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Physical fitness and 6.5-year mortality in an 85-year-old community-dwelling population

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ABSTRACT

Although poor physical fitness is known to be associated with increased mortality in adult and elderly populations, this association is not conclusive in very elderly. The purpose of the present study was to evaluate the association for a very old community-dwelling population. The participants (90 males, 117 females) were 85-year-old individuals residing in Fukuoka, Japan. Baseline examinations including muscle strength of the handgrip and leg extension, one-leg standing, leg stepping rate, and walking were performed in 2003 and these subjects were followed for 6.5 years. During the follow-up period, 81 individuals (49 males and 32 females) died. Handgrip strength and leg extension strength at age 85 were stronger in surviving men than in non-survivors. Total mortality adjusted for both gender and serum level of total cholesterol fell 5–6% with a 1-kg increase in the handgrip strength of a single hand or both hands. Total mortality also decreased 2% with a 1 kg increase in the leg extension strength of both legs. With adjustment for gender and total cholesterol, mortality fell by 57% in participants of the walking test and fell by 45% in participants of the stepping-rate test compared to mortality in nonparticipants. No association was found between mortality and participation in the handgrip strength test, leg extension strength test, or one-leg standing time test. In conclusion, not only poor muscle strength in handgrip or leg extension, but also nonparticipation in walking test or leg-stepping test were independent predictors of total mortality in a very elderly population.

1. Introduction

An association between mortality and physical activity or physical fitness is known in patients with diseases such as diabetes (Kokkinos et al., 2009c; Lyerly et al., 2009; McAuley et al., 2009a), hypertension (Kokkinos et al., 2009a,b; McAuley et al., 2009b), and cardiovascular diseases (Al-Khalili et al., 2007; Carlisle and Swart, 2007; Holtermann et al., 2010; Mandic et al., 2010) and in community-dwelling adults (Rantanen, 2003; Miller et al., 2005; Kokkinos et al., 2008; Park et al., 2009) and old (Mitnitski et al., 2005; Spencer et al., 2005; Newman et al., 2006b; Sui et al., 2007; Cesari et al., 2009b; Ling et al., 2010) persons. Strength of the handgrip (Newman et al., 2006a; Gale et al., 2007; Ling et al., 2010) and lower extremities (Newman et al., 2006a) was a predictor of mortality in elderly individuals. Walking speed (Cesari et al., 2009a; Bandinelli et al., 2009) and standing balance (Bandinelli et al., 2009; Cesari et al., 2009a) were also associated with mortality in the elderly.

Although there are several studies that examined the relations between physical fitness and mortality among the elderly as mentioned above, there have been very few investigations of very old community-dwelling persons of age 80 years and over. The ages of the subjects in these investigations were 60 years and over (Sui et al., 2007), 65 years and over (Mitnitski et al., 2005; Gale et al., 2007; Bandinelli et al., 2009; Cesari et al., 2009b), 65–83 years (Spencer et al., 2005), 70–79 years (Cesari et al., 2009a; Newman et al., 2006a,b), and 85 or 89 years (Ling et al., 2010), respectively. In the very old population of 85-year-old or 89-year-old community-dwelling individuals (Ling et al., 2010), the mortality of the subjects in the lowest tertile for handgrip strength

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at age 85 years was 1.35 times higher than that of the subjects in the highest tertile, and the mortality of the lowest tertile at age 89 years was 2.04 times higher. We also examined the association between mortality and physical fitness in a Japanese 80-year-old community-dwelling population, and found that all-cause mortality fell with increasing stepping rate of the lower extremities, and mortality due to pneumonia fell with increasing leg extension strength (Takata et al., 2007). However, in this population, no association was found between mortality and physical fitness measurements such as handgrip strength or one-leg standing balance (Takata et al., 2007).

Non-participating men aged 40–59 who stopped bicycle exercising tests because of impaired breathing had a higher mortality during follow-up for 26 years (Bodegard et al., 2005). Nonparticipation for regular exercise was associated with higher mortality among women aged 40–70 years (Nechuta et al., 2010). Thus, although mortality seems higher in non-participants than in participants for exercise program, little is known about an association in mortality with nonparticipation for fitness test in a very elderly population.

Although it is likely that very old community residents also have a similar association between poor physical fitness and increased mortality, this finding is not conclusive. Therefore, the purpose of the present study was to evaluate this association for another very old community-dwelling population. In addition, an association between mortality and nonparticipation in fitness test was evaluated.

2. Materials and methods

2.1. Participants

The data were from 5 years of follow-up in a population-based study of age-related general and oral health in Fukuoka Prefecture, Japan. The subjects in this study were 827 persons who were 85 years of age, who were born in 1917 and lived in 1 of 9 districts (Bunzen City, Munakata City, Yukuhashi City, Tobata Ward of Kitakyushu City, Kanda Town, Katsuyama Town, Toyotsu Town, Tsuiki Town, or Shinyoshitomi Village) in Fukuoka Prefecture, Japan. Of the 827 persons, 410 refused, 210 had died in the previous 5 years, and 207 participated in the present study, when physical fitness measurements were made and questionnaires were obtained. Of 207, 140 subjects were independent and was able to go out using public transportation by an own effort, and 53 subjects were independent, but went out only to the neighborhood by an own effort. Some subjects ($n = 12$) were living in indoor and almost independent, but did not go out without assistance, and 2 subjects were living in indoor and needed some assistance. No subjects took part in some fitness program. There were no exclusion criteria. The study was approved by the Human Investigations Committee of Kyushu Dental College, and was conducted in full accordance with ethical principles, including the World Medical Association Declaration of Helsinki, as revised in 2002. Informed written consent was obtained from all participants according to the principles mentioned above.

2.2. Physical fitness

The 85-year-old subjects completed five types of neuromuscular tests in 2003: two tests of muscle strength (hand-grip, isometric leg extension), one test of balance (one-leg standing time), one test of neuromuscular endurance (stepping rate), and one test of walking (walking speed and step). Handgrip strength test, leg extension strength test, one-leg standing test, stepping rate test, and 10 m walking test were selected, because these were safe and easy for very elderly individual. Handgrip strength test and leg extension strength test have been used in previous studies for elderly. One-leg standing test for assessing balance ability was done with eyes open to avoid falling. Stepping rates test was an index of agility of legs. Waling test 10 m was adopted for assessing lower leg functional capacity. Physical fitness tests were started from mild exercise test, and the rest time between assessments was taken approximately 10 min not to leave fatigue for the next test. The numbers of subjects participating in the tests were 198, 159, 169, 168, and 166, respectively. The hand-grip strength (Rantanen et al., 1998) on each side was measured by a Smedley hand dynamometer (DM-100S; Yagami, Nagoya, Japan). Handgrip strength test was done carefully in standing position so that dynamometer or an arm did not touch lower extremities when they measured it. The width of the dynamometer was adjusted for each participant so that the proximal interphalangeal joint becomes a right angle. Two values for each hand–one for each hand when used alone (single hand on left side, single hand on right side) and one for each hand when used in combination with the other hand (both hands mainly on right side, both hands mainly on left side)—were averaged together to determine the score for the test. Leg extension strength (Sonn et al., 1995) was measured by a portable chair incorporating a strain gage connected to a load cell. The material for isometric leg extension test was checked and calibrated before starting the daily test. The subject sat upright with a single leg or both legs hanging vertically and the knee initially bent at 90°. The trial was performed once for each single leg. The values for the two sides were averaged to find the subject's single leg extension strength score ((right leg + left leg)/2). The leg extension strength test with both legs was performed once. The stepping rate (Shindo et al., 1987) was measured once for each side using an industrial stepping rate counter (Stepping Counter GF-300; Yagami, Nagoya, Japan); while sitting, the subject was instructed to step with each leg as rapidly as possible for 10 s. The stepping rates obtained for each side were also averaged to determine the subject's score. The one-leg standing time (Haga et al., 1986) was defined as the number of seconds the subject was able to stand on one leg (with eyes open) without hopping or putting down the raised foot, or until 2 min had elapsed. Each subject took instructions from a study investigator, who observed the test from beginning to end. One trial was performed on the right leg and one trial on the left leg, and the average value of the two side measurements was considered to be the individual's score. Walking speed (Shinkai et al., 2000) was defined as the number of seconds required for individuals to walk 10 m. Walking steps were defined as the number of steps required for subjects to walk 10 m. The walking trial was performed twice, with the average value taken as the score for the subject. The baseline examinations were completed in October and November of 2003; these included medical examinations, blood sampling, and a questionnaire filled out in various public buildings. We recorded medical complication, medication, smoking, drinking, and education period from questionnaire. Blood pressure, total cholesterol, HbA1c, and body mass index (BMI) were taken from medical examination. The subjects were kept in a sitting position, and the sitting blood pressure was measured via an oscillometric method using an automatic device. BMI was defined as weight (kg) divided by square of the height (m^2). Most of the information is shown in Table 3. Percent of subjects who took medicine with prescription drug were 80.5%. Blood sampling was done to measure the serum concentrations of total cholesterol and blood concentration of HbA1c.

