Ph.D.Thesis

Videofluorographic study of effortful swallowing and K-method swallowing

（努力嚥下とKメソッドによる嚥下法に関するVideofluorographyを用いた研究）

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In the name of ALLAH, the most gracious and most merciful.

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Contents

Section 1

Introduction

Videofluorographic examination (VF) is the most commonly used instrumental procedure for the examination of swallowing function, together with fiberoptic endoscopy[1]. Using the former procedure, we can obtain the temporal and spacing information. Although we can measure the distance and angles using this method, the rates of mechanical distortion and enlargement, and some other factors, make it unreliable. However, temporal measurements are more reliable.

Once Magendie[2] proposed the theory of constant propulsion of swallow as a) the time from the start of swallowing until the bolus passes through the oropharyngeal isthmus (oral, voluntary stage), b) the time from the bolus enters into the pharyngeal space until it passes through the upper esophageal sphincter (pharyngeal, involuntary stage), and c) the time from the bolus enters into the esophagus until it passes through the cardiac orifice (esophageal, involuntary stage). The theory still has been used nowadays, and Logemann added oral preparatory stage when food is manipulated in the mouth and masticated if necessary, reducing it to a consistency ready for swallow, before oral phase[3]. There were confusion to use the phase and stage in this field. So the following definition was proposed by Shin and Umezaki[4]. The movement of the bolus is referred to as a "phase", and the time progress of the patterned output from the medullary swallowing center is referred to as a "stage". When we measure the swallowing timing, we need to determine the "zero" second. In that paper, the authors used the time when the bolus head reaches the floor of the piriform sinus. This point is not the beginning of the pharyngeal phase. Start of pharyngeal phase is used in many researches[5]. In this study, I focused on the timing of bolus movement, hyoid bone movement, and laryngeal movement.

There are many rehabilitation techniques for swallowing disturbance. Of these, effortful swallowing is one of the most popular techniques. It represents a volitional attempt by the patient to increase the force applied to the bolus from structures within the swallowing mechanism. The K-method is a newly proposed method by speech therapist Chieko Kojima[6]. It is a slightly complicated method, in that before starting to swallow, the patient must make a tongue posture to produce a "ki" sound while keeping the bolus on the tongue surface, and then swallow. As the swallow is not seen on the outside, it is difficult to know when the rehabilitation training is achieved. Therefore, VF is sometimes used for evaluation during training of dysphagia patients.

The purpose of this study was to clarify the relationship among the bolus movement, laryngeal movement, and hyoid bone movement in natural (control), effortful, and K-method swallowing using VF. Recognition of normal swallowing pattern is essential for optimal evaluation of effect of a newly developed rehabilitation method such as K-method.

Section 2

Materials and methods

2.1 Volunteers

Nine volunteers, comprising seven females and two males aged 25–59 years (mean±SD: 39.4±13.5 years), were recruited.

Their professions were dentists (4) and speech pathologists (5). No orofacial or neck region diseases, and no swallowing or breathing disorders were found.

Informed consent was obtained from each volunteer before the videofluoroscopic examination. Ethical Committee for Epidemiology of Hiroshima University approved this study protocol by No.1064.

2.2 Materials

The swallowing materials were prepared using liquid barium sulfate (contrast medium) with food and beverage thickener (Katamaru-kun; Miyagen Co., Wakayama, Japan) to make its thickness jelly-like. This material will be called “test food” in this study.

The apparatus used was x-ray fluoroscopy with 9 inch Image Intensifier (Curevista, Hitachi Medico, Tokyo, Japan). The volunteers sat on a chair for fluoroscopy named Vess Chair (Vess, Ohio, USA) during

VF. Only lateral examination was done under the voltage 69~74kV and current 3mA. The video camera, mini DV HandyCam (DCR-TRV900, Sony, Tokyo, Japan) was used to record the data.

2.3 Methods

During lateral VF examination, each volunteer was asked to swallow 3 ml of test food three times using three different swallowing methods: 1) natural swallowing as a control; 2) effortful swallowing; and 3) K-method swallowing as a rehabilitation method. All videofluorographic study of swallowing were performed with each subject, seated upright on the Vess Chair in the lateral plane and registered in the mini digital videotapes.

The videotape data were retrieved to the computer (MacPro, Apple Japan, Tokyo, Japan) using soft wares, QuickTime Pro and Final Cut Pro (Apple Japan, Tokyo, Japan). Time code was created and registered in each frame of the video-series by Final Cut Pro as seconds and frames (Figure 1). The speed of video is 30 frames/second. Timing of each event frame was calculated from the time code.

2.4 Time measurements of the swallow

Eighteen events were defined, and time measurements were performed. The time measurements were based on the frame when the bolus first passed through the posterior margin of the mandible as 0 second. This event is defined as beginning of pharyngeal phase. Events occurring earlier than that point were recorded as minus, and those occurring after that point were recorded as plus.

Definitions (Figure 2): The frame of the swallowing events was defined as below.

1. Start of swallow; the first frame of the movement of the tongue tip to scoop the test food that was given to the mouth floor by a 10-milliliter syringe.
2. Close the mouth; Subjects close the mouth to swallow, but not all the subjects contacted the upper and lower teeth. Some do not occlude the mouth completely. In some cases, recording started after closure of the mouth.
3. Tipper position; the time when the subject scooped out the bolus and the tongue tip pressed against the upper incisors and maxillary alveolar ridge.
4. Hyoid bone starts to elevate; when subjects open their mouth, hyoid bone lowers. It is the time when the elevation of hyoid bone occurs when they close or start to swallow,
5. Maximum elevation of the hyoid bone; the time when the hyoid bone reaches the highest position before its rapid anterior movement occurs.
6. Start of the rapid anterior movement of the hyoid bone; the time when the hyoid bone starts a rapid anterior motion after elevation.
7. Most anterior position of the hyoid bone; the time when it stops suddenly after the rapid anterior movement.
8. Start the hyoid bone lowering; the time when the hyoid bone

starts to lower from the most anterior position after short stay.

9. End of the hyoid bone lowering: the time when the hyoid bone stopped lowering.

10. Start of the pharyngeal phase; the time when the bolus head passes the posterior edge of the mandibular ramus or inferior border of the mandible.

11. End of the oral phase; the time when the bolus tail passes the posterior edge of the mandibular ramus or inferior border of the mandible.

12. Open lingual seal; the time when the soft palate starts to move upward to open lingual seal.

13. Start of velopharyngeal closure; the time when the soft palate starts to contact the posterior wall to make a velopharyngeal closure.

14. Re-open velopharyngeal closure; the time when the soft palate starts to lose the contact from the posterior and pharyngeal air space re-appear in the velopharyngeal region.

15. Open the esophageal orifice: the time when the esophageal orifice opens to for the bolus to enter into the esophagus, the cricopharyngeal muscle loosens and opens the entrance of the esophagus.

16. Close the esophageal orifice; the time that the orifice of the esophagus closes after the bolus passes through the cricopharyngeal region.

17. Total laryngeal closure; the time that the air space of the laryngeal vestibule totally disappears.

18. Start of continuous laryngeal elevation; the time that the larynx starts to elevate continuously just before the bolus swallowing.

19. Maximum laryngeal elevation; the time that the larynx reaches

the highest position and stays a while afterwards during the laryngeal elevation.

2.5 Measurement of the timing

The measurement of the timing was done by observing the swallowing videos with slow motion and stop motion. All video series were enlarged so that the images are easily observed. Since the time code was registered as seconds and frames, frames were converted to seconds divided by 30. Start of the pharyngeal phase (bolus movement) was used as time zero. The software used for the statistical analysis was JMP (SAS Institute Japan, Tokyo, Japan).

2.6 Statistical analysis

Wilcoxon test was used for the statistical analysis. One way analysis of ANOVA and Single regression analysis were used for Study 1. As for Comparison for 2 groups in 3 groups, nonparametric-paired comparison of Wilcoxon test was used for Study 2 and 3.

2.7 Studies

Study 1. Relationship among the movement of the bolus, hyoid bone and larynx on the start of pharyngeal phase

Aim: The purpose of this Study 1 was to clarify the relationship of start of pharyngeal phase (bolus; phase) and pharyngeal stage (hyoid movement, laryngeal movement; stage).

Methods: Distribution of the timing of "Start of rapid anterior movement of hyoid bone (RAMHB)" and "start of continuous laryngeal elevation (CLE)" was analyzed using bar graphs, bivariate relation analysis and one-way analysis for Control, Effortful, and K-method swallowing. Start of the pharyngeal phase was used for the reference as time zero. In K-method, 2 step-elevation was observed in half of the subjects. As the 2^{nd} continuous elevation was used for all swallowing measurement, we added the 1^{st} step-measurement as modified continuous laryngeal elevation (MCLE).

Study 2. Pattern analysis of Control, Effortful and K-method swallowing

Aim: The purpose of Study 2 was to know the reproducibility of patterns of order of the events occurrence.

