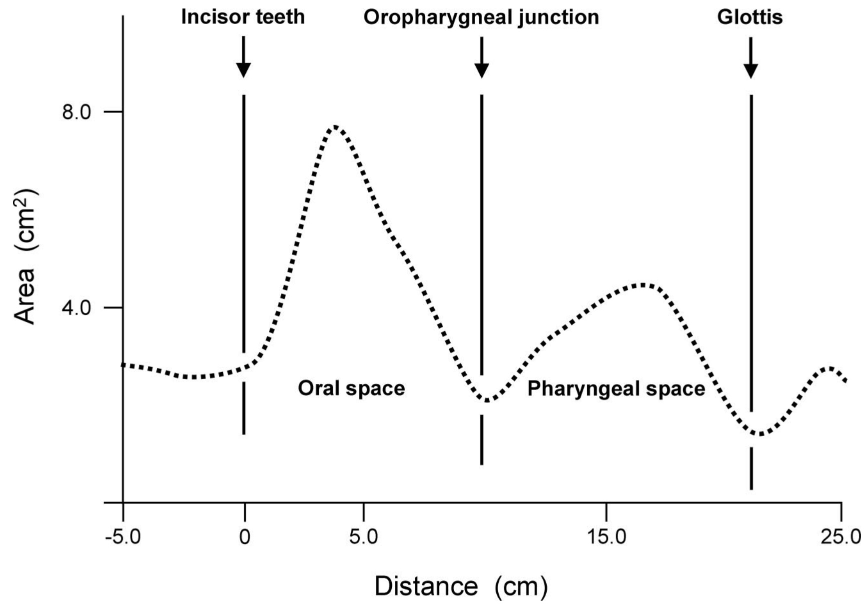

Fig. 1. Acoustic reflectometry tracing showing various components of upper airway beginning from incisor teeth to glottis.

the prelabor group progressed to class 4 airway at the conclusion of the labor. Spearman correlation analysis of the change in prelabor and postlabor airway class with weight at time of pregnancy, height, duration of labor, and intravenous fluids administered during labor were conducted.

In study 2, a paired *t* test was used to evaluate the statistical significance of differences between prelabor and postlabor acoustic reflectometry parameter values. The changes in prelabor and postlabor oral and pharyngeal volumes were correlated with weight at time of pregnancy, height, duration of stages of labor, and intravenous fluids administered during labor by Spearman correlation.

For all analyses, a *P* value less than 0.05 was considered statistically significant, and we used SAS version 9.1 software (SAS Institute Inc., Cary, NC) for all analyses.

Results

In study 1, 70 women were recruited and 61 completed the study by way of spontaneous vaginal delivery. Nine parturients underwent cesarean delivery and hence were eliminated from the study analysis. Forty women opted for epidural analgesia for labor and delivery. Characteristics of the pregnant women are shown in table 1. Table 2 shows the distribution of the Samsoon modification of the Mallampati airway prelabor and postlabor. Wilcoxon signed rank test revealed a significant change in airway class between prelabor and postlabor airway data. The results were significant ($P < 0.001$), with each of the 23 subjects who exhibited a difference moving to a higher class. The airway increased by one grade higher in 20 parturients (33%) and two grades higher in 3 parturients (5%) by the end of labor as compared with that in early labor. There were eight parturients in the prelabor group who progressed to class 4 airways at the end of labor compared with those who did not (Wilcoxon rank sum test, $P < 0.01$). There were 30 parturients with airway class 3 or 4 in the postlabor group compared with 17 in the prelabor group (McNemar test, $P < 0.001$). Figure 2 shows airway pictures before (class 1 airway) and after labor (class 3 airway). Labor and delivery variables are shown in table 3. There was no significant correlation of changes in airway class with weight, height, duration of various stages of labor, or fluid administered during labor (table 4). Nineteen of the 23 patients (82%) who had a worsened airway class with labor reverted to admission grade within 36–48 h postpartum.

In study 2, 28 parturients participated in the study for initial evaluation and 21 women completed the postlabor/delivery study after spontaneous vaginal delivery. The remaining had cesarean delivery and therefore were excluded from the study. Twenty women received epidural analgesia. There was a significant decrease in oral volume ($P < 0.05$), pharyngeal volume ($P < 0.001$), and

Table 1. Patient Characteristics in Studies 1 and 2

	Age, yr	Height, cm	Weight, kg	Gravida	Para	Gestation, wk	Cervical Dilatation at First Measurement, cm
Study 1	31.1 (4.9)	162 (7.0)	79.0 (12.3)	2.6 (1.3)	1.4 (1.1)	38.6 (1.0)	2.4 (0.5)
Study 2	32.0 (4.6)	160 (4.5)	79.3 (15.0)	2.7 (1.4)	1.3 (1.0)	38.9 (1.1)	2.4 (0.5)

Data are presented as mean (SD).