2.3. Follow-up for death

The 207 participants were followed up for 6 years and 5 months after the physical fitness tests and baseline examination.

Confirmation of whether the patient was living or had died was obtained by asking the family by calling or visiting the home. The cause of death was classified according to the 10th version of the International Classification of Diseases (ICD-10). Seven subjects were lost to follow-up over the 6 years and 5 months.

2.4. Statistical analysis

All data are reported as means ± SDmg/dL. The differences in mean values between groups were determined using analysis of variance. Categorical variables were compared using the chi-squared test. Associations of physical fitness measurements and time with 6.5-year mortality were assessed using the multivariate Cox proportional hazards regression analysis, in which only gender was adjusted for (Model 1), or both gender and serum level of total cholesterol were adjusted for (Model 2) as confounding factors. Results were considered to be statistically significant at $p < 0.05$.

3. Results

3.1. Physical fitness and basal characteristics

Physical fitness measurements, such as single-handgrip strength (right side), single-handgrip strength (left side), double-handgrip strength (right side), double-handgrip strength (left side), one-leg standing time, stepping rate of legs, leg extension strength (single leg), leg extension strength (both legs), walking speed, and walking steps are shown in Table 1. The scores on the muscle strength tests were much higher in males than in females, while that for standing time was much longer in males than in females, that for stepping rate or walking speed was much faster in males than in females, and that for walking steps was lower in males than in females. Scores on the tests of handgrip strength and leg extension strength were significantly higher in males who survived the 6.5-year follow-up period than in those who died. On the other hand, one-leg standing time, stepping rate, walking speed, and walking steps did not differ between those who survived the follow-up period and those who did not (Table 2A). In females, none of the scores on any fitness measurements differed between survivors and non-survivors (Table 2B). Basal characteristics other than physical fitness measurements are shown in Table 3. Males died at a much higher rate than females, and serum levels of total cholesterol were much higher in individuals who survived than in those who died during the follow-up years. The prevalence of smokers, alcohol drinkers, and patients with complications did not differ between survivors and non-survivors, and no difference was found in BMI, systolic blood pressure (SBP), HbA1c, or education period between the groups.

Table 1
Physical fitness measurements in 85-year-old males and females at the start of the study.

Physical fitness tests	Gender (n)	Mean ± SDmg/dL	p value
Handgrip strength, single hand, right (kg)	Male (84) Female (114)	26.4 ± 6.4 17.1 ± 3.8	0.001
Handgrip strength, single hand, left (kg)	Male (81) Female (114)	24.9 ± 6.0 16.2 ± 4.0	0.001
Handgrip strength, both hands, right (kg)	Male (82) Female (115)	26.4 ± 6.7 16.9 ± 3.7	0.001
Handgrip strength, both hands, left (kg)	Male (82) Female (115)	24.2 ± 6.0 15.5 ± 3.9	0.001
One-leg standing time (s)	Male (77) Female (92)	14.2 ± 1.6 5.3 ± 0.6	0.001
Stepping rate (steps/10 s)	Male (76) Female (92)	8.2 ± 0.9 6.5 ± 0.7	0.001
Leg extension strength, single leg (kg)	Male (71) Female (88)	27.8 ± 8.3 17.3 ± 6.0	0.001
Leg extension strength, both legs (kg)	Male (71) Female (88)	49.2 ± 15.8 29.9 ± 10.3	0.001
Walking speed (s)	Male (75) Female (91)	6.1 ± 1.6 7.4 ± 2.2	0.001
Waking step number (steps)/10 m	Male (75) Female (91)	13.6 ± 2.6 16.4 ± 4.8	0.001

3.2. Causes of death

During the 6.5-year follow-up period from October 2003 to March 2010, 81 individuals (49 males and 32 females) out of 207

Table 2
Physical fitness measurements in 85-year-old males and females at the start of the study who died and did not die during the follow-up period.

Physical fitness tests	Alive or Dead (n)	Mean ± SDmg/dL	p value
A. Males			
Handgrip strength, single hand, right (kg)	Alive (36) Dead (45)	28.7 ± 6.9 24.5 ± 5.6	≤0.004
Handgrip strength, single hand, left (kg)	Alive (36) Dead (42)	26.8 ± 6.1 23.2 ± 5.5	≤0.007
Handgrip strength, both hands, right (kg)	Alive (36) Dead (43)	28.5 ± 7.3 24.7 ± 5.9	≤0.013
Handgrip strength, both hands, left (kg)	Alive (36) Dead (43)	26.1 ± 6.2 22.7 ± 5.4	≤0.012
One-leg standing time (s)	Alive (36) Dead (39)	12.2 ± 14.7 11.3 ± 14.3	≤0.792
Stepping rate (steps/10 s)	Alive (36) Dead (38)	35.9 ± 9.2 33.7 ± 7.2	≤0.270
Leg extension strength, single leg (kg)	Alive (33) Dead (36)	29.9 ± 7.9 25.6 ± 8.3	≤0.033
Leg extension strength, both legs (kg)	Alive (33) Dead (36)	54.3 ± 15.5 44.3 ± 15.0	≤0.008
Walking speed (s)	Alive (37) Dead (36)	5.9 ± 1.4 6.3 ± 1.8	≤0.237
Waking step number (steps)/10 m	Alive (37) Dead (36)	13.3 ± 2.6 14.0 ± 2.5	≤0.219
B. Females			
Handgrip strength, single hand, right (kg)	Alive (79) Dead (31)	17.4 ± 3.3 16.1 ± 4.9	≤0.123
Handgrip strength, single hand, left (kg)	Alive (79) Dead (31)	16.5 ± 3.9 15.3 ± 4.4	≤0.167
Handgrip strength, both hands, right (kg)	Alive (79) Dead (32)	17.2 ± 3.2 16.2 ± 4.7	≤0.186
Handgrip strength, both hands, left (kg)	Alive (79) Dead (32)	15.8 ± 3.8 14.4 ± 4.3	≤0.098
One-leg standing time (s)	Alive (65) Dead (23)	5.2 ± 6.1 3.0 ± 1.7	≤0.095
Stepping rate (steps/10 s)	Alive (67) Dead (21)	28.7 ± 5.6 27.6 ± 9.3	≤0.527
Leg extension strength, single leg (kg)	Alive (63) Dead (21)	16.8 ± 5.7 18.8 ± 7.6	≤0.189
Leg extension strength, both legs (kg)	Alive (63) Dead (21)	29.2 ± 9.3 32.2 ± 13.1	≤0.246
Walking speed (s)	Alive (67) Dead (20)	7.5 ± 2.3 7.5 ± 2.3	≤0.949
Waking step number (steps)/10 m	Alive (67) Dead (20)	16.7 ± 5.1 16.0 ± 3.8	≤0.593

died. Of these 81 subjects, 27 deaths were due to cardiovascular disease (9 heart failures, 8 strokes, 5 myocardial infarctions, 2 aortic aneurysms, 1 carotid artery aneurysm, 1 case of hypertensive heart disease, 1 details unknown); 14 were due to cancer (3 gastric cancer, 2 lung cancer, 2 colon cancer, 2 hepatic cancer, 1 uterine cancer, 1 urinary tract cancer, 1 gallbladder cancer, 1 laryngeal cancer, 1 cancer of unknown organ); 11 to respiratory tract disease (10 pneumonia, 1 respiratory failure); 10 to senility; 3 to gastrointestinal disease (1 pancreatitis, 1 liver cirrhosis, 1 details unknown); 3 to exogenous death (2 injury, 1 suffocation); 1 to renal failure, 1 to multiple organ failure, and 11 to unknown causes.