Methods: Nineteen events as defined before were used. The pattern of occurrence order distribution was made from the time measurement. As for Close the mouth (Event 2), some cases took time after taking food in the mouth to Start to swallow. X-ray was not exposed for a while for the purpose to reduce the subject's exposure. In these cases the examination re-started with closed mouth. So Close the mouth became 1st in these cases. Open lingual seal (Event 12) also started from the examination and it was considered as 1st occurrence.

Three repeated swallows in each method by 9 subjects gained 27 swallowing data for each method. The occurrence order patterns were generated and model patterns were created using median and statistical comparison ($p<0.05$, Wilcoxon test). In this proposed model, if there were significant difference between the event groups, the event was regarded as independent, and if there were no difference between the event groups, they were included in the same brackets. In the case the median was the same, the average was also considered to determine the order.

Study 3. Temporal analysis of Control, Effortful and K-method swallowing

Aim: The purpose of this experiment was to clarify the temporal difference among the swallowing of Control, Effortful and K-method

Methods: Duration of Oral transit time (OTT), Pharyngeal transit time, (PTT) Pharyngeal delay time (PDT), Swallowing time (ST), and modified oral transit time (MOTT) that was calculated by start from tipper position to the end of the pharyngeal phase. Nonparametric-paired comparison of Wilcoxon test was used for this study comparison.

The definitions are shown as followings.

- OTT (sec): the length of the time it takes the bolus to move through the cavity from the first frame showing backward movement of food (event 1) until the bolus tail passes the landmark in the posterior oral cavity, defined as the spot where the lower edge of the ramus of the mandible crosses the tongue base (event 11).
- PTT (sec): the time it takes the bolus to move through the pharynx from start of the pharyngeal phase (10) until the bolus tail passes through the cricopharyngeal region (16).
- PDT (sec): the time from beginning of the pharyngeal phase (10) until the pharyngeal swallow triggered. Triggering of the pharyngeal swallow is defined as the first frame showing laryngeal elevation (18).

  Swallow time: the length of the time from start of swallow to the re-closing of the esophagus
- MOTT (sec): Event 3 was used for start of swallowing
- ST (sec): the time from the Start of swallow (1) until the bolus tail passes through the cricopharyngeal region (16)

Section 3: Results

Results 1:

The distribution of the timing of Start of RAMHB and CLE in Control swallowing was shown Figure 3. The mean of Start of RAMHB was 0.02±0.22 seconds and that of CLE is 0.02±0.27 seconds. Those timings are very close to zero.

The distribution of timing of RAMHB and CLE in effortful swallowing was shown in Figure 4. The mean of Start of RAMHB was 0.08±0.24 seconds and that of CLE was 0.11±0.26 seconds. Those timings are a little longer (later) than zero, but still they were very close to zero. The difference was only 2 to 3 frames.

The distribution of timing of RAMHB and CLE in K-method swallowing was shown in Figure 5. The mean of start of RAMHB was 0.19±0.40 seconds and that of CLE was 0.24±0.39 seconds. In Figure 6, modified Start of CLE was shown in (b) with adjusted scale of that of CLE (a; the same distribution of Figure 5 (b)). The mean of modified CLE was -0.97±1.48 seconds. The distribution of 1st step (Figure 6(b)) was quite early compare with 2nd step (Figure 6 (a)). The mean difference was 1.21(0.24-(-0.97)=1.21) seconds. Further when the modified CLE was divided into 2 groups by 1-step subjects (group 1; Gr1) and 2-step subjects (group 2; Gr2), the difference became clearer (Figure 7). The mean Gr1 was -0.00±0.10 seconds whereas that of Gr2 was -2.17±1.52 seconds. These 2 groups were significantly different (p<0.0001*).

Figure 8 showed the bivariate relationship between start of RAMHB and CLE in 3 methods (Figure 8(a)(b)(c)). The relationship between these 2 events has a very high correlation (R^2= 0.917955, R^2=0.876748, R^2=0.97238; p<0.0001*). Figure 8(d) showed the bivariate relationship between start of RAMHB and modified CLE in K-method swallowing (R^2= 0.144, p=0.058). After grouping of K-method results were shown in Figure 8(f,g). The relationship between start of RAMHB and CLE became apparent, but in group 2, it was very weak.

One-way analysis of start of RAMHB and CLE was done (Figure 9). There were no significant differences in RAMHB. However, on CLE (Figure 9(b)), the distribution between K-method and Control was significantly different (p=0.0037*). Modified K-method and other distributions were compared, it was totally different from others.(p<0.05). Further, K method was divided into K1(Gr1) and K2(Gr2). The result was Figure 9(c). K2 was different from others and K1 had similar distribution as others (K2 / C; p =0.0001*, K2 / E; p =0.0016*, K2 / K1 p <0.0001*).

Results 2:

The pattern of event occurrence order was created as Figures 10 to 12. No same patterns were observed in all methods of swallowing, even in Control swallowing (Figure 10). Modified K-method swallowing was also created and no same pattern was observed (Figure 12).

Tables 1 – 4 summarized these patterns. In the tables, occurrence order was in the top line. Event numbers were aligned by the order of occurrence in the left column. The median was used for this alignment. In Table 3 event 18, the lead protector was superimposed to the lower part of larynx in 1 swallow. As a result the datum was not available.

Swallowing started from events 1(Start of swallow), 2(Close the mouth), 4(Hyoid bone starts to elevate), 12(Open lingual seal) and 18(Modified continuous laryngeal elevation). Start from 2 was 15 in Control, 19 in Effortful, 15 in K-method and 14 in modified K-method. Start from 1 was 9 in Control, 5 in Effortful, 8 in K-method and 6 in modified K-method. Start from 4 was 2 in Control, 3 in Effortful, and 6 in K-method and modified K-method. Start from 12 was 1 in Control and Effortful, 2 in K-method. Start from 18 was 5 in modified K-method.

The proposed models of event orders were shown as below. The numbers in brackets showed no significant difference ($p<0.05$). If the median was the same in events, the average was considered.

Proposed model of Control swallowing

(2,1)→4→3→(5,12)→(18,13,6)→10→15→(11,17)→19→7→8→(16,14)→9

Proposed model of Effortful swallowing

2→(1,4)→3→(5,12)→13→(6,10,18)→(15,17)→11→(7,19)→8→16→14→9

Proposed model of K-method swallowing

2→(1,4)→(5,3)→(12,13)→(10,6)→18→(15,17,11)→(7,19)→8→(14,16)→9

Proposed model for modified K-method

(2,1,4)→(5,3)→(12,13,18)→(6,10)→(15,17)→11→(7,19)→8→(14,16)→9

Using these proposed models, table of order of event occurrence for each swallowing method was created (Table 5(a)). Furthermore, arrangement of expression was made inserting blank cells and made Start of pharyngeal phase (10) in the same row. (Table 5 (b,c,d)). Event occurrence 2,1,4,5,12,13,10,15,8, and 9 became in the same rows. 17 and 11, 7 and 19, and 14 and 16 were next to each other. 3 and 6 were within next to the next. Only 18 (Start of continuous laryngeal elevation) of Effortful and K-method swallowing was apart from Control swallowing and modified K-method swallowing.

Results 3:

Measurement of OTT, PTT, PDT, MOTT were as follows.

Table 6 to 8 summarized the results of OTT, PTT, PDT, MOTT, MPDT in each swallowing method.

OTT was observed as longest in K-method (Mean±SD: 2.90±1.50 seconds), followed by Control and Effortful swallowing (1.58±0.57, 1.58±0.52 seconds, respectively). K-method and Control swallowing, and K-method and Effortful swallowing were significantly different (p=0.0003, p=0.0002, respectively).

PTT was longest in K-method (0.88±0.38 seconds), next in effortful (0.74±0.23 seconds), then in control (0.67±0.24 seconds). Only K-method and Control swallowing was significantly different (p=0.0138).

PDT was longest in K-method (0.24±0.39 seconds), next in effortful (0.11±0.26 seconds), and in control (0.02±0.27 seconds). Only K-method and Control swallowing was significantly different (p=0.0039).

MOTT was almost the same in Control (0.98±0.46 seconds) and in Effortful swallowing (1.04±0.45 seconds), and the longest in K-method (1.80±1.03 seconds). Control and Effortful swallowing were significantly different from K-method (p=0.0031, p=0.0085, respectively).

ST was almost the same in Control (1.96±0.56 seconds) and in Effortful swallowing (1.97±0.49 seconds), and the longest in K-method (3.00±1.29 seconds). Control and Effortful swallowing were significantly different from K-method (p=0.0014, p=0.0010, respectively).

Section 4: Discussion and Conclusion

This study was intended to verify how the K-method is different from other rehabilitation methods for dysphagia. There are many factors to influence the results of VF, such as food consistency, food volume, feeding method, swallowing postures, etc. In this study, thin liquid was not used and food volume was fixed. So limited information was gained. As thin liquid was not used, the function of lingual seal (lingo-palatal closure) could not be evaluated because even it was open, food (bolus) did not enter into pharynx earlier.

