Impact of spinal kyphosis on gastric myoelectrical activity in elderly patients with osteoporosis

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ABSTRACT

An association between spinal kyphosis and gastroesophageal reflux disease (GERD) was reported in recent years. However, it remains unclear whether spinal kyphosis affects gastric motility. We evaluated the changes in myoelectrical activity measured by electrogastrography (EGG) in elderly osteoporosis patients. A total of 18 patients scheduled for the treatment of osteoporosis were included in this study. They were analyzed by recording EGG to assess myoelectrical activity and heart rate variability (HRV) to evaluate the autonomic nervous system function before and after meals. Dominant power (DP) representing the strength of gastric electrical activity and dominant frequency (DF) representing its frequency were analyzed in blocks with a 5-minute duration. We divided the patients into 2 groups, thoracolumbar kyphosis (TLK) and non-TLK groups, and compared them. There were no significant differences between the 2 groups in background data. In the non-TLK group, DPs post 0–5 min were significantly higher than those during pre 5–0 min in channels 1 and 3 (P < 0.05 and P < 0.01). DF deviation in the TLK group was significantly higher than that in the non-TLK group at 10 to 15 postprandial minutes (P < 0.05). Low frequency/high frequency activity measured by HRV, reflecting the activity of the sympathetic nervous system, in the TLK group was significantly lower than that in the non-TLK group while eating (P < 0.01). The EGG of patients with spinal kyphotic deformity showed a similar change to that of patients with GERD; the spinal kyphotic deformity itself may affect gastric electrical activity.

Vertebral fracture is one of the common clinical manifestations of osteoporosis, and the fracture is likely to occur around the thoracolumbar transition. Multiple vertebral fractures cause postural kyphotic deformities around the thoracolumbar transition, influencing not only activities of daily living but also the end-organ function, such as pulmonary hypofunction, dysphagia, and gastroesophageal reflux disease (GERD) (5, 8, 10, 24, 25, 27).

GERD is defined as chronic symptoms or mucosal damage caused by the abnormal reflux of gastric acid into the esophagus (9). The prevalence of GERD increases with age; older patients are more likely to develop severe disease (31). Factors that may contribute to GERD in the elderly include age-related physiological changes such as age-related spinal kyphotic deformity, hiatal hernia, and the oral use of some drugs (10, 12, 38). The frequency of hiatal hernia is higher in females with aging than in men, similar to sex differences in patients with osteoporosis (12). Kusano et al. reported a positive correla-
tion between the size of hiatal hernia and severity of kyphosis (18). In terms of mechanisms underlying these relationships in elderly GERD patients, both the increase in intra-abdominal pressure caused by spinal kyphotic deformity and the presence of esophageal hiatus hernia can be causes (10, 12).

There have been several reports of poor gastric emptying in GERD patients (6, 22, 23, 30). Electrogastrography (EGG), a method that records the myoelectrical signal from the gastric smooth muscle through electrodes positioned on the abdominal skin, has been utilized to evaluate the gastric function in a non-invasive manner (2, 4). This examination is a reliable method in the field of gastrointestinal internal medicine, and it is frequently used clinically (16, 17). This technique has revealed abnormality of the gastric motor function in GERD patients (7, 15, 28, 34). However, it remains unclear whether spinal kyphotic deformity affects gastric motility and subsequently leads to GERD.

We previously investigated electrical signal changes before and after meals in a spinal kyphotic model of healthy adults, and confirmed abnormality of the gastric motor function similar to that in GERD patients (35). However, no studies have directly examined the relationship between spinal kyphotic deformity and gastric motility in elderly people.

The aim of this study was to evaluate the changes in myoelectrical activity measured by EGG in elderly osteoporosis patients with spinal kyphotic deformity.

MATERIALS AND METHODS

Subjects. A total of 18 patients, with a mean age of 75.9 years (65 to 88), being all outpatients visiting a single institution for the treatment of osteoporosis and spinal kyphotic deformity between January 2016 and December 2017 were included in the present study because there were many patients with spinal deformities in patients with osteoporosis. We excluded patients who had a history of surgical treatments for gastrointestinal diseases, neurological diseases, psychiatric diseases, or diabetes. All patients had received bisphosphonate for osteoporosis treatments at the time of evaluation, and 8 patients had been prescribed proton pump inhibitors.