3.3. Association between physical fitness and mortality

Associations between physical fitness measurements and total mortalities were assessed by multivariate Cox regression analyses adjusted for gender difference. These analyses were performed to calculate the risk for mortality associated with a 1 kg, 1 s, 1 step/10 s, 1 step/10 m increase (continuous analysis) in each respective fitness measurement (Table 4A). Another adjustment had both gender and serum level of total cholesterol as confounding factors (Table 4B). Since all subjects were 85 years old at the start of the study, age was not included as a confounding factor in these analyses. The relative hazard ratios (HR) for all-cause mortality adjusted only for gender difference fell 6–7% with each 1 kg increase in handgrip strength, regardless of whether the strength for a single hand or both hands or for the right side or left side was assessed. With a 1-kg increase in the leg extension strength of both legs, HR for all-cause mortality decreased 2% (Table 4A). Similarly, HR for total-cause mortality adjusted both for gender and serum level of total cholesterol fell 5–6% with a 1-kg increase in handgrip strength in a single hand or both hands, whether on the right side or left side. Total mortality also decreased 2% with a 1-kg increase in the leg extension strength of both legs (Table 4B).

3.4. Association between nonparticipation and mortality

Since all subjects were 85 years old, some of them were not able to perform the physical fitness tests. The number of subjects who did not participate in the tests ranged from 9 to 48 as shown in Table 5. The association between total mortality and participation in the fitness tests was also assessed by multivariate Cox analysis, with adjustment only for gender difference or for both gender and serum level of total cholesterol. No association was found between mortality and participation in the handgrip strength test or leg extension strength test, while apparent associations were found between mortality and participation in the walking, stepping rate, and one-leg standing time tests when adjusted for gender difference. Participants in the walking test showed a 62% decrease in mortality compared to nonparticipants. The mortality rates of participants in the stepping rate test and the one-leg standing test also were lower than those in nonparticipants by 53% and 44%, respectively (Table 5A). Similarly, with adjustment both for gender and serum level of total cholesterol, mortality fell by 57% in participants in the walking test and fell by 45% in participants in the stepping rate test compared to mortality in nonparticipants. No association was found in mortality with participation in the handgrip strength test, leg extension strength test, or one-leg standing time test (Table 5B).

Table 3
Baseline characteristics at the age of 85 years in individuals who survived or did not survive the follow-up period.

Basal characteristics	Alive	Dead	*p* value
% men	31.9	60.5	≤0.001
% smokers	4.2	6.5	≤0.485
% alcohol drinkers	53.0	51.3	≤0.810
% complications	76.4	73.1	≤0.608
BMI (kg/m^2)	22.87 ± 3.03	22.26 ± 4.05	≤0.226
SBP (mmHg)	144.1 ± 23.6	144.4 ± 25.2	≤0.926
Total cholesterol (mg/dL)	205.1 ± 37.1	179.1 ± 30.3	≤0.001
HbA1c (%)	5.46 ± 0.57	5.48 ± 0.79	≤0.242
Education period (years)	9.4 ± 2.3	9.6 ± 3.0	≤0.634

BMI, body mass index; SBP, systolic blood pressure.

Table 4
Multivariate Cox analyses of total mortality and physical fitness measurements such as handgrip strength, one-leg standing time, leg extension strength, stepping rate, and walking as assessed at the start of the study. The analyses were adjusted only for gender difference (A) or were adjusted both for gender and serum level of total cholesterol (B).

Physical Fitness Measurements	Hazard ratio	95% CI	*p* value
A. Adjusted for gender difference			
Hand grip strength, single hand, right (kg)	0.925	0.887–0.966	≤0.001
Hand grip strength, single hand, left (kg)	0.925	0.883–0.968	≤0.001
Hand grip strength, both hands, right (kg)	0.936	0.899–0.975	≤0.001
Hand grip strength, both hands, left (kg)	0.927	0.886–0.970	≤0.001
One-leg standing time (s)	0.990	0.964–1.016	≤0.434
Stepping rate (steps/10 s)	0.977	0.948–1.010	≤0.172
Leg extension strength, single leg (kg)	0.962	0.929–1.001	≤0.054
Leg extension strength, both legs (kg)	0.975	0.955–0.995	≤0.015
Walking speed (s)	1.074	0.942–1.223	≤0.286
Walking step number (steps)/10 m	1.015	0.947–1.088	≤0.681
B. Adjusted both for gender and serum level of total cholesterol			
Hand grip strength, single hand, right (kg)	0.940	0.900–0.982	≤0.005
Hand grip strength, single hand, left (kg)	0.938	0.897–0.982	≤0.006
Hand grip strength, both hands, right (kg)	0.949	0.912–0.988	≤0.011
Hand grip strength, both hands, left (kg)	0.942	0.901–0.985	≤0.009
One-leg standing time (s)	0.993	0.968–1.020	≤0.627
Stepping rate (steps/10 s)	0.984	0.953–1.016	≤0.322
Leg extension strength, single leg (kg)	0.967	0.933–1.002	≤0.061
Leg extension strength, both legs (kg)	0.978	0.958–0.997	≤0.027
Walking speed (s)	1.063	0.927–1.218	≤0.385
Walking step number (steps)/10 m	1.011	0.939–1.089	≤0.770

CI, confidence interval.

4. Discussion

In an 85-year-old community-dwelling population, handgrip strength and leg extension strength were greater in males who survived the follow-up period of 6.5 years than in those who died, while no difference was found between survivors and non-survivors among females. With multivariate Cox analysis adjusted for only gender or for the combination of gender and serum level of total cholesterol, mortality was found to have an association with the handgrip strength of a single hand or both hands and the leg extension strength of both legs. The relative risk of mortality fell 5–7% with a 1-kg increase in the handgrip strength of single hand or both hands, and it fell 2% with a 1-kg increase in the leg extension strength of both legs. Participants in the walking test had 57% lower mortality than nonparticipants, and participants in the stepping rate test had 45% lower mortality than nonparticipants,

Table 5
Multivariate Cox analyses of total mortality and participation in fitness tests such as hand-grip strength, one-leg standing time, leg extension strength, stepping rate, and walking as assessed at the start of the study. The analyses were adjusted only for gender difference (A) or were adjusted both for gender and serum level of total cholesterol (B).

Physical Fitness tests	Yes	No	Hazard ratio	95% CI	*p* value
A. Adjusted for gender difference					
Handgrip strength, single hand, right	198	9	0.823	0.331–2.047	≤0.676
Handgrip strength, single hand, left	195	12	0.604	0.288–1.266	≤0.182
Handgrip strength, both hands, right	197	10	0.779	0.335–1.812	≤0.562
Handgrip strength, both hands, left	197	10	0.779	0.335–1.812	≤0.562
One-leg standing time	169	38	0.557	0.330–0.942	≤0.029
Stepping rate	168	39	0.472	0.284–0.784	≤0.004
Leg extension strength, single leg	159	48	0.638	0.391–1.041	≤0.072
Leg extension strength, both legs	159	48	0.638	0.391–1.041	≤0.072
Walking speed	166	41	0.382	0.233–0.626	≤0.001
Walking steps	166	41	0.382	0.233–0.626	≤0.001
B. Adjusted for gender and serum level of total cholesterol					
Handgrip strength, single hand, right	198	9	1.221	0.442–3.372	≤0699
Handgrip strength, single hand, left	195	12	0.780	0.355–1.715	≤0.536
Handgrip strength, both hands, right	197	10	1.065	0.425–2.669	≤0.894
Handgrip strength, both hands, left	197	10	1.065	0.425–2.669	≤0.894
One-leg standing time	169	38	0.633	0.372–1.078	≤0.092
Stepping rate	168	39	0.551	0.329–0.924	≤0.024
Leg extension strength, single leg	159	48	0.754	0.458–1.240	≤0.266
Leg extension strength, both legs	159	48	0.754	0.458–1.240	≤0.266
Walking speed	166	41	0.428	0.260–0.705	≤0.001
Walking steps	166	41	0.428	0.260–0.705	≤0.001

CI, confidence interval; HR, hazard ratio.

when adjusted for gender and serum total level. With an adjustment made only for gender, participants in the one-leg standing test also had a 44% lower mortality rate than non-participants. These findings suggest that not only muscle strength but also other physical abilities may be associated with mortality in a very old population. When assessing physical fitness measurements in a very old population, the influence of participation or nonparticipation on the findings should be considered. No association between fitness measurements and mortality in female may be partly due to much lower score of fitness measurements. Lower mortality in female (28.3%) than in men (56.3%) also may induce a lack of association in mortality with fitness measurement. However, further studies are needed to clarify the gender difference.