Many reports[3,7-9] used the definition of Start of pharyngeal phase as the time when the bolus head passes the posterior edge of the mandibular ramus or inferior border of the mandible, because it is easy to determine the frame and better reproducibility can be gained. On the other hand Kendal et al[10] reported the definition of Onset of pharyngeal transit as the first movement of the bolus from a stable or "hold" position that passes the posterior nasal spine. Posterior nasal spine is easy to identify when cepahlometric radiograph in orthodontic treatment is taken, but as for the videofluorograph of swallowing, it is rather difficult to identify this anatomical landmark. This was the reason we did not use this definition.

Tipper position was defined and used in this study. According to Dodds et al[11] there are 2 types of onset of oral swallowing phase, Tipper and Dipper. If it is Dipper type, major part of bolus is in anterior sublingual meatus, beneath anterior tongue tip. With onset of swallowing, tongue tip dips beneath bolus in a scooping motion to elevate bolus to supralingual location, as in tipper swallow. When bolus is supralingual and tongue tip reaches back of maxillary incisor, dipper swallow proceeds in same manner as a tipper swallow.

In Study 1, the relationship between rapid hyoid movement and continuous laryngeal elevation was evaluated. The continuous laryngeal elevation is often used as the Start of pharyngeal stage[12].

In control swallowing, both RAMHB and CLE were very close to zero (0.02±0.22 seconds, 0.02±0.27seconds, respectively). Standard deviation was very small. As a result we can conclude that there are no difference between start of the pharyngeal phase and start of the pharyngeal stage in control. That means in normal swallowing pharyngeal phase and pharyngeal stage can be regarded as the same timing and both RAMHB and CLE can be regarded as the start of the pharyngeal stage.

In effortful swallowing, both RAMHB and CLE (0.08±0.24 seconds, 0.11±0.26 seconds, respectively) were also very close to zero (bolus movement; phase), but a little longer than control swallowing (within 2 frames). Standard deviation was almost the same as control swallowing. That may indicate intentional swallowing take a little longer time than control swallowing.

In K-method swallowing, although both RAMHB and CLE were also close to zero (0.19±0.40 seconds, 0.24±0.38 seconds, respectively), it was much longer than Control and Effortful swallowing. Further standard deviation was also doubled. Large standard deviation may indicate the difficulty of the way of K-method swallowing.

In Modified K-method swallowing 2 groups were observed in CLE, Gr1 (1-step CLE) and Gr2 (2-step CLE). If Modified K-method swallowing was not divided, the correlation between RAMHB and

Modified CLE was not seen, but if divided, it was seen in Gr1. This indicated that Gr1 could not change the timing of CLE, suspected failure of K-method swallowing.

K-method swallowing requires to make /ki/ sound position silently. This was required to pull the larynx earlier and then swallow the bolus. That means 2-step elevation of larynx is critical to do K-method swallowing[13)]. Four subjects made 2-step CLE and 5 subjects made 1-step CLE. Although the indication how to make K-method swallowing, it may be difficult and more detailed explanation how to make K-method swallowing is necessary.

From Study2, the beginning of swallowing was from events 1 (Start of swallow; tongue), 2(Close the mouth; masticatory muscles), 4(Hyoid bone starts to elevate; suprahyoid muscles), 12(Open lingual seal; soft plate muscles and tongue) and 18(Modified continuous laryngeal elevation: external laryngeal muscles). From these 5 events, Open lingual seal is the function to allow the bolus entering into the pharynx. Lingual seal is required to maintain the liquid bolus in the oral cavity and if it is disturbed, premature swallow occurs and the risk of aspiration becomes high. In this study only thickened test food was used and no risk for premature swallow. So this function was not clarified in this study.

2-step swallows were observed in Modified K-method. This was intentionally done by instruction of K-method swallowing. When actually pronouncing /ki/ sound, the elevation of larynx accompanied. However, it was difficult for some subjects to pretend pronouncing /ki/ without actual sound. Five failed and 4 succeeded resulting 2 groups.

During closing the mouth, a little elevation of hyoid bone often be seen, but this movement was not every time related to continuous elevation.

Continuous elevation of hyoid bone may relate more to the tongue position. To scoop up the test food on the tongue (1: Start swallow) and then swallowing occurs. This pattern is called Dipper swallow11). After starting the swallow, tipper position occurs. As OTT is different between Tipper type and Dipper type, although this study forced the subjects to swallow with dipper type, tipper type OTT was also measured as MOTT. The mean OTT in Control was 1.58 seconds in our study and maximum was 2.6 seconds. The mean of MOTT in control was 0.98 seconds and the maximum was 1.87 seconds. Logemann[5)] in her textbook stated OTT is always under 1.5 seconds in normal subjects and usually less than 1 second. She also stated that OTTs have been found to lengthen slightly with age and bolus consistency (thicker boluses result in slightly slower OTTs). As our experiment used thick food, even MOTT was a little longer. However Sonies et al[14)] reported that the mean of total swallowing time of healthy younger volunteers (18-54 y) was less than 1.5 seconds and that of older healthy volunteers was almost 2.5 seconds.

In K-method it was 1.58 times longer than Control and Effortful swallowing. It was because K-method requires the action to make /ki/ sound position and keeps the position and starts to swallow from that position. This complicated way of K-method may take time to prepare to swallow and OTT became very long.

PTT was also become gradually longer in Effortful and K-method, but not so different. It may be because it was rather reflective action and not necessary to think about how it should be managed. To strengthen the swallow might take time a little longer.

PDT was not different among the methods. This result was very similar with the report of Logemann's review[15)].

ST was longest in K-method followed by Effortful and Control. This was occurred by the same reasons.

In conclusion RAMHB and CLE could be the beginning of the pharyngeal stage, but if it was modified by intention, the timing of CLE could be changed. CLE should not be the reference of the onset of the pharyngeal stage. It may be influenced by the volitional swallow. K-method swallowing can be differentiated by other swallowing using time measurement. The most important event was the laryngeal elevation. It was indicated that the 2-step elevation might be the critical.

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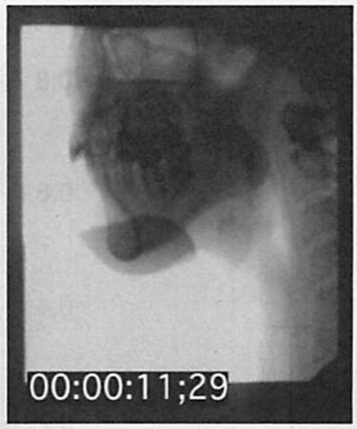
Figure 1 Time code was superimposed in each frame. The time of this frame is 9 seconds and 4 frames, that is, 9 and 4/30 (9.13) seconds.

Figure 2-1 Definition. (1) Start of swallow (2) Close the mouth (3) Tipper position (4) Hyoid bone starts to elevate (5) Maximum elevation of the hyoid bone (6) Start of the quick anterior movement of the hyoid bone

(10)



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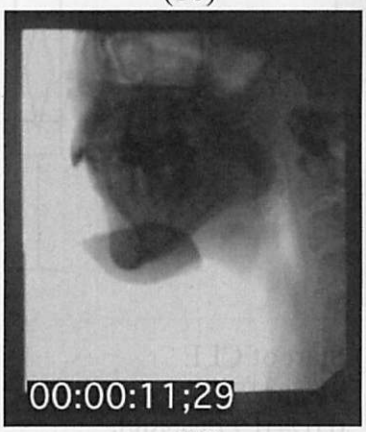

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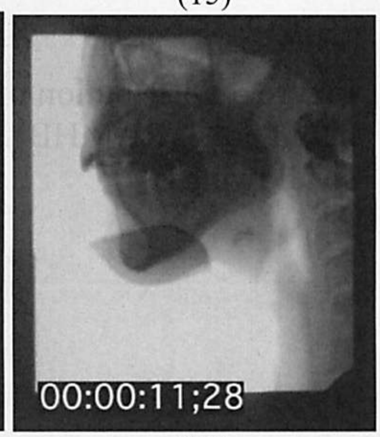
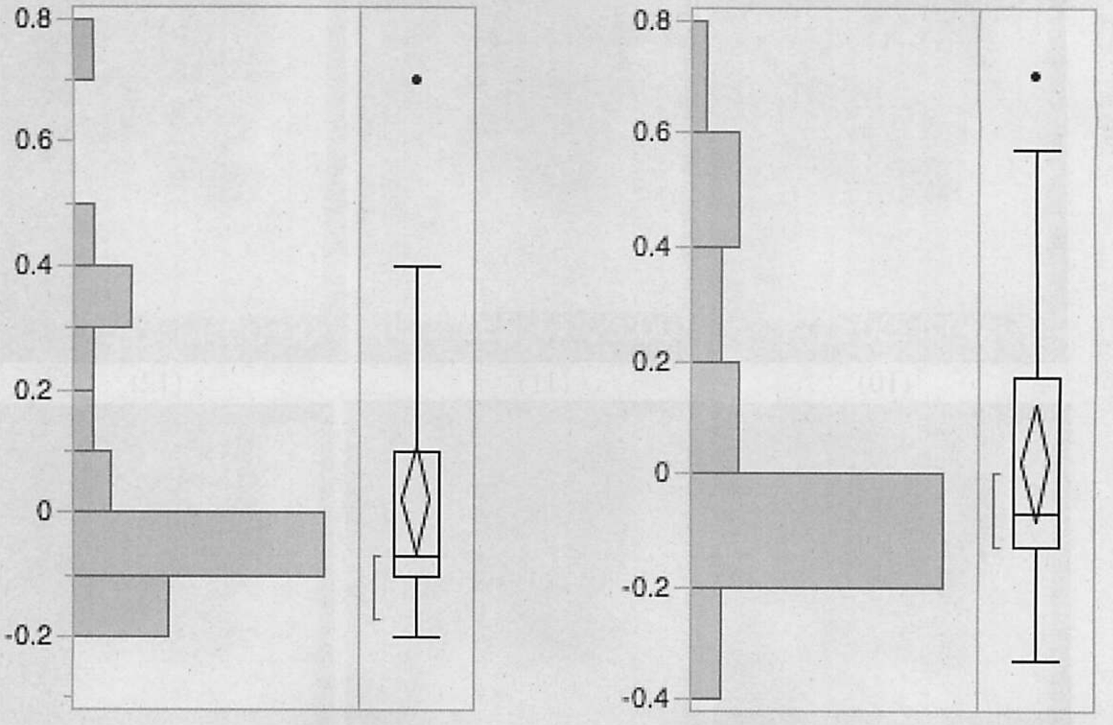