On lateral standing X-rays of the spine including the sacrum and pelvis, we measured the thoraco-lumbar kyphosis (TLK) angle from T10 to L2, the thoracic kyphosis (TK) angle from T4 to T12, lumbar lordosis (LL) angle from L1 to S1, sagittal vertical axis (SVA) angle, and sacral slope (SS) angle to check the spinal alignment (26, 33). We performed laboratory examinations of bone metabolic markers: intact procollagen I N-terminal propeptide (P1NP) and tartrate-resistant acid phosphatase 5b (TRACP5b). We measured the bone mineral density on antero-posterior views of the lumbar spine from L2 to L4 and the femoral neck (Discovery, Hologic Inc., MA, USA). The frequency scale for the symptoms of GERD (FSSG) score is one of the methods for diagnosing GERD, involving a simplified questionnaire for evaluation of the symptoms of GERD (19). The cutoff score for GERD is set at 8 points in the FSSG score, and we evaluated the presence of GERD based on this score.

Patients were divided according to the maximum TLK angle into those with TLK angles greater than half the maximum (TLK group) and those with TLK angles less than half the maximum (non-TLK group).

Experimental design. All subjects were instructed to refrain from eating and drinking after 7:00 a.m. on the experimental day. The experiment was performed between 12:00 and 2:00 p.m. in an air-conditioned, silent room, with nobody in the room except the subject. We recorded the EGG and heart rate variability (HRV) with a neutral posture, in which subjects sat on a chair with a backrest. All subjects were instructed not to speak and to minimize other oral movements to avoid influencing the results of EGG and HRV (3, 14). At the beginning of measurement, fasting EGG and HRV were recorded for 10 min. To stimulate myoelectrical activity, semisolid jelly food (300 kcal, 300 g) was eaten by the subjects over a period of 5 min. Subjects fed themselves while maintaining their posture without using the abdominal muscles (11, 20). Postprandial EGG and HRV were then recorded for 30 min.

EGG recording and analysis. After gentle skin abra

sion to enhance electrical conduction, five silver/silver chloride adhesive electrodes (Vitrode M; Nihon Kohden, Tokyo, Japan) were attached to the abdominal skin surface in positions determined in a previous study (Fig. 1) (29). Four-channel monopolar recording (Channels 1, 2, 3, and 4) was conducted with a portable recording device (NIPRO electrogastrogram EG; NIPRO, Osaka, Japan) with the subjects in a sitting position. EGG signals were isolated using a bandpass filter between 0.035 and 0.2 Hz to exclude unnecessary noise, such as that from the heartbeat, respiration, and body movement. Signals were then digitally recorded at a sampling rate of 1 Hz. After recording of the raw EGG data, EGG
signal analysis was performed using a short-term Fourier transformation (Fig. 2). The analysis time was 120 s, and shift time was 20 s. The peak voltage in each frequency spectrum from 0.035 to 0.2 Hz was defined as the dominant power representing the strength of gastric electrical activity, and the frequency at dominant power in each frequency spectrum was defined as the dominant frequency representing the frequency of gastric electrical activity. All data were analyzed using EGS1 software (Gram, Urawa, Japan).

Dominant power and frequency data were analyzed in blocks of 5 min: from 10 to 5 min before eating (pre 10–5), 0 to 5 min before eating (pre 5–0), eating, 0 to 5 min after eating (post 0–5), 5 to 10 min after eating (post 5–10), 10 to 15 min after eating (post 10–15), 15 to 20 min after eating (post 15–20), 20 to 25 min after eating (post 20–25), and 25 to 30 min after eating (post 25–30). Mean ± SD of the dominant power and frequency were then calculated for each interval. The standard deviation of the dominant power and frequency for each interval were defined as the dominant power deviation and dominant frequency deviation, respectively.

**HRV recording and analysis.** After skin abrasion to enhance electrical conduction, two electrodes (the same type as used in EGG recordings) were attached to the right upper chest and left side of the abdomen (i.e., lead II of electrocardiography (ECG)). Recording of ECG data was conducted with a portable recording device (Pocket ECG monitor; Nihon Kohden, Tokyo, Japan) while simultaneously recording EGG. The ECG signals were isolated using a bandpass filter between 0.4 and 20 Hz, and then digitally recorded at a sampling rate of 2,000 Hz. After recording of the raw ECG data, the R-R interval (RRI) was calculated to estimate heart rate variability, and the change in RRI over time was analyzed with short-term Fourier transformation. The frequency from 0.04 to 0.15 Hz in the R-R interval spectrum was defined as low frequency, and that from 0.15 to 0.4 Hz was defined as high frequency. Low/high frequency reflects the activity of the sympathetic nervous system and the high frequency reflects the activity of the parasympathetic nervous system, so we calculated these parameters to evaluate the autonomic nervous system function (1, 39). All data were analyzed using LabVIEW software (National Instruments Japan, Tokyo, Japan). Low and high frequency data were analyzed for the same 5-min periods as for EGG, and their mean ± SD were calculated.

The study was approved by the Institutional Review Board for Clinical Research at our university (approval number: 11RS001). This was a prospective randomized study, and informed consent was obtained from all patients.