Table 2. Influence of Labor on Airway Class Distribution Evaluated Using the Samsoon Modification of Mallampati Class in Study 1

		Postlabor Airway Class			
Prelabor Airway Class		1	2	3	4
1	9	4	4	1	0
2	35	0	23	10	2
3	17	0	0	11	6
4	0	0	0	0	0
Total	61	4	27	22	8

Significant change in airway class between prelabor and postlabor ($P < 0.001$). There is significant increase in class 3 and 4 airways (30) at the end of labor compared with prelabor (17) ($P < 0.001$).

mean pharyngeal area ($P < 0.05$) after labor and delivery as compared with prelabor values in 21 parturients who completed the study (table 5). A scatter plot of individual pharyngeal volumes before and after labor is presented with an identity line (fig. 3). There was no significant correlation between decreases in oral and pharyngeal volumes and various parameters obtained during labor (tables 3 and 4).

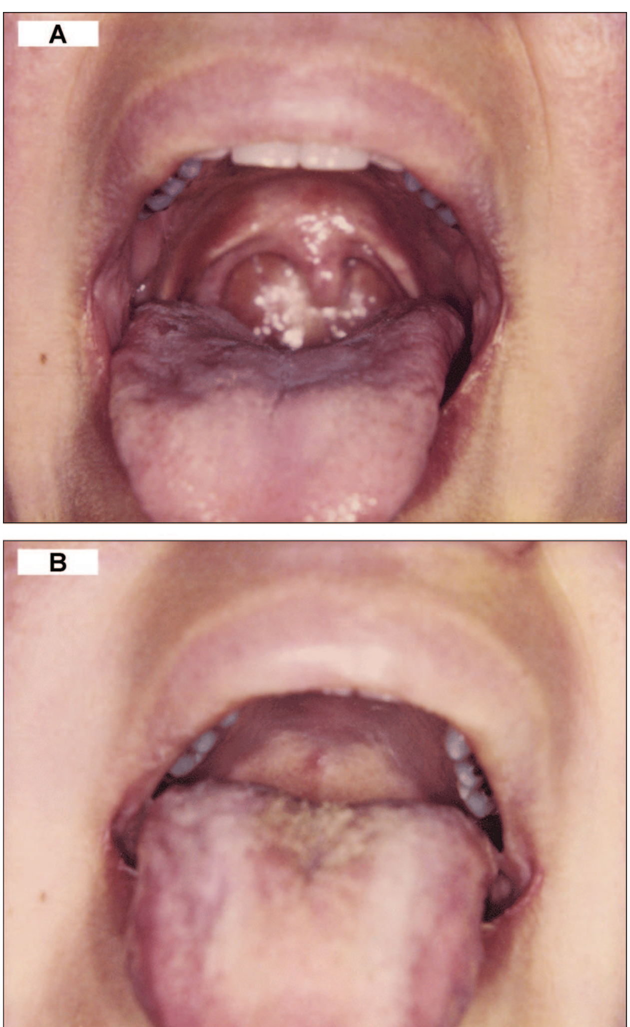

Fig. 2. Airway pictures prelabor (Samsoon modification of Mallampati class 1 airway; *A*) and postlabor (Samsoon modification of Mallampati class 3 airway; *B*).