(18)

(19)

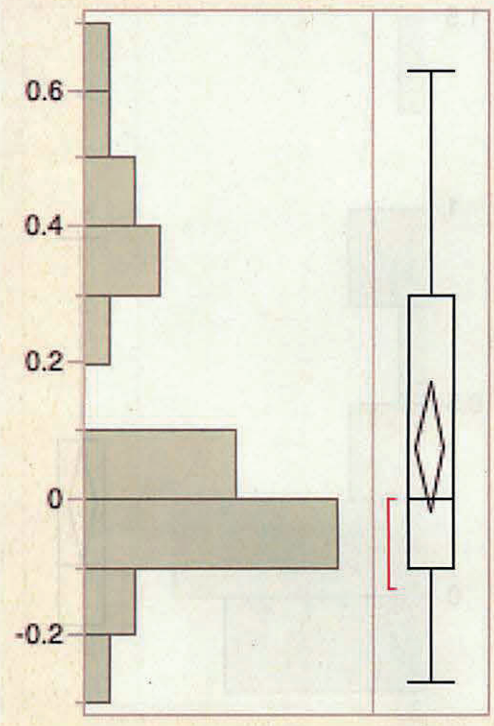
Figure 2-2 Definition. (10) Start of the pharyngeal phase (11) End of the oral phase (12) Open lingual seal (13) Start of velopharyngeal closure (14) Re-open velopharyngeal closure (15) Open the esophageal orifice (16) Close the esophageal orifice (17) Total laryngeal closure (18) Start of continuous laryngeal elevation (19) Maximum laryngeal elevation



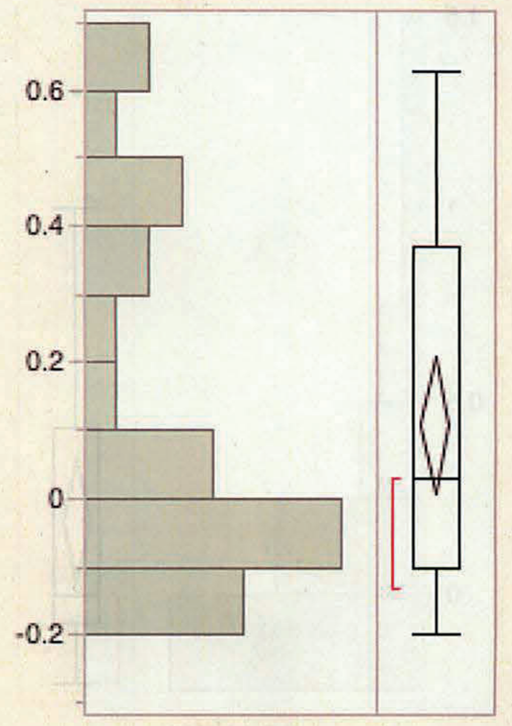
(a) Start of RAMHB
Mean±SD
0.02±0.22 seconds

(b) Start of CLE
Mean±SD
0.02±0.27 seconds

Figure 3 Distribution of the timing of Start of rapid anterior movement of hyoid bone (RAMHB) and continuous laryngeal elevation (CLE) in control swallowing

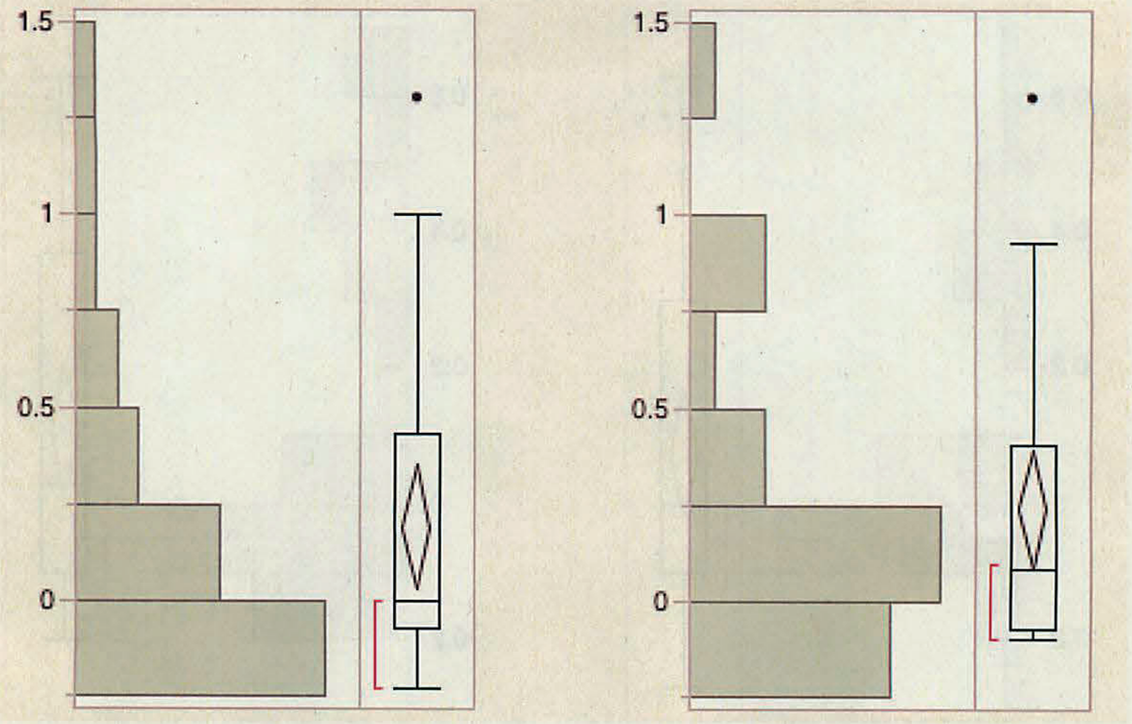


(a) Start of RAMHB
Mean±SD
0.08±0.24 seconds



(b) Start of CLE
Mean±SD
0.11±0.26 seconds

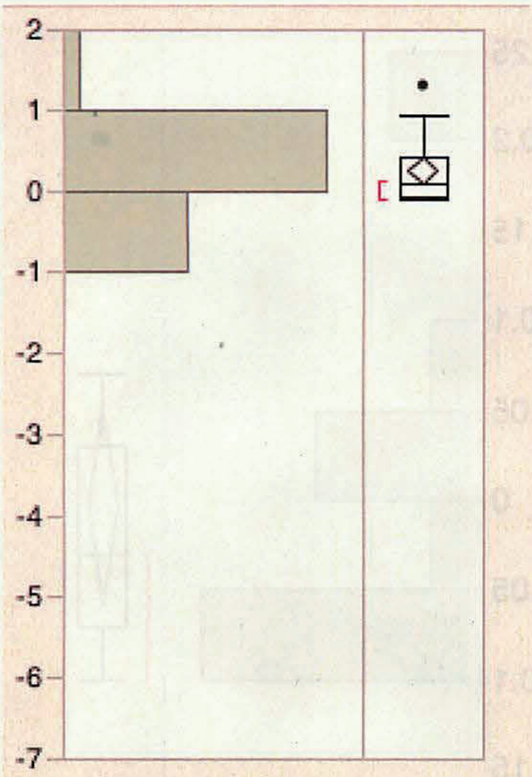
Figure 4 Distribution of t the timing of Start of RAMHB and CLE in effortful swallowing