**Statistical analysis.** All values are expressed as the mean ± SD. Both a paired-sample *t*-test and Wilcoxon signed rank test were used for comparison between the TLK and non-TLK groups each time. Two-factor analysis of variance (ANOVA) was used to test for significance. Statistical differences between pre 5–0, when the electrical signal stabilized, and each postprandial timepoint for each group were compared using the Friedman rank test for multiple comparisons. Probability (P) values less than 0.05 were considered significant.

**RESULTS**

There were no significant differences between the 2 groups in background data, such as the bone mineral density, laboratory examinations, and spinal parameters excluding the thoraco-lumbar kyphosis.
The FSSG score and the presence of GERD tended to be slightly higher in the TLK group, but there was no significant difference. In the non-TLK group, the dominant powers post 0–5 and eating were significantly higher than those during pre 5–0 in channels (CH) 1 and 3 ($P < 0.05$ and $P < 0.01$). However, there was no significant difference between pre 5–0 and postprandial in the

**Table 1  Patient characteristics between the 2 groups**

| Variables          | TLK +       | TLK −       | $P$   |
|--------------------|-------------|-------------|-------|
| Numbers            | 9           | 9           |       |
| Age (years)        | 74.9 ± 5.3  | 77.0 ± 6.1  | 0.445 |
| Female/Male        | 9/0         | 8/1         | 1     |
| FSSG score         | 7.4 ± 6.4   | 4.0 ± 3.5   | 0.180 |
| GERD present       | 6           | 3           | 0.346 |
| BMD (g/cm$^2$)     |             |             |       |
| Lumbar spine       | 0.790 ± 0.155 | 0.738 ± 0.271 | 0.621 |
| Proximal femur     | 0.536 ± 0.086 | 0.520 ± 0.103 | 0.717 |
| Laboratory examinations |   |             |       |
| NTX (nmol BCE/L)   | 15.1 ± 3.0  | 16.0 ± 6.2  | 0.718 |
| BAP (μg/L)         | 12.6 ± 3.9  | 12.1 ± 3.8  | 0.770 |
| Spinal parameters  |             |             |       |
| TK                 | 37.0 ± 19.2 | 24.1 ± 20.1 | 0.181 |
| TLK                | 41.7 ± 17.2 | 10.3 ± 3.3  | <0.001|
| LL                 | 28.8 ± 13.6 | 32.9 ± 19.4 | 0.610 |
| SVA                | 70.0 ± 34.6 | 69.0 ± 79.5 | 0.973 |
| SS                 | 17.8 ± 9.9  | 22.2 ± 11.6 | 0.395 |

Values are expressed as number of patients or mean ± SD with ranges.

TLK: thoraco-lumbar kyphosis, BMD: bone mineral density, FSSG: frequency scale for the symptoms of GERD, GERD: gastroesophageal reflex disease, TK: thoracic kyphosis, LL: lumbar lordosis, SVA: sagittal vertical axis, SS: sacral slope

(TLK) (Table 1). The FSSG score and the presence of GERD tended to be slightly higher in the TLK group, but there was no significant difference.
The dominant frequency while eating in the non-TLK group was significantly lower than that of pre 5–0 in CH 2 \((P < 0.05)\), and the dominant frequencies post 20–25 and post 25–30 in the non-TLK group were significantly higher than those of pre 5–0 in CH 3 \((P < 0.05)\) (Fig. 5). However, these findings did not show any special findings. The dominant frequency deviation showed a high trend overall in the TLK group, and the dominant frequency deviation in the TLK group was significantly higher than that in the non-TLK group at post 10–15 in CH 4 \((P < 0.05)\) (Fig. 6). The presence of spinal kyphosis deformed the rhythm of the post-meal gastric elec-

TLK group (Fig. 3). Presence of spinal kyphosis suppressed postprandial dominant power increase. In the TLK groups, the dominant power deviations post 0–5 and eating were significantly higher than those during pre 5–0 in CH 1 and 3 \((P < 0.05)\). In addition, dominant power deviations post 0–5 and eating in the non-TLK group were significantly higher than those during pre 5–0 in CH 1, 2, and 4 \((P < 0.01\) and \(P < 0.05)\) (Fig. 4). The dominant power deviation increased after meals in both groups, and regardless of the presence or absence of spinal kyphosis, the intensity of the electric signal in the stomach after meals was unstable and varied.
Some reports have shown abnormality of gastric electrical activity by EGG in GERD patients, and irregular myoelectrical activity of the stomach has often been reported using EGG in GERD patients (7, 15, 28, 34). Orr et al. measured EGG in elderly GERD patients and found not only an irregular rhythm of myoelectrical activity but also a decline of the dominant frequency and suppression of a postprandial dominant power increase (28). In our previous research, just bending thoracolumbar vertebrae of healthy adults led to abnormal changes of gastric electrical activity similar to those of GERD patients, and we showed the postprandial signal.