Much like our findings for handgrip measurements, associations were previously found between total mortality and handgrip strength in 85-year-old and 89-year-old populations in Holland (Ling et al., 2010). In a Cox regression analysis using handgrip strength as a continuous variable, an increase of 11% in all-cause mortality occurred for each 5-kg reduction at age 85 years and of 24% at age 89 years. In other studies of elderly populations aged 65 and over (Gale et al., 2007) and 70–79 years (Newman et al., 2006a), handgrip strength was a predictor of all-cause mortality. Leg extension strength also predicted mortality in elderly persons (Newman et al., 2006a).

Although walking speed and walking step length were not associated with mortality in our study of 85-year-old persons, participation in the walking test was predictive of long survival, suggesting that poor walking ability may be associated with an increase in mortality. Nonparticipants in the walking test may be more likely than participants to have poor walking ability. This finding was similar to the findings in previous studies of elderly populations. Walking speed was an independent predictor of mortality in older Mexican-Americans aged 65 years and over (Cesari et al., 2009b). In well-functioning older persons with a mean age of 73.6, gait speed was predictive of mortality (Cesari et al., 2009a). Among older women aged 65 years and over, a high level of walking for exercise as assessed by questionnaire was associated with lower all-cause mortality (Gregg et al., 2003). Participants in the stepping rate test had 45% lower mortality than nonparticipants, although no association was found between mortality and stepping rate in the present study. We previously found an association between total mortality and stepping rate in an 80-year-old population (Takata et al., 2007). These findings were suggestive of the presence of similar associations in 85-year-old persons. Not only baseline physical fitness performance but also changes in physical activity have been associated with mortality in elderly populations. Increasing and maintaining physical activity levels were associated with lower mortality among older women aged 65 years or older (Gregg et al., 2003).

In the present study, we found associations between mortality and performance on various physical fitness tests such as the handgrip strength of a single hand and of both hands and the leg extension strength of both legs. We also found associations between mortality and participation in the walking test and the stepping rate test of the legs. These findings suggest that not only handgrip strength, as reported by Ling et al. (2010), but also performance on other fitness tests were independent predictors of total mortality in this population. Thus, we extended the association between physical fitness and mortality to an 85-year-old population.

Although some studies have shown an association between balance and mortality in elderly, we did not find the association. This discrepancy may be partly due to different methods for measuring balance ability. The previous investigators adopted tandem standing (Bandinelli et al., 2009; Blain et al., 2010; Cesari et al., 2009a), while we used one-leg standing with eye open. Age of subjects was also different, subjects of the previous studies were aged between 70 and 79 (Cesari et al., 2009a), 65 and older (Bandinelli et al., 2009), or 75 and older (Blain et al., 2010), whereas our subjects were 85-year-old. Moreover, in the present study, considerably many subjects did not participate in one-leg standing test, inducing no association between mortality and standing time.

There are limitations to our findings. In the present study, the sample size was small ($n = 207$). The potential of the sample is not enough to establish firm conclusions in the analysis of participant and non-participant, especially in some analysis comparing groups with one of the sample size group smaller than 15 subjects. Future

studies with greater sample size are needed to confirm this aspect. There were 7 subjects who were lost to follow-up over the 6 years and 5 months (follow-up rate, 96.6%). Residual confounding factors other than gender and serum level of total cholesterol could have influenced our findings. However, the present findings still clearly indicate that the results of physical fitness tests such as handgrip strength, leg extension strength, and probably also participation in walking and stepping rate tests are predictive of total mortality at the age of 85 in community-dwelling elderly.

5. Conclusion

Poor muscle strength of handgrip or leg extension was found to be an independent predictor of total mortality in an elderly 85-year-old Japanese community-dwelling population. Moreover, nonparticipation in tests of walking or leg stepping rate was independently associated with increased mortality in the very elderly population.

Conflict of interest statement

None

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Mechanisms involved in regulation of osteoclastic differentiation by mechanical stress-loaded osteoblasts

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ABSTRACT

Mechanical stress is known to be important for regulation of bone turnover, though the detailed mechanisms are not fully understood. In the present study, we examined the effect of mechanical stress on osteoblasts using a novel compression model. Mouse osteoblastic MC3T3-E1 cells were embedded in three-dimensional (3D) gels and cultured with continuous compressive force (0–10.0 g/cm^2) for 48 h, and the conditioned medium were collected. RAW264.7 cells were then incubated with the conditioned medium for various times in the presence of receptor activator of nuclear factor-κB ligand (RANKL). Conditioned medium was found to inhibit the differentiation of RAW264.7 cells into osteoclasts induced by RANKL via down-regulation of the expression of tumor necrosis factor receptor-associated factor 6 (TRAF6), phosphorylation of IκBα, and nuclear translocation of p50 and p65. Interestingly, the conditioned medium also had a high level of binding activity to RANKL and blocked the binding of RANK to RANKL. Furthermore, the binding activity of conditioned medium to RANKL was reduced when the 3D gel was supplemented with KN-93, an inhibitor of non-canonical Wnt/Ca^{2+} pathway. In addition, expression level of osteoprotegerin (OPG) mRNA was increased in time- and force-dependent manners, and remarkably suppressed by KN-93. These results indicate that osteoblastic cells subjected to mechanical stress produce OPG, which binds to RANKL. Furthermore, this binding activity strongly inhibited osteoclastogenesis through suppression of TRAF6 and the nuclear factor-kappa B (NF-κB) signaling pathway, suggesting that enhancement of OPG expression induced by mechanical stress is dependent on non-canonical Wnt/Ca^{2+} pathway.

1. Introduction

Bone mass homeostasis is regulated by an interaction of various factors, including growth factors, hormones and mechanical loading [1,2], and some researchers have reported that mechanical stress applied to several types of cells maintained bone metabolism including bone formation and bone resorption [3–5].

Receptor activator of nuclear factor-κB ligand (RANKL), identified as a membrane-bound protein, is an essential factor for osteoclastogenesis produced by osteoblasts and stimulates osteoclast precursors to differentiate via binding to the receptor, RANK. OPG is a member of tumor necrosis factor (TNF) receptor family that acts as a decoy receptor of the RANKL [6].

RANKL interacts with RANK, resulting in recruitment of intracellular tumor necrosis factor receptor-associated factor 6 (TRAF6) and activation of signaling pathways including nuclear factor of kappa B (NF-κB) and mitogen-activated protein kinase (MAPK) [7–9]. Furthermore, RANKL activates the nuclear translocation and DNA binding of the NF-κB proteins (p50 and p65) via phosphorylation and degradation of IκBα [10,11].

Wnt pathway, confirmed to play critical roles in bone development and homeostasis, is classified into 3 pathway groups; the β-catenin-dependent canonical Wnt pathway, non-canonical planar cell polarity pathway, and non-canonical Wnt/Ca^{2+} pathway [12]. It has been demonstrated that canonical Wnt pathway modulates several aspects of osteoblast physiology including proliferation, differentiation, bone matrix formation and apoptosis [13–16]. Findings in a recent genetic study indicated that Wnt/β-catenin pathway is involved in the expression of both RANKL and OPG [17]. On the other hand, mechanical loading was shown to induce differentiation of mesenchymal progenitor cells through the non-

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canonical Wnt/Ca^{2+} pathway [18]. However, the role of non-canonical Wnt/Ca^{2+} pathway in regard to mechanical stress-induce osteoclastogenesis has not been fully elucidated. In the present study, we investigated the mechanisms of the non-canonical Wnt/Ca^{2+} pathway involved in osteoclastogenesis induced by compressive force.