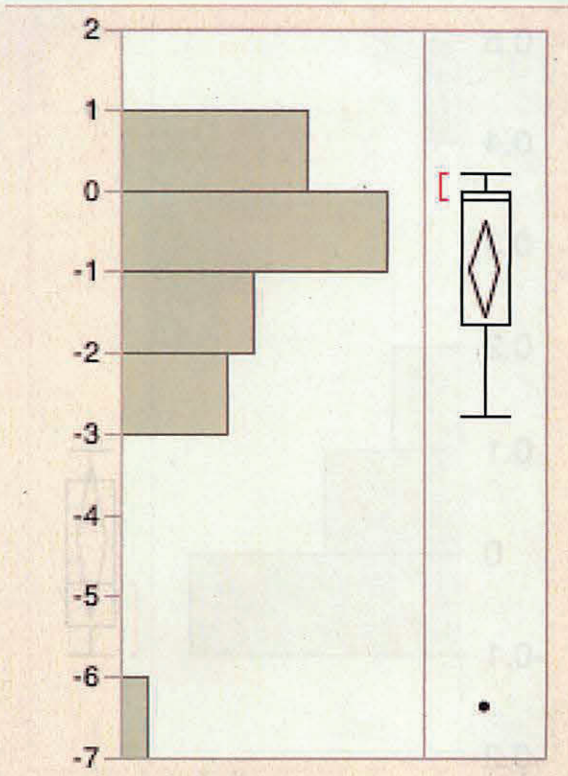
(a)Start of RAMHB
Mean±SD
0.19±0.40 seconds

(b) Start of CLE
Mean±SD
0.24±0.39 seconds

Figure 5 Distribution of the timing of Start of RAMHB and CLE in K-method swallowing

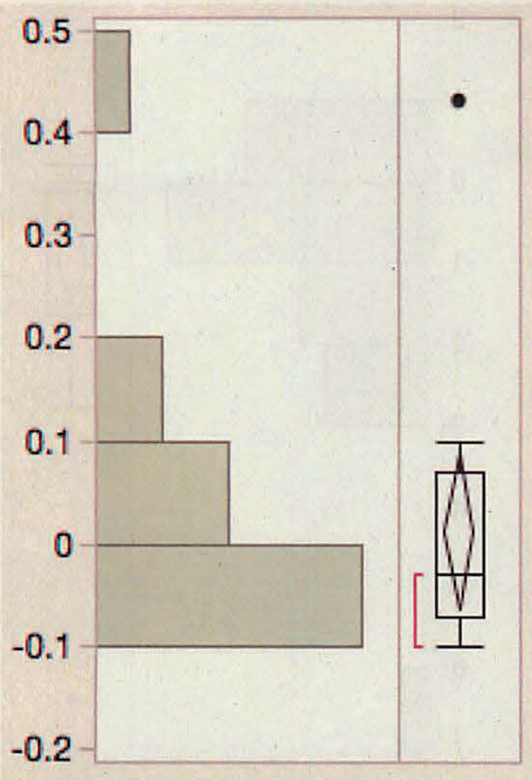


(a) Start of CLE
Mean±SD
0.24±0.39 seconds

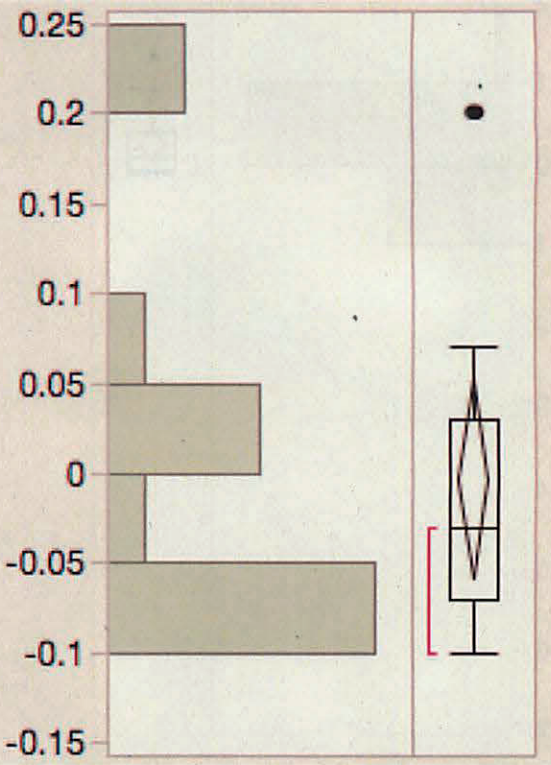


(b) Modified Start of CLE
Mean±SD
-0.97±1.48 seconds

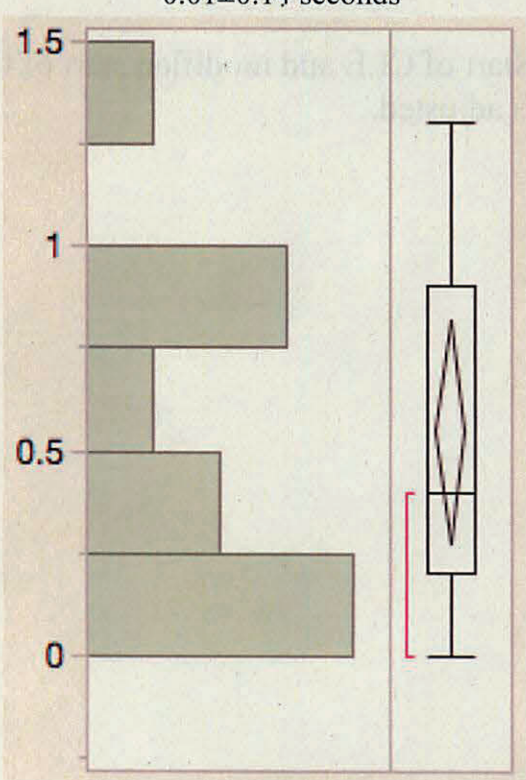
Figure 6 Distribution of the timing of Start of CLE and modified start of CLE in K-method swallowing. The scale was adjusted.



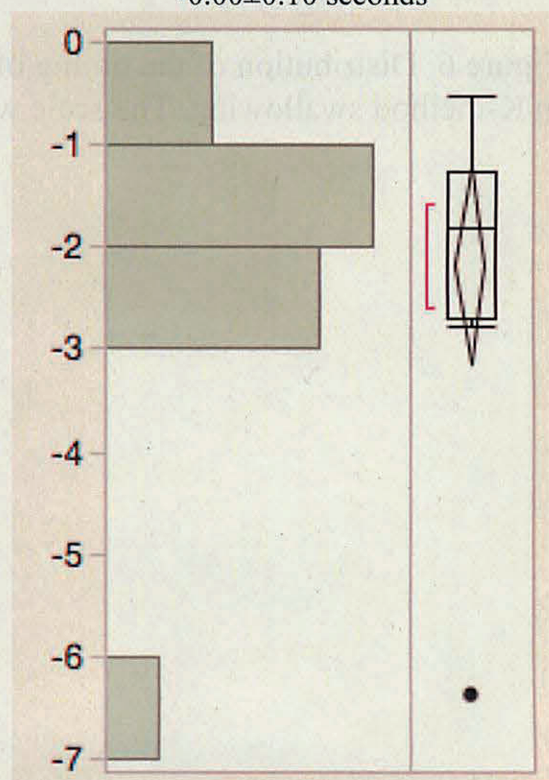
(a) Start of CLE of Gr1 (N=15)
Mean±SD
0.01±0.14 seconds



(b) Modified Start of CLE of Gr1 (N=15)
Mean±SD
-0.00±0.10 seconds

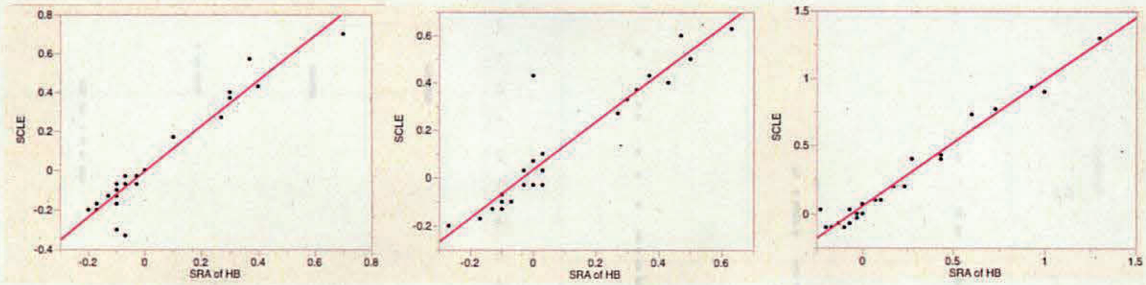


(c) Start of CLE of Gr2 (N=11)
Mean±SD
0.55±0.40 seconds

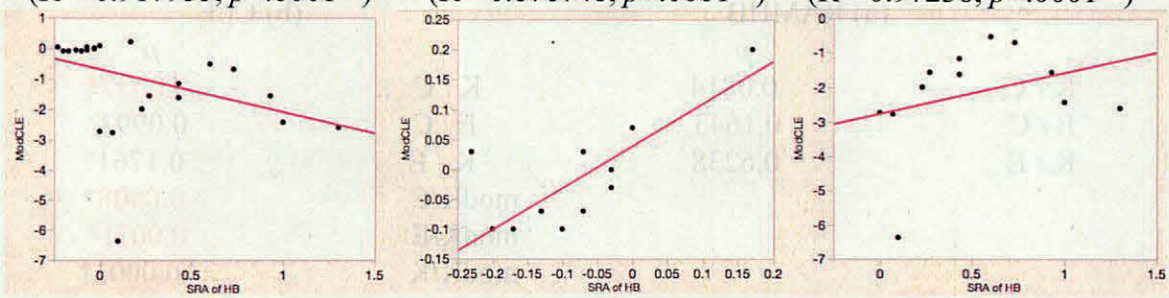


(d) Modified Start of CLE of Gr2 (N=15)
Mean±SD
-2.17±1.52 seconds

Figure 7 Distribution of Start of CLE and modified start of CLE in K-method; (a) and (b) are Gr1 (1-step), (c) and (d) are Gr2 (2-step).