There was no significant change in the high frequency. The low frequency/high frequency showed a low trend overall in the TLK group, and the low frequency/high frequency in the TLK group was significantly lower than that in the non-TLK group at eating ($P < 0.01$) (Fig. 7). Presence of spinal kyphosis suppressed cardiac sympathetic nerve activity.

DISCUSSION

The present study is the first to evaluate the relationship between spinal deformity and GERD in osteoporosis patients using EGG. Some reports have shown abnormality of gastric electrical activity by EGG in GERD patients, and irregular myoelectrical activity of the stomach has often been reported using EGG in GERD patients (7, 15, 28, 34). Orr et al. measured EGG in elderly GERD patients and found not only an irregular rhythm of myoelectrical activity but also a decline of the dominant frequency and suppression of a postprandial dominant power increase (28). In our previous research, just bending thoracolumbar vertebrae of healthy adults led to abnormal changes of gastric electrical activity similar to those of GERD patients, and we showed the post-
Gastric activity in elderly

There are some reports of reactions of the heart and vascular system being triggered by an artificial increase in internal gastric pressure (21, 32, 36, 37). These reports indicate that the blood pressure and heart rate increased as a result of sympathetic nervous activity of the heart and vascular system. In the present study, the low frequency/high frequency at eating in TLK patients was significantly lower than that in non-TLK patients, and sympathetic activity of the heart was suppressed in TLK patients. Considering the autonomic nerve reflection system, parasympathetic nervous activity in the stomach may be suppressed in patients with spinal kyphotic deformity.

Fig. 7 Results of high frequency and low frequency/high frequency for each thoraco-lumbar kyphosis (TLK) presence and channel. \(^*\)TLK+ compared with TLK−, \(P < 0.01\).

Other organs and tissues. There are some reports of reactions of the heart and vascular system being triggered by an artificial increase in internal gastric pressure (21, 32, 36, 37). These reports indicate that the blood pressure and heart rate increased as a result of sympathetic nervous activity of the heart and vascular system. In the present study, the low frequency/high frequency at eating in TLK patients was significantly lower than that in non-TLK patients, and sympathetic activity of the heart was suppressed in TLK patients. Considering the autonomic nerve reflection system, parasympathetic nervous activity in the stomach may be suppressed in patients with spinal kyphotic deformity.

There have been various reports on electrode positioning for EGG, but the optimal positions have not yet been determined (7, 28, 29). Although we may be able to evaluate whether our electrodes were correctly positioned to detect the cardia or pylorus, we do not know whether these positions are optimal for EGG recording. In the present study, a significant increase of postprandial dominant power deviation in non-TLK patients occurred only in CH 1 and 3, and in non-TLK patients in CH 2 and 4. CH 1 and 2 are near the exit of the stomach, and CH 2 and 4 are close to the entrance of the stomach. Depending on the spinal kyphotic deformity, the site where the dominant power variability occurs after food enters the stomach may change. We do not know the clinical significance of this change in gastric electrical activity, and so further study is necessary in the future.

In one of our previous studies, we evaluated the relationship between GERD and kyphotic deformity of the thoracic and lumbar vertebrae, the number of vertebrae showing compressive changes, and use of oral medication. As a result, only kyphotic deformity of lumbar vertebrae and the number of vertebrae showing compressive changes were related to GERD (26). However, we did not evaluate the deformity of the thoracolumbar transition in the previous study. Considering that thoracolumbar transition is the most likely to cause vertebral fracture and the number of compression changes of vertebrae is related to GERD, it is appropriate to evaluate the relationship between kyphotic deformity of thoracolumbar transition and GERD.

This study is the first prospective randomized study to report the impact of spinal kyphosis on gastric myoelectrical activity in patients with osteoporosis. However, limitations of this study should also be noted. One limitation was the small number of patients. The reason was that since the protocol might
burden the patients, the institutional review board advised us to conduct the study with as few participants as possible. Actually, there were not many patients agreeing to informed consent. Although various factors might lead to a bias, such as complications of internal disorders and physical activity, it was possible to show significant results in the present study despite the small number of patients.

In conclusion, to the best of our knowledge, the present study is the first to directly evaluate the relationship between kyphotic deformities of the thoracolumbar transition and GERD using EGG. The EGG present study is the first to directly evaluate the relationship between kyphotic deformities and GERD, and the spinal kyphotic deformity itself may affect gastric electrical activity. We need to perform further detailed studies considering various influencing factors involving more patients with spinal kyphotic deformity to clarify the effect of spinal deformity on gastric electrical activity.

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