2. Materials and methods

2.1. Reagents

Human recombinant RANKL was purchased from Oriental Yeast Co., Ltd. (Shiga, Japan). Anti-p38 MAPK polyclonal and anti-phosphorylated p38 MAPK polyclonal antibodies were purchased from Cell Signaling Technology, Inc. (Beverly, CA, USA). Anti-p50 monoclonal, anti-p60 monoclonal, anti-IκBα monoclonal, anti-phospho-IκBα monoclonal, anti-TRAF6 monoclonal, and anti-RANK monoclonal antibodies were obtained from Santa Cruz Biotechnology. (Santa Cruz, CA, USA).

2.2. Cell cultures

The murine monocyte/macrophage cell line RAW264.7 was maintained in α-minimal essential medium (α-MEM; Gibco, Gland Island, NY, USA) containing 10% fetal bovine serum (FBS), with penicillin G (100 U/ml) and streptomycin (100 μg/ml). The murine osteoblastic cell line MC3T3-E1 was cultured in α-MEM supplemented with 10% FBS and antibiotics. The cells were maintained at 37 °C in an atmosphere containing 5% CO_2.

2.3. Application of compressive force

To examine the effect of static compressive force, MC3T3-E1 cells were cultured in a three-dimensional (3D) cell culture system [19]. Briefly, collagen gel cultures were assembled by mixing 7 volumes of 0.3% type I-A collagen solution (Nitta-gelatin, Osaka, Japan), 1 volume of 20 mM HEPES buffer containing 2.2% sodium bicarbonate and 0.05% sodium hydroxide, and 1 volume of cell suspension to provide a final cell density of 1×10^6 cells/ml. The gel mixtures were allowed to polymerize for 1 h, following transfer to 6-well plates to promote nutrient diffusion from their surroundings. The gel mixtures in each well were cultured with 2 ml of α-MEM containing 1% FBS, and allowed to set for 24 h prior to force loading. Compressive force was applied using a sterile titanium plate (32 mm in diameter) and plastic cylinder placed over the gels, which was adjusted by adding lead granules to the cylinder. In some experiments, KN-93, a selective Ca^{2+}/calmodulin-dependent protein kinase II inhibitor (Sigma–Aldrich, St. Louis, MO, USA), was added to the collagen gels.

2.4. Kinetic analysis using quartz-crystal microbalance (QCM)

A 27-MHz QCM (Affinix Q; Initium Inc., Tokyo, Japan) was employed to analyze the affinity of RANKL and conditioned medium harvested from 3D cultures of MC3T3-E1 cells. RANKL (2 μl; 10^{-11} M) was immobilized directly on the gold electrode surface of the QCM ceramic sensor chip, after which the sensor chip was soaked in a chamber containing 8 ml of distilled water at 25 °C until frequency equilibrium was attained. Conditioned medium (volume 800 μl) was added to the equilibrated solution containing the RANKL-immobilized sensor chip. The binding of conditioned medium to RANKL was determined by monitoring the alterations in frequency resulting from changes in mass on the electrode surface [20].

2.5. Western blot analysis

MC3T3-E1 cells were mixed into the collagen gels and subjected to 7.5 g/cm^2 of compressive force for indicated times, and conditioned medium were collected. Next, RAW 264.7 cells (2.5×10^5 cells/well) were cultured in 6-well plates in α-MEM containing 10% FBS in the presence or absence of RANKL (40 ng/ml) along with the conditioned medium. The cells were then washed twice with phosphate buffer saline (PBS; pH 7.2) and lysed in lysis buffer (75 mM Tris–HCl containing 2% SDS and 10% glycerol, pH 6.8). In some experiments, nuclear factors were isolated using a NucBuster™ Protein Extraction Kit (EMD Biosciences Inc., Darmstadt, Germany) according to the manufacturer's instructions. Protein contents were measured using a DC protein assay kit (Bio-Rad, Hercules, CA, USA). Equivalent sample volumes were subjected to 10% SDS–PAGE and transferred to polyvinylidene difluoride membranes (Millipore Corp., Bedford, MA, USA). Non-specific binding sites were blocked by immersing the membrane in 10% skimmilk in PBS for 1 h at room temperature, after which the membrane was washed 4 times with PBS, followed by incubation with the diluted primary antibody at 4 °C overnight. After washing the membrane, chemiluminescence was produced using enhanced chemiluminescent (ECL) reagent (Amersham Pharmacia Biotech, Uppsala, Sweden) and detected with Hyperfilm-ECL (Amersham Pharmacia Biotech).

2.6. Evaluation of osteoclastic differentiation

RAW264.7 cells were cultured in 24-well plates (7×10^4 cells/well) with RANKL (40 ng/ml) in the presence of conditioned medium from the 3D cultures of MC3T3-E1 cells, for 3 days. Adherent cells were fixed and stained with tartrate-resistant acid phosphatase (TRAP) (Sigma Chemical Co., St. Louis, MO, USA). TRAP-positive multinucleated cells containing three or more nuclei were considered to be osteoclasts and counted under a microscope.

2.7. Real-time RT-PCR analysis

Total RNA was isolated from compressed 3D-gels using ISOGEN-LS (Nippon Gene, Tokyo, Japan). Briefly, collagen gels containing cells were washed extensively with PBS and minced in ISOGEN-LS, then RNA was isolated according to the manufacturer's instructions. Extracted total RNA was reverse transcribed and subjected to real-time RT-PCR, in which the PCR products were detected using FAST SYBR® Green Master Mix (Applied Biosystems, Foster City, CA). The primer sequences used were as follow; β-actin forward, 5′-CTGAACCCTAAGGCCAACCGTG-3′ and reverse 5′-GGCATACAGGGACAGCACAGCC-3′, and OPG forward, 5′-GCCTGGGACCAAAGTGAATG-3′ and reverse 5′-CTTGTGAGCTGTGTCTCCGTTT-3′. Thermal cycling and fluorescence detection were done using a StepOne™ Real-Time PCR System (Applied Biosystems). Real-time RT-PCR efficiency (E) was calculated according to the equation provided by Rasmussen [21], as follows: $E = 10[-1/\text{slope}]$, for β-actin and various target genes. The slope was determined from the graph of ng of the cDNA substrate (x-axis) versus the cycle number at the crossing point (CP) (y-axis). The CP value was the PCR cycle number that represented the CP in SYBR® Green fluorescence intensity above the automatic noise-based threshold. The fold increase in copy numbers of mRNA was calculated as the relative ratio of target gene to β-actin, following the mathematical model presented by Pfaffl [22].

$$\text{Fold increase} = \frac{(E_{\text{TARGET}})^{\text{CP TARGET(MEAN control-MEAN subject)}}}{(E_{\beta}-\text{actin})^{\text{CP}\beta-\text{actin(MEAN control-MEAN subject)}}}$$

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2.8. OPG measurement

The amounts of OPG in the conditioned medium were determined using an OPG ELISA kit (R&D Systems, Minneapolis, MN, USA), according to the manufacturer's instructions.

2.9. Statistical analysis

Statistical differences were determined using an unpaired Student's *t*-test with Bonferroni correction for multiple comparisons. All data are expressed as the mean ± standard deviation of three examinations, with similar results obtained in each experiment.

3. Results

3.1. Effect of conditioned medium derived from MC3T3-E1 cells on osteoclastogenesis induced by RANKL

To determine whether mechanical stress in our compression model had effect on osteoclast differentiation, we first evaluated the number of osteoclasts by counting TRAP-positive multinucleated cells (Fig. 1A). Conditioned medium derived from MC3T3-E1 cells inhibited the differentiation of RAW264.7 cells into osteoclast-like cells in a loading force-dependent manner (Fig. 1B). The inhibitory effect of the conditioned medium began to be seen at 7.5 g/cm^2 of loading force (Fig. 1C). In addition, the effect of conditioned medium on proliferation of RAW264.7 cells was examined using a WST-1 assay. However, no effect on cell growth was seen for up to 48 h (data not shown).