Discussion

Airway changes have been observed during the course of pregnancy. There is an increase in the number of the Samsoon modification of the Mallampati class 4 by 34% at 38 weeks of gestation from those at 12 weeks of gestation.[8] The underlying cause for this change is attributed to fluid retention that occurs with pregnancy.[8] Our studies show that labor and delivery are also associated with further airway changes, thus confirming previous anecdotal observations.[9] Study 1 used the standard airway evaluation criteria that are currently in daily practice. Although pregnant women with a class 4 airway at the beginning of the study were excluded, there were 8 women with a class 4 airway at the conclusion of the study. Fifty percent of women (30) at the conclusion of labor had a class 3 or class 4 airway. The relation between increasing airway classification and relative ease or difficulty at intubation in term pregnant women undergoing cesarean delivery during general anesthesia was studied by Rocke *et al.*[12] The relative risk of encountering difficult intubation in pregnant women with a class 3 airway was 7.58 times more compared with parturients with a class 1 airway during general anesthesia. This relative risk increased to 11.3 in pregnant women with a class 4 airway. This suggests that a change in airway class from 2 to 4 in parturients is associated with enhanced relative risk of encountering difficult intubation from 3.23 to 11.3. Therefore, women undergoing labor may be at increased risk of difficult intubation, particularly if labor is associated with airway changes. Hence, it is prudent to reevaluate the airway in women in labor presenting for cesarean delivery just before commencement of the anesthetic, rather than obtaining the information from the prelabor evaluation data sheet. Although the majority of cesarean deliveries may be performed during regional anesthesia, general anesthesia cannot altogether be avoided. It may be needed in emergent circumstances with no or inadequate regional anesthesia. Increases in airway class by one grade can increase the relative risk of difficult intubation, particularly in the presence of other coexisting factors. The factors that are likely to increase the risk of difficult intubation are short neck, receding mandible, protruding maxillary incisors, and morbid obesity.[12,13] In the presence of these factors, changes in airway class during labor can potentially increase the cumulative risk of encountering difficulties in securing the airway at induction of general anesthesia and may necessitate implementation of backup airway management strategies.

We understand that there are some limitations of study 1. There is always a subjective error on the part of the

Table 3. Median (IQR) for Labor and Delivery Variables in Studies 1 and 2

	Fluids Administered During Labor, ml	Time Interval between Evaluations, min	First Stage of Labor, min	Second Stage of Labor, min	Third Stage of Labor, min	Total Duration of Labor, min
Study 1	2,300 (1,100)	420 (390)	570 (360)	75 (90)	11 (8)	668 (379)
Study 2	2,500 (900)	480 (215)	660 (240)	45 (65)	7 (6)	698 (390)

IQR = interquartile range.

parturients in opening their mouth for airway evaluation. To obviate this, we trained each subject beforehand to open the mouth as wide as possible without phonation. To minimize evaluator errors, all photographs were taken with the camera lens at 10 inches from the uvula, or the most distant visible portion of the palate if the uvula was not visualized. The angulation errors were also minimized by ensuring that the parturient was seated upright with head in the neutral position and the camera held such that the lens axis was parallel to the ground. The photographs were evaluated by an anesthesiologist not involved in the study to eliminate the evaluator's bias of airway evaluation. However, the study personnel obtaining the airway evaluation pictures knew whether the pregnant woman was in the prelabor or postlabor period. This was unavoidable because of the location of these parturients in the labor and delivery floor or postpartum floor in the hospital.

Because of inherent unavoidable limitations of study 1, we studied airway changes using an altogether different approach to airway analysis. Acoustic reflectometry is a noninvasive test that produces a length–*versus*–cross-sectional area map of the airway.[11] A unique advantage of this measurement is that it can also measure pharyngeal volume (fig. 1). Upper airway (airway volume) has two components: an oral component and a pharyngeal component. The oral component is the one normally assessed using Mallampati classification. The pharyngeal volume is concealed and not evaluated in clinical practice. An airway volume less than 40.2 ml has been shown to be associated with diminished ability to view glottis openings in nonpregnant subjects undergoing general anesthesia and intubation.[11] In addition, acoustic reflectometry has been shown to accurately predict complete inability to ventilate a patient *via* a mask. However, it did not predict the absolute inability to intubate a patient.[14] Acoustic reflectometry airway volumes have been found to match computed tomography measured airway volumes.[15] Hence, it is a reasonable noninvasive method to evaluate airway changes during labor and delivery. Our results in study 2 showed that there is a significant decrease in oral airway volume, which is in accord with the Samsoon modification of the Mallampati airway class changes in study 1. However, in addition, the pharyngeal volumes and mean pharyngeal area also decreased significantly after labor and delivery. We do not know whether these decreases in the volume of the pharyngeal portion of the airway would contribute to difficult intubation, because none of the pregnant women enrolled in the study had general anesthesia. There are also no data demonstrating the relation between pharyngeal volume and intubation difficulties. However, it is conceivable that decreasing pharyngeal volumes could potentially pose an impediment to intubation. This belief is supported by the case reports of difficult intubation in cases of pharyngolaryngeal edema consequent to pregnancy-induced hypertension, fluid overload in conjunction with the antidiuretic properties of oxytocin, and prolonged strenuous beardown efforts.[16–21] Our finding of decreased pharyngeal volume after labor assumes great importance in parturients who may have class 4 airways at the beginning of labor. These women must be examined carefully for any other associated factors that may contribute to difficult intubation to minimize surprises of encountering a difficult airway at intubation. Furthermore, it is also likely that variations in pharyngeal volume changes from parturient to parturient could be responsible for decreased predictability