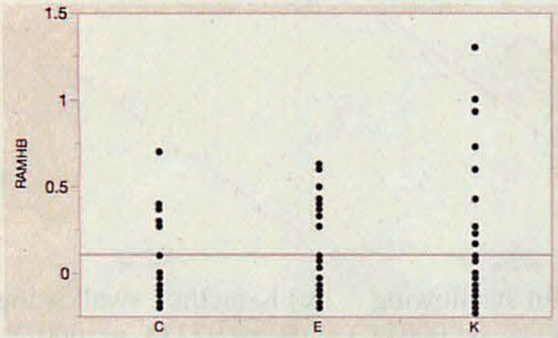


(a) Control swallowing (R^2= 0.917955, p<.0001*) (b) Effortful swallowing (R^2=0.876748, p<.0001*) (c) K-method swallowing (R^2=0.97238, p<.0001*)



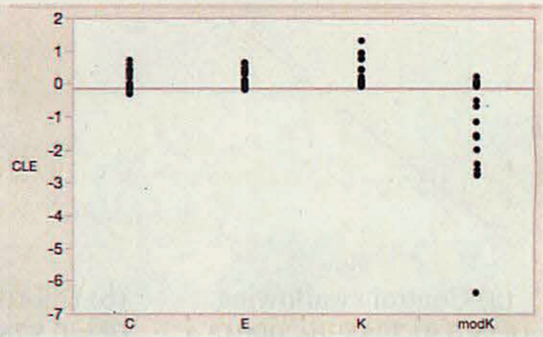
(d) Modified K-method (total) (R^2= 0.144, p=0.058) (e) Modified K-method (Gr1) (R^2= 0.640, p=0.0003*) (f) Modified K-method (Gr2) (R^2= 0.103, p=0.309)

Figure 8 Bivariate relationships between start of RAMHB and CLE in 3 methods (a,b,c) and , Modified CLE in K-method (d)



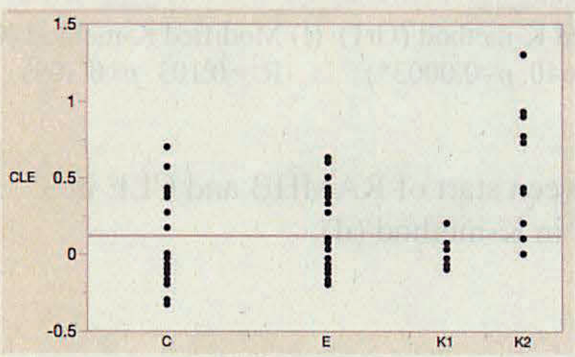
(a) RAMHB

	p
K / C	0.0814
E / C	0.1643
K / E	0.6238



(b) CLE

	p
K / C	0.0037*
E / C	0.0992
K / E	0.1761
modK/C	0.0408*
modK/E	0.0011*
modK/K	<0.0001*



(c)Modified CLE

	p
K2 / C	0.0001*
K2 / E	0.0016*
K2 / K1	<0.0001*
E/C	0.9992
K1/C	0.3840
K1/E	0.3836

Figure 9 One-way analysis of start of RAMHB and CLE. C; Control swallowing, E; Effortful swallowing, K; K-method swallowing, K1; Modified K-method (Gr1), K2: Modified K-method (Gr2).

Control

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	case	No
1	2	3	4	18	12	5,13		6	10	11,17		15	7	19	8	14,16		9	6-1	1
		4	3	5,12		13	10	6	18	11	15	19	7	17	8	14	16	9	5-2	2
	2,4		3	12	5	13	18	6	10	17	15	7	11,19		8	14,16		9	7-3	3
	3	2	12	4	18	5,13		6	10	17	11	15	7	19	8	16	14	9	6-3	4
	4	2	3	5	12	10	6	13	18	15	17	11,19		7	8	14	16	9	8-3	5
				12	5	13	6	18	10	15,17		7,11,19			8	16	14	9	7-2	6
					10	5	6,18		13	11	15,17		19	7	8	16	14	9	9-3	7
					13	5	6	18	10	17	15	7,19		11	8	16	14	9	7-1	8
					13,18		5	6	10	17	11,15		7	19	8	16	14	9	6-2	9
2	1	4	3	5	12	6,18		13	10	15	11	17	7	19	8	14	16	9	1-3	10
											17	7,11,19			8	16	14	9	3-3	11
						18	6	13	10	11,15		17	7,19		8	14	16	9	1-1	12
			5	3	12	6,10,13,18				11	15,17		7,19		8	14	16	9	4-1	13
						6,13,18			10	11	15	17	7,19		8,16		14	9	2-1	14
						13	6,10,18			15,17		19	7,11		8	14	16	9	2-3	15
							10	6	18	15,17		11	7	19	16	8	14	9	8-1	16
						18	6,13		10	15	7	11,19		17	8,14,16			9	4-3	17
		12	4	5	3	6,13		18	10	15,17		11	7,19		8	14	16	9	2-2	18
	1,4		3	5	12	6,18		10,13		17	15	11	7,19		8	14	16	9	1-2	19
	4	1	3	5	12	18	6,13		10	15	11	7,17,19			8	14	16	9	3-1	20
				12	5	6,18		13	10	15	7,11		17,19		8	16	14	9	3-2	21
			5	3	12	10	13	6	18	15	17	11,19		7	16	14	8	9	8-2	22
		5	1	3	12	13,18		6	10	15	7,19		17	11	8	16	14	9	4-2	23
	12	1	4	3	5	10	13	6,18		11,15		17,19		7	8	14,16		9	5-1	24
4	1	2	3,5		12	6,18		13	10	11	15	17	7	19	8	16	14	9	9-2	25
	2	1	3	5	12	6,18		10,13		11	15,17		7	19	8	14,16		9	9-1	26
12	2	4	1	3	5	10	13	6	18	11	15	7,19		17	8	14	16	9	5-3	27