3.2. Interaction between RANKL and conditioned medium derived from MC3T3-E1 cells

To examine the interaction of conditioned medium and RANKL, we investigated the affinity between them using a QCM technique. Medium conditioned by 0 g/cm^2 of compressive force decreased the frequency by 745 Hz, while it was decreased by 2200 Hz when we used medium conditioned by 7.5 g/cm^2 of compressive force (Fig. 2A). To investigate whether MC3T3-E1 cells under mechanical stress produce OPG, we examined OPG mRNA expression in MC3T3-E1 cells in the collagen gels. Mechanical stress caused an up-regulation of OPG mRNA expression at 6 h (Fig. 2B). These enhancement was in time- and dose-dependent manners (Fig. 2C).

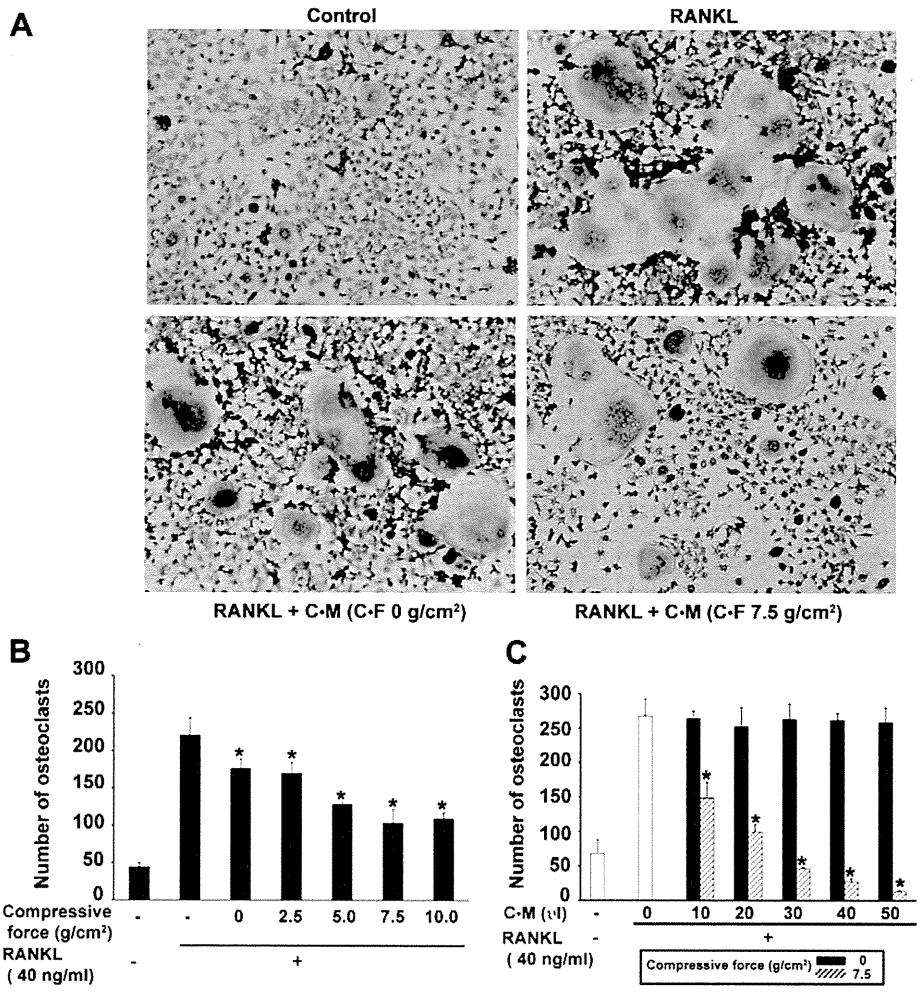

Fig. 1. Effect of conditioned medium derived from MC3T3-E1 cells on osteoclastogenesis induced by RANKL RAW264.7 cells (7.0×10^4 cells/ml) were cultured with conditioned medium derived from MC3T3-E1 cells subjected to 7.5 g/cm^2 of compressive force and RANKL (40 ng/ml). The number of TRAP-positive multinucleated cells was counted. (A) Images showing osteoclast formation. (B) MC3T3-E1 cells were subjected to 0–10 g/cm^2 of compressive force, then the conditioned medium was collected and used as stimulants. (C) Medium conditioned by 7.5 g/cm^2 of compressive force (0–50 μl) were added to RAW264.7 cells. Data are expressed as the mean ± SD of triplicate cultures. Student's *t*-test, $^*P < 0.05$.

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3.3. Effect of conditioned medium derived from MC3T3-E1 cells on RANKL-induced activation of NF-κB signaling pathway in RAW264.7 cells

We investigated the effect of mechanical stress on signal transduction in the process of osteoclast differentiation in RAW264.7 cells cultured with conditioned medium derived from MC3T3-E1 cells. Addition of medium conditioned by 7.5 g/cm^2 of force suppressed the expression of TRAF6, whereas the expression of RANK was not changed (Fig. 3A). Furthermore, we evaluated the effect of conditioned medium on phosphorylation of p38 MAPK and IκBα and expression of p50/p65, the most common NF-κB dimer, during osteoclast differentiation of RAW264.7 cells. Conditioned medium did not affect the phosphorylation of p38 MAPK (Fig. 3B). In contrast, it inhibited the phosphorylated levels of IκBα and expression of p50/p65 in the nuclear fraction of RAW264.7 cells induced by RANKL (Fig. 3C).

3.4. Involvement of non-canonical Wnt/Ca^{2+} pathway in RAW264.7 cells under the mechanical stress

To investigate the relationship between the non-canonical Wnt/Ca^{2+} pathway and osteoclast differentiation, we examined the effect of KN-93, a selective Ca^{2+}/calmodulin-dependent protein kinase II inhibitor, on the expression of OPG mRNA in RAW264.7 cells. MC3T3-E1 cells in collagen gel were cultured with KN-93 for 24 h and subjected to 7.5 g/cm^2 of compressive force for 12 h. Quantitative real-time RT-PCR analysis revealed that the expression of OPG mRNA induced by mechanical stress was remarkably suppressed by KN-93 (Fig. 4A). Finally, we determined the amount of OPG protein in conditioned medium by ELISA. Mechanical stress increased OPG secretion from MC3T3-E1 cells in a force-dependent manner, which was significantly suppressed by KN-93 (Fig. 4B). To examine the interaction between conditioned medium and RANKL, the affinity between them were determined using a QCM technique. In the presence of KN-93, the reduction of frequency by conditioned medium (7.5 g/cm^2) was recovered by 1618–958 Hz (Fig. 4C).

4. Discussion

It has been reported that mechanical stress functions as a critical regulatory factor in bone metabolism, and is also a postnatal determinant of bone homeostasis and skeletal morphology [23]. Although mechanical stress generates response from mechanosensitive cells, including bone cells, fibroblasts and epithelial cells have also been found to have responsiveness to mechanical stress [23,24]. Furthermore, recent studies have shown that osteoclast differentiation of RAW264.7 cells induced by RANKL was significantly decreased with oscillatory fluid flow [25]. Mechanical stress was also found to inhibit the expression of RANKL by murine stromal cells [26]. We previously reported that compressive mechanical force promoted osteoclast formation through RANKL expression in synovial cells derived from rat knee joints [4], while another study demonstrated that compressive force stimulation increased the levels of soluble RANKL and decreased those of OPG [27]. However, accurate details of the mechanisms by which mechanical