Table 4. Correlation Analysis of Change in Prelabor and Postlabor Measurements with Weight, Height, Duration of Labor, and Fluids for Study 1 (n = 61) and Study 2 (n = 21)

Variable	Study 1 Change in Airway Class ρ* (*P* Value) Airway	Study 2 Change in Airway Volume ρ* (*P* Value) Oral Volume	Pharyngeal Volume
Weight	−0.16 (<0.2)	−0.41 (<0.06)	−0.24 (<0.3)
Height	0.05 (<0.7)	−0.08 (<0.7)	−0.03 (<0.9)
Fluids	0.06 (<0.6)	0.03 (<0.9)	0.08 (<0.4)
Duration of labor			
First stage	0.01 (<0.9)	0.01 (<0.9)	0.01 (<0.9)
Second stage	0.09 (<0.5)	0.08 (<0.7)	0.40 (<0.07)
Third stage	−0.05 (<0.7)	0.15 (<0.5)	0.09 (<0.7)

* Rho (ρ) is the Spearman correlation coefficient.

Table 5. Airway Volume Data, Prelabor and Postlabor, in Study 2

Parturients, n = 21	Oral Volume, ml	Mean Oral Area, cm^2	Pharyngeal Volume, ml	Mean Pharyngeal Area, cm^2
Prelabor	49.10 (14.6)	5.84 (1.3)	26.87 (10.4)	3.10 (1.6)
Postlabor	44.40 (15.0), $P < 0.05$	6.06 (1.9)	21.80 (8.4), $P < 0.001$	2.70 (1.4), $P < 0.05$

Data are presented as mean (SD). Oral volume and pharyngeal volume data were computed from acoustic waveforms for each patient prelabor and postlabor using acoustic reflectometry software.

of intubations from the Samsoon modification of the Mallampati airway class.

The most likely cause of decreasing airway caliber in women undergoing labor and delivery is escalating soft tissue mucosal edema. We did not find a correlation between airway changes and amount of fluids administered during labor or duration of labor. It is possible that the predominant factor responsible for aggravating airway edema is straining and pushing, which is an integral part of labor and delivery. Our data in study 2 give some credence to this speculation. There is a positive relation between the duration of stage 2 of labor, which is associated with maximum pushing and straining, with decreases in pharyngeal volume ($P < 0.07$; table 4). Further studies with a larger sample size may confirm this relation. Nonetheless, it is difficult to quantify the degree of pushing and straining during labor, and its effect on airway edema. Moreover, stress and straining varies enormously from woman to woman. Straining and pushing can increase central venous pressure and intracapillary pressure. This can favor the Starling equation toward exacerbating mucosal edema in the presence of decreased oncotic pressure, which is a normal accompaniment of pregnancy. Additional intravenous fluids can exacerbate this response by further decreasing oncotic pressure and increasing airway edema.[22]

In conclusion, pregnant women undergoing labor and delivery may be vulnerable to developing airway changes. This may increase the risk of confronting difficult intubation, particularly in the presence of other predisposing factors contributing to difficult intubation. It is imperative to examine the airway immediately before cesarean delivery, rather than relying solely on information from prelabor evaluation. Further studies should analyze whether women with preeclampsia have a greater susceptibility to develop airway changes compared with healthy pregnant women.

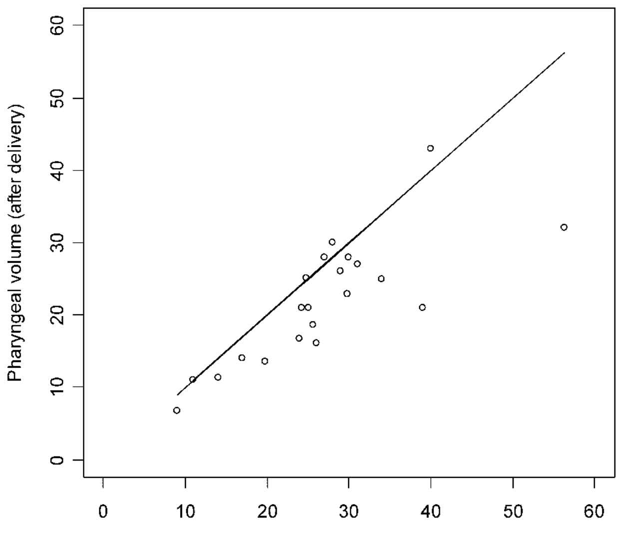

Fig. 3. Plot of pharyngeal volume (ml) before and after delivery.

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