Figure 10 Pattern of Control swallowing

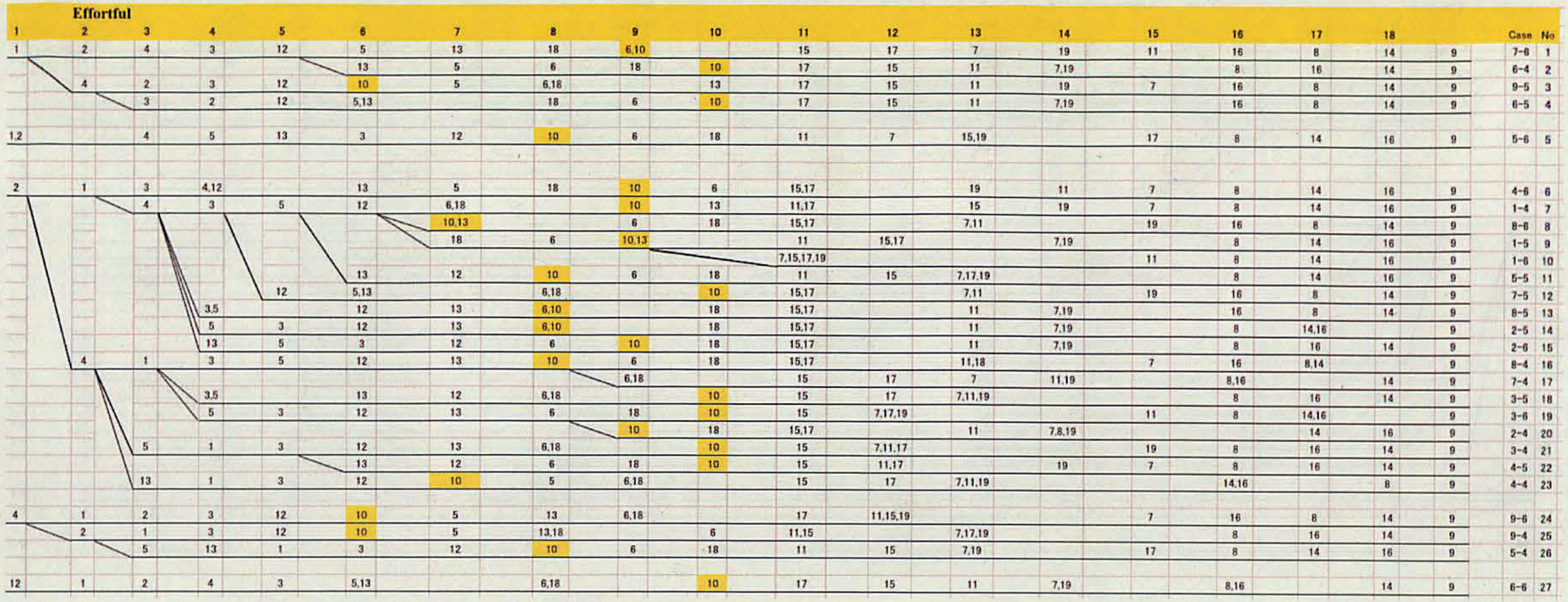


Figure 11 Pattern of Effortful swallowing

K-method

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19		No
1	2	4	3	5	13	12	10	6	18	17	15	7,11		19	8	14	16	9	7-8	1
	4	3	2	5	12	10	13	6	18	15	17	11,19		7	16	8	14	9	8-8	2
			2,12		10	13	5	6	18	15,17		11	7,19		16	8	14	9	8-7	3
			13	2	5	12	6,10		-	17	15	7,11,19			16	8	14	9	6-9	4
		3	5	2	12	10	13	6	18	15	17	11	19	7	16	8	14	9	8-9	5
1,2		4	5	3	12	6,18		10,13		11,17		15	7,19		8	14	16	9	1-8	6
						10	13,18		6	11,15,17			7,19		8	14,16		9	9-9	7
2	1	3	4,5		12	6	13	10	18	17	15	11	7	19	8	14	16	9	4-8	8
						13	6,18		10	15,17		7	11,19		8	14	16	9	4-9	9
			13	4,5		12	6,10		18	15,17		11	7	19	8	14	16	9	4-7	10
		4	3	12	10	5	6,18		13,15		11	17	7,19		8	14	16	9	9-7	11
			5	3	12	6,18		10	13	11,15,17			7,19		8	14	16	9	1-9	12
			13	5	3	12	10	6,18		11	7,15,19			17	8	14	16	9	5-7	13
		12	4	13	5	3	10	6	18	7,11		15,17,19			8	14	16	9	5-8	14
	1,4		13	5	3	12	6	10,18		15,17		11,19		7	8	14	16	9	7-9	15
	4	1	3	5	13	12	10	11	6,18		7,15,17			19	8	14	16	9	5-9	16
			5	3	12	6,18		10,13		17	11	7,15,19			8	14	16	9	1-7	17
						10	18	6,13		11,15		17,19		7	8	14,16		9	9-8	18
		13	5	1	3,12		6	10	18	17	15	11	7,19		8	16	14	9	2-7	19
					12	3	6,18		10	15	17	11	7,19		8	16	14	9	2-9	20
2,4		1	5	12	3	13	6	18	10	15	17	7,11,19			8	14,16		9	3-7	21
4	2	5	1	3	12	13	6	18	10	15	7,11,17			19	8	14,16		9	3-8	22
										15,17		19	7,11		8	14,16		9	3-9	23
		13	5	1	3	12	10	6	18	17	15	7	11,19		8	14	16	9	7-7	24
	13	2	5	1	12	3	6	10	18	15	17	7,11		19	8	16	14	9	2-8	25
12	1	2	4	3	13	10	5	11	6,18		15	17,19		7	8	16	14	9	6-8	26
	1,2		4	3	13	10	5	11	18	6	15,17		19	7	8	16	14	9	6-7	27

Figure 12 Pattern of K-method swallowing

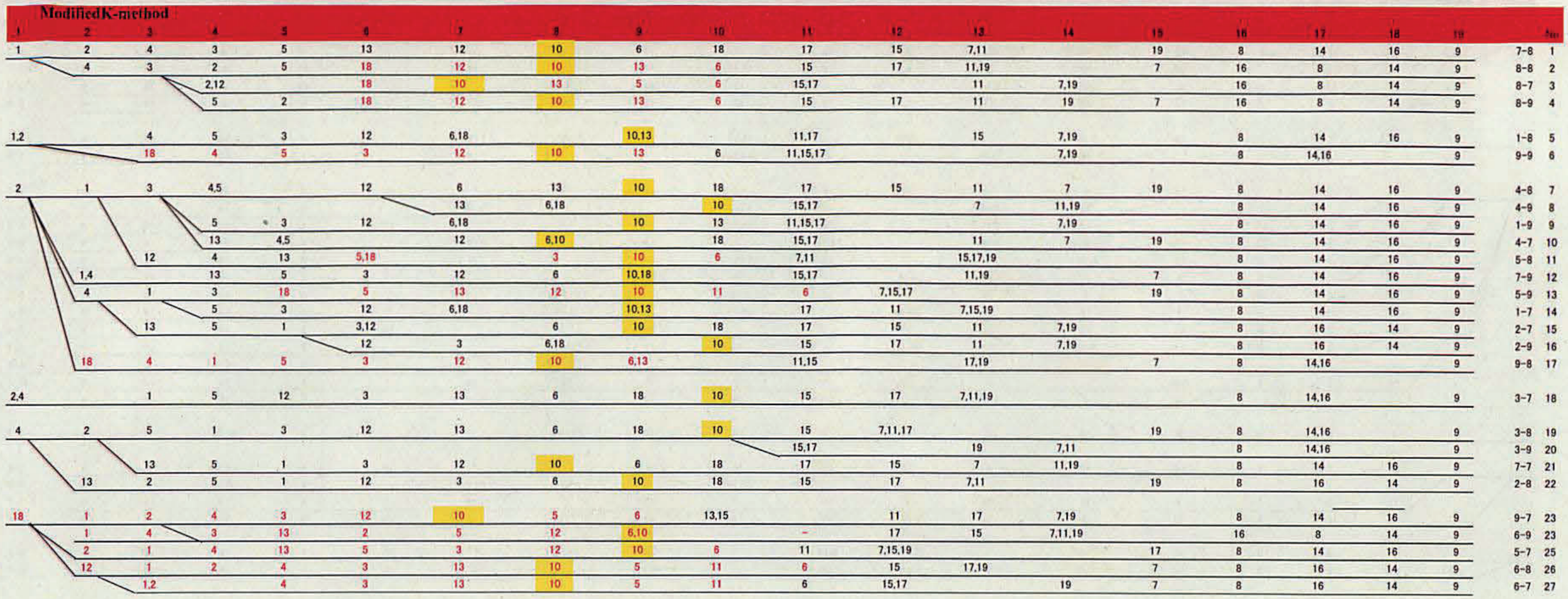


Figure 13 Pattern of Modified K-method swallowing: Red colored fonts were changed order by using modified CLE (18)

Table 1 Events distribution of Control swallowing

Control		Occurrence Order																		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	total
Event No	2	15	5	7																	27
	1	9	11	5	2																27
	4	2	11	10	3	1															27
	3		1	1	15	9	1														27
	5			1	7	9	5	4	1												27
	12	1	1	1	1	7	16														27
	18					1	2	12	3	4	5										27
	13						2	11	5	8	1										27
	6							9	8	10											27
	10						1	5	3	2	16										27
	15											14	11	2							27
	11											10	5	8	2	2					27
	17											10	6	6	2	3					27
	19												1	11	8	7					27
	7												3	6	14	4					27
	8																25	1	1		27
	16																4	13	10		27
	14																1	15	11		27
	9																			27	27

Proposed model of occurrence

(2,1)→4→3→(5,12)→(18,13,6)→10→15→(11,17)→19→7→8→(16,14)
→9

Table 2 Events distribution of Effortful swallowing

Occurrence Order

Effortful		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	total
Event No	2	19	4	3	1																27
	1	5	12	6	3	1															27
	4	3	10	12	2																27
	3			2	15	7	3														27
	5			3	6	8	4	5	1												27
	12	1			1	7	12	6													27
	13			1	2	1	8	9	2	2	2										27
	6							1	14	10	2										27
	10						3	2	7	7	8										27
	18							3	9	6	9										27
	15											17	8	2							27
	17											15	8	2		2					27
	11											6	3	13	2	3					27
	7											1	3	9	8	6					27
	19											1	2	8	13	3					27
	8														1		17	8	1		27
	16																11	8	8		27
	14																1	11	15		27
	9																			27	27

Proposed model of occurrence

2→(1,4)→3→(5,12)→13→(6,10,18)→(15,17)→11→(7,19)→8→16→14→9

Table 3 Events distribution of K-method swallowing

K-method	Occurrence No 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	total
Event No 2	15	5	3	2	2															27
1	8	9	4	2	4															27
4	6	9	6	5	1															27
5		1	1	13	6	2	1	3												27
3			7	3	10	4	3													27
12	2		1	1	1	15	7													27
13		1	3	4	1	4	5	4	3	2										27
10						2	6	7	7	5										27
6							4	11	8	3	1									27
18							3	5	5	13										26
15											15	9	3							27
17											14	7	5		1					27
11									3		7	2	12	3						27
7											1	3	7	10	6					27
19												1	9	11	6					27
8																23	4			27
14																	19	8		27
16																4	10	13		27
9																			27	27

In event 18, the lead protector was superimposed to the lower part of larynx in 1 swallow. As a result the datum was not available.