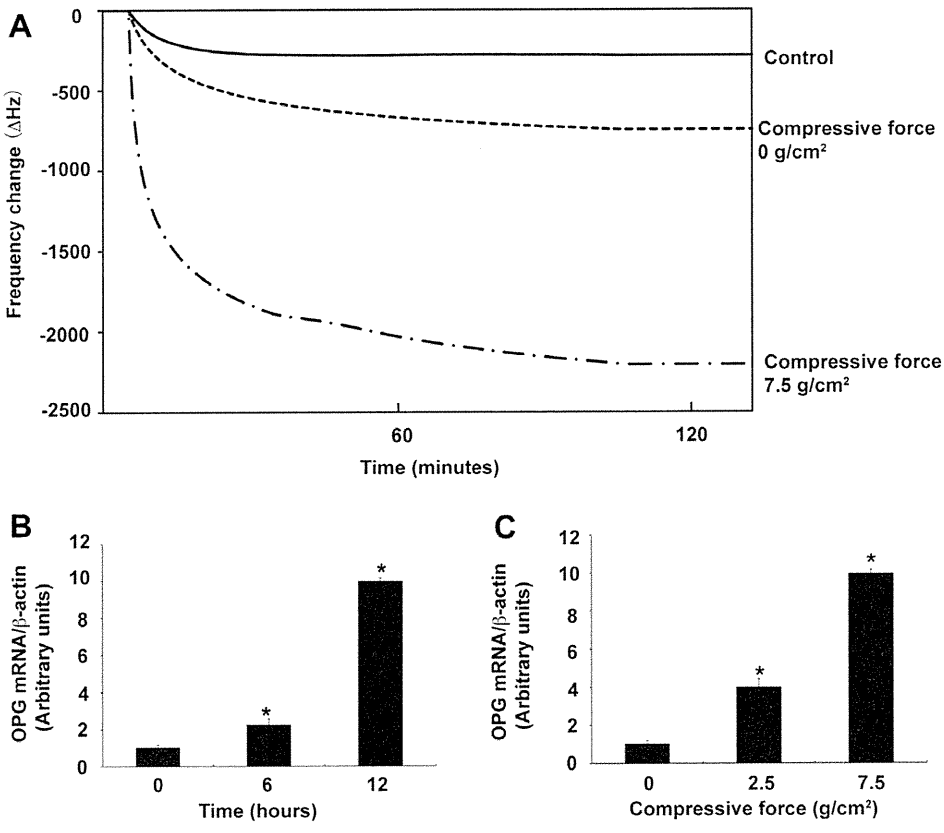

Fig. 2. Conditioned medium derived from MC3T3-E1 cells blocks binding of RANK to RANKL via enhancement of OPG expression MC3T3-E1 cells were cultured in collagen gels and subjected to 7.5 g/cm^2 of compressive force for 48 h, then conditioned medium were collected. (A) The binding ability of RANKL to conditioned medium was assessed using a QCM, as described in Section 2. MC3T3-E1 cells were cultured in collagen gels and subjected to compressive force. The fold change in OPG copy number between control and treated culture was determined by real-time RT-PCR, as described in Section 2. (B) Representative results from a time-dependent experiment with a compressive force of 7.5 g/cm^2. (C) Representative results from a force-dependent experiment at the time point of 12 h. Data are expressed as the mean ± SD of triplicate culture. Student's *t*-test, $^*P < 0.05$.

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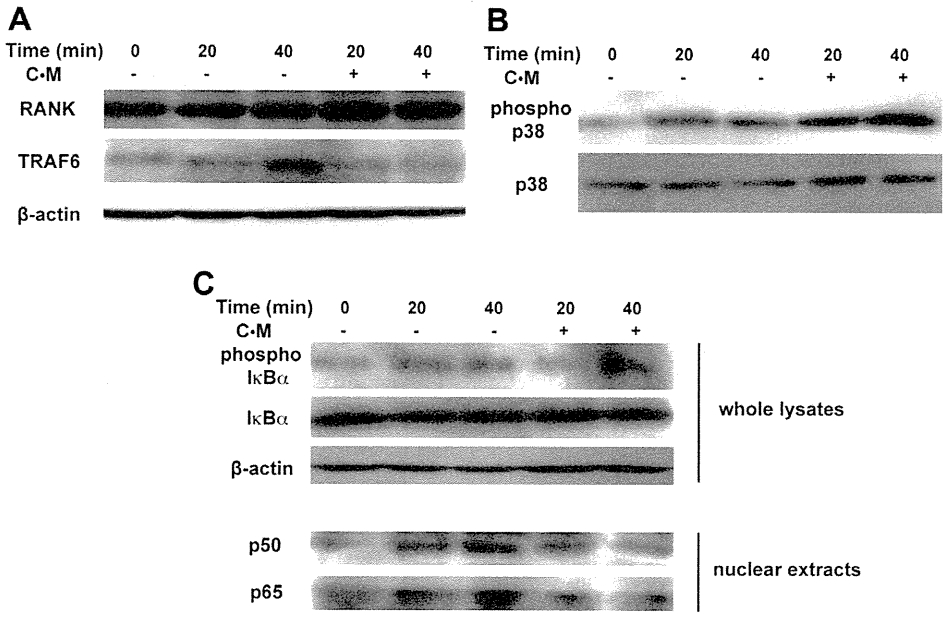

Fig. 3. Conditioned medium derived from MC3T3-E1 cells subjected to compressive force interferes with NF-κB signaling pathway in RAW264.7 cells RAW264.7 cells were stimulated with RANKL (40 ng/ml) in the presence or absence of conditioned medium derived from MC3T3-E1 cells subjected to compressive force for the indicated times. Whole cell lysates or nuclear fractions of RAW264.7 cells were subjected to immunoblotting analysis. (A) Expressions of RANK and TRAF6. (B) Expressions of p38 MAPK and phosphorylated p38 MAPK. (C) Expression of IκBα, phosphorylated IκBα, and expression of p50 and p65.

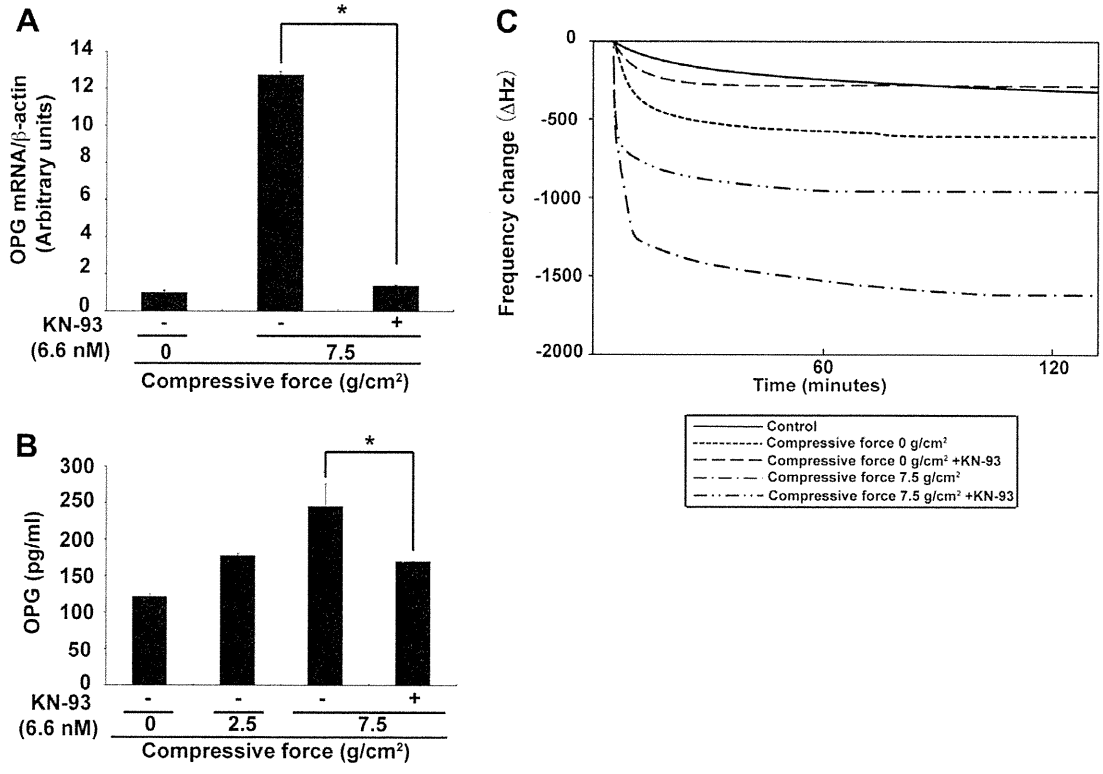

Fig. 4. Involvement of non-canonical Wnt/Ca^{2+} pathway in the induction of OPG in MC3T3-E1 cells by compressive force MC3T3-E1 cells were cultured in collagen gels and subjected to compressive force in the presence or absence of KN-93. (A) The fold change in OPG copy number between control and treated culture was determined by real-time RT-PCR, as described in Section 2. (B) MC3T3-E1 cells were cultured in collagen gels and subjected to 0–7.5 g/cm^2 of compressive force for 24 h in the presence or absence of KN-93, then culture medium were collected. The amount of OPG in the culture medium was determined as described in Section 2. (C) MC3T3-E1 cells were cultured in collagen gels and subjected to 7.5 g/cm^2 for 48 h in the presence or absence of KN-93, then culture medium samples were collected. The binding ability of RANKL to conditioned medium was assessed using a QCM, as described in Section 2. Data are expressed as the mean ± SD of triplicate cultures. The experiment was performed 3 times, with similar results obtained in each. Student's *t*-test, $^*P < 0.05$.

stress affects the productions of RANKL and OPG have yet to be reported.