Proposed model of occurrence for K-method
2→(1,4)→(5,3)→(12,13)→(10,6)→18→(15,17,11)→(7,19)→8→(14,16)
→9

Table 4 Events distribution of modified K-method swallowing

Modified K-method / Event No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	total
2	14	4	3	4	1	1														27
1	6	8	6	3	4															27
4	6	7	6	5	3															27
5		1	1	11	6	3	1	1	3											27
3			6	3	7	7	3	1												27
12		2	1	1		12	8	3												27
13		1	3	2	3	1	7	2	6	2										27
18	5	1	1		1	4	3	2	4	6										27
10							2	9	11	5										27
6							4	9	5	6	3									27
15											15	9	3							27
17											14	7	5		1					27
11										3	7	2	12	3						27
7											1	3	7	10	6					27
19												1	9	11	6					27
8																23	4			27
14																	19	8		27
16																4	10	13		27
9																			27	27

Modified proposed model for K-method
(2,1,4)→(5,3)→(12,13,18)→(6,10)→(15,17)→11→(7,19)→8→(14,16)→
9

Table 5 Order of event occurrence by median

(a) Original

Order	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Control	2	1	4	3	5	12	18	13	6	10	15	11	17	19	7	8	16	14	9
Effortful	2	1	4	3	5	12	13	6	10	18	15	17	11	7	19	8	16	14	9
K-method	2	1	4	5	3	12	13	10	6	18	15	17	11	7	19	8	14	16	9
Modified K-method	2	1	4	5	3	12	13	18	6	10	15	17	11	7	19	8	14	16	9

(b) Arranged; events numbers in the brackets of each swallowing method were same colored

Order	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Control	2	1	4	3	5	12	18	13	6	10	15	11	17	19	7	8	16	14	9
Effortful	2	1	4	3	5	12	13	6	10	18	15	17	11	7	19	8	16	14	9
K-method	2	1	4	5	3	12	13	10	6	18	15	17	11	7	19	8	14	16	9
Modified K-method	2	1	4	5	3	12	13	18	6	10	15	17	11	7	19	8	14	16	9

(c)Arranged; adjusted for aligning event 10 in the same row (9th), blank cells were inserted to align as many same events number as possible

Order	1	2	3	4	5		6		7		8	9		10	11	12	13	14	15	16	17	18	19
Control	2	1	4	3	5		12	18	13		6	10			15	11	17	19	7	8	16	14	9
Effortful	2	1	4	3	5		12		13		6	10		18	15	17	11	7	19	8	16	14	9
K-method	2	1	4		5	3	12		13			10	6	18	15	17	11	7	19	8	14	16	9
Modified K-method	2	1	4		5	3	12		13	18	6	10			15	17	11	7	19	8	14	16	9

(d) Colored brown for all in the same row, purple for 3, green for 2

Order	1	2	3	4	5		6		7		8	9		10	11	12	13	14	15	16	17	18	19
Control	2	1	4	3	5		12	18	13		6	10			15	11	17	19	7	8	16	14	9
Effortful	2	1	4	3	5		12		13		6	10		18	15	17	11	7	19	8	16	14	9
K-method	2	1	4		5	3	12		13			10	6	18	15	17	11	7	19	8	14	16	9
Modified K-method	2	1	4		5	3	12		13	18	6	10			15	17	11	7	19	8	14	16	9

Table 6 Summary of Control swallowing

Control	OTT(sec)	PTT(sec)	PDT(sec)	MOTT'sec)	ST(sec)
1-1	1.10	0.60	-0.13	0.67	1.57
1-2	1.30	0.57	-0.10	0.83	1.70
1-3	1.43	0.57	-0.13	0.97	1.87
2-1	0.73	0.77	0.00	0.30	1.37
2-2	0.77	0.67	-0.03	0.37	1.23
2-3	1.17	0.67	0.00	0.53	1.57
3-1	1.90	0.53	-0.20	1.60	2.27
3-2	2.23	0.47	-0.20	1.67	2.53
3-3	1.60	0.43	-0.17	1.37	1.83
4-1	0.97	0.50	-0.13	0.47	1.30
4-2	0.93	0.47	-0.13	0.70	1.10
4-3	1.27	0.50	-0.13	0.60	1.53
5-1	1.10	0.80	0.27	0.67	1.47
5-2	1.67	0.70	0.17	0.47	2.13
5-3	1.00	0.87	0.37	0.53	1.47
6-1	1.73	0.60	-0.33	0.93	2.20
6-2	1.33	0.50	-0.17	0.87	1.63
6-3	1.77	0.53	-0.30	1.40	2.13
7-1	1.50	0.50	-0.03	0.90	1.73
7-2	1.83	0.47	-0.07	0.97	2.10
7-3	1.87	0.53	-0.07	1.40	2.13
8-1	2.60	1.13	0.57	1.57	2.97
8-2	2.50	1.10	0.43	1.33	2.83
8-3	2.60	1.07	0.40	1.57	2.93
9-1	2.53	0.60	-0.03	1.87	3.00
9-2	1.20	0.60	-0.07	0.50	1.67
9-3	2.13	1.33	0.70	1.33	2.57
Mean	1.58	0.67	0.02	0.98	1.96
SD	0.57	0.24	0.27	0.46	0.56

Table 7 Summary of Effortful swallowing

Effortful	OTT(sec)	PTT(sec)	PDT(sec)	MOTT(sec)	ST(sec)
1-5	1.13	0.57	-0.13	0.73	1.57
1-6	1.13	0.63	-0.10	0.83	1.53
1-7	1.33	0.63	-0.10	1.13	1.80
2-4	0.97	0.67	0.03	0.47	1.40
2-5	1.10	0.63	0.07	0.40	1.50
2-6	1.17	0.63	0.03	0.37	1.57
3-4	1.53	0.57	-0.17	1.27	1.93
3-5	2.17	0.63	-0.13	1.13	2.57
3-6	1.77	0.60	-0.20	1.13	2.20
4-4	1.37	0.83	0.27	1.10	1.70
4-5	0.80	0.73	-0.07	0.40	1.37
4-6	0.87	0.73	-0.03	0.60	1.37
5-4	1.07	0.87	0.37	0.67	1.50
5-5	2.57	1.03	0.43	2.27	3.13
5-6	2.03	0.67	0.10	0.43	2.47
6-4	1.60	0.53	-0.07	1.10	1.93
6-5	1.40	0.50	-0.13	1.10	1.70
6-6	1.53	0.57	-0.10	1.10	1.90
7-4	1.33	0.53	0.03	1.03	1.60
7-5	2.10	0.47	-0.03	1.60	2.37
7-6	1.93	0.47	-0.03	1.43	2.17
8-4	2.77	0.93	0.33	1.77	3.10
8-5	2.30	0.97	0.43	1.40	2.57
8-6	1.90	1.17	0.60	1.40	2.27
9-4	1.77	1.07	0.50	1.03	2.10
9-5	1.73	1.20	0.63	1.17	2.10
9-6	1.17	1.17	0.40	0.97	1.73
Mean	1.58	0.74	0.11	1.04	1.97
SD	0.52	0.23	0.26	0.45	0.49

Table 8 Summary of K-method swallowing

K-method	OTT(sec)	PTT(sec)	PDT(sec)	MOTT'sec)	ST(sec)
1-7	4.13	0.53	-0.07	1.40	3.97
1-8	1.93	0.57	-0.07	1.10	1.97
1-9	4.23	0.57	-0.10	1.33	4.37
2-7	0.87	0.57	0.03	0.57	1.03
2-8	0.80	0.70	0.03	0.57	1.07
2-9	1.10	0.67	-0.03	0.73	1.20
3-7	1.50	0.53	-0.10	0.93	1.83
3-8	1.27	0.53	-0.07	0.77	1.60
3-9	1.50	0.50	-0.10	1.27	1.77
4-7	3.93	0.63	0.07	3.70	3.67
4-8	3.53	0.77	0.03	2.83	3.77
4-9	3.60	0.63	-0.07	3.20	3.53
5-7	6.10	0.67	0.10	0.40	6.50
5-8	6.97	0.93	0.10	3.43	4.57
5-9	4.33	1.03	0.43	3.20	4.50
6-7	2.40	1.63	0.90	1.97	2.60
6-8	2.20	1.87	1.30	1.87	2.70
6-9	2.17	0.57	-	1.83	2.43
7-7	1.83	0.83	0.20	1.40	1.77
7-8	3.67	0.97	0.20	2.87	3.73
7-9	2.23	0.80	0.00	1.13	2.43
8-7	3.43	1.33	0.77	2.73	3.73
8-8	3.77	1.33	0.73	3.07	4.10
8-9	3.43	1.00	0.40	2.97	3.73
9-7	2.37	0.80	0.20	0.77	2.70
9-8	2.47	1.07	0.40	1.03	2.77
9-9	2.67	1.60	0.93	1.43	3.07
Mean	2.90	0.88	0.24	1.80	3.00
SD	1.50	0.38	0.39	1.03	1.29