We previously showed that our 3D culture system made it possible to study the role of loaded osteoblasts in initiation of the bone

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remodeling process, as it partially mimicked the *in vivo* environment [19]. 3D gel-embedded cultures of various cells were reported to support cell proliferation as well as differentiation into several different types of cells [19,28,29]. In the present study, mouse osteoblast lineage, MC3T3-E1 cells were embedded in 3D gels and cultured with mechanical stimuli, after which the conditioned medium were collected and added to RAW264.7 cells. We found that conditioned medium significantly decreased osteoclast differentiation (Fig. 1). Furthermore, compressive force enhanced the gene expression of OPG in MC3T3-E1 cells in both time- and force-dependent manners (Fig. 2B and C).

OPG is produced by several types of cells including osteoblastic cells, and has been shown to be a soluble decoy receptor for RANKL that blocks osteoclast formation by inhibiting RANK–RANKL interactions. In the present study, we clarified that mechanical stress increases the expression of OPG in MC3T3-E1 cells and then inhibits osteoclastogenesis. Other inhibitory factors for osteoclastogenesis such as interferon-γ (IFN-γ and Toll-like receptor (TLR) ligands have been shown to function by suppression of RANK signaling in osteoclast precursors [30]. We also evaluated the release of IFN-γ protein derived from MC3T3-E1 cells into the conditioned medium, however, no significant stimulation by mechanical stress was observed (data not shown). Together, these results suggest that the inhibitory effect of medium conditioned by mechanical stress on osteoclastogenesis is mainly dependent on the up-regulation of OPG expression.

A number of studies have investigated signaling pathways induced by RANK–RANKL binding. The cytoplasmic domain of RANK was shown to contain a binding site for TRAF6 [31]. In another study, NF-κB, MAPK, c-Jun N-terminal protein kinase (JNK), p38, and extracellular signal-regulated kinase (ERK) were found to be activated downstream of TRAF6 and induced osteoclast differentiation [32]. NF-κB is present in the cytoplasm as an active heterotrimer consisting of p50, p65, and IκBα subunits. Upon activation of the complex, phosphorylation and degradation of IκBα exposes nuclear localization signals on the p50/p65 complex, leading to nuclear translocation and binding to specific regulated sequences in DNA [33]. We found that mechanical stress suppressed the expression of TRAF6 protein, phosphorylation of IκBα, and nuclear translocation of p50 and p65 (Fig. 3). These results suggest that down-regulation of TRAF6 and NF-κB-mediated signaling pathway is correlated with inhibition of osteoclastogenesis by conditioned medium of mechanical-loaded osteoblast.

Mechanical stress is also known to stimulate multiple transduction cascades in several types of cells. It has been demonstrated that application of mechanical stress activates MAPKs, JNK, and ERK [34–36]. Furthermore, the canonical Wnt/β-catenin pathway was shown to have an important role in regulating osteoblast and osteoclast functions, as well as involvement in mechanotransduction [12]. Among the three Wnt pathways, non-canonical Wnt/Ca^{2+} pathway is well known to regulate two different downstream signaling pathways, the Ca^{2+}/calmodulin-dependent protein kinase (CaMK) and calcineurin, Ca^{2+}/calmodulin-dependent phosphatase (CaMP) pathway [37]. Although calcineurin regulates osteoclast differentiation via activity of the nuclear factor of activated T cells [38], the effect of CaMK in osteoclastogenesis is not clear. Yu et al. [18] reported that mechanical stress-mediated OPG induction was regulated by the non-canonical Wnt/Ca^{2+} pathway and especially the CaMK II-NLK cascade in myoblast lineage cells. Interestingly, we clearly demonstrated that the expression level of OPG mRNA and protein induced by mechanical stress was remarkably suppressed by KN-93, a selective Ca^{2+}/calmodulin-dependent kinase II inhibitor (Fig. 4A and B). Furthermore, the enhanced binding ability of medium conditioned by mechanical stress was diminished by the addition of KN-93 (Fig. 4C). Together, these findings suggest that stimulation of OPG mRNA and protein expression by mechanical stress is dependent on CaMK.

In conclusion, we found that compressive force enhanced the expression of OPG in osteoblasts by activation of the non-canonical Wnt/Ca^{2+} pathway. These results suggest that osteoblasts have the capacity to sense changes in mechanical stress, resulting in regulation of osteoclastogenesis.

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社会的ニーズに対応した歯科保健医療教育プログラム開発のための調査研究

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Current Demand for Specialists in Oral Care and Dysphagia Rehabilitation in Hospitals, Healthcare Institutions and Dental Clinics

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Abstract

This study assessed the social demand for specialists in oral care and dysphagia rehabilitation in hospitals, healthcare institutions and dental clinics to create an educational program for dental hygienists. Data were obtained from a questionnaire survey of hospitals, geriatric health services facilities, welfare services facilities for persons with disabilities, and dental clinics in Fukuoka Prefecture in 2006, and they were compared to those obtained by the same method in 2004. In 2006, oral care was performed for inpatients in 95.1 % of hospitals and for persons in 94.9 % of other healthcare institutions. Dysphagia rehabilitation was performed for inpatients in 73.2 % of the hospitals and for persons in 23.3 % of the other healthcare institutions. Although nurses provided the majority of the oral care, a small number of them were replaced by oral specialists, such as dentists, dental hygienists and speech–language–hearing therapists. Dysphagia rehabilitation was carried out by a wide variety of the specialists in hospitals and other healthcare institutions in 2006, compared to the institution in 2004. The special knowledge and skills for maintenance of oral functions, those for understanding elderly patients and others, and nutritional knowledge as well are necessary for specialists integrating oral care and dysphagia rehabilitation in hospitals and other healthcare institutions. Thus, it is important for dental hygienists as integrated specialists to obtain special knowledge concerning nutrition, in addition to knowledge and skills for maintenance of oral functions and an understanding of elderly patients and others.

Key words: Oral care/Dysphagia rehabilitation/Hospitals/Healthcare institutions

抄　　録

医療現場における口腔ケアと摂食・嚥下リハビリテーション（以下，摂食嚥下リハ）の現状と課題を把握し，この分野で貢献するべき人材を育成するための教育プログラムを構築することを視野に入れ，アンケート調査を実施した．調査は平成18年（以下，今回）に，福岡県内の病院，高齢者・障害者施設（以下，施設）および歯科医院を対象として行われた．必要に応じて平成16年（以下，前回）に病院と施設において実施された同様の調査と比較，検討した．今回の調査では病院と保健施設の，それぞれ95.1％，94.9％が口腔ケアを，73.2％，23.3％が摂食嚥下リハを実施していると回答した．また，前回の調査と比べ，口腔ケア担当者の職種として第一位は看護師であったがその割合は減少し，より口腔領域の専門性が高い歯科医師，歯科衛生士，言語聴覚士などの割合が増加していた．一方，摂食嚥下リハにおいては，より多くの医療職が関与して実施されているとの回答が得られた．この結果は，摂食嚥下リハにおけるチーム医療によって実施されていることを反映したものと考えられた．口腔ケアおよび摂食嚥下リハに携わる人材には，「口腔機能管理における専門的知識と技術」と「高齢者に対する知識や介護技術」，ついで「栄養学的知識の習得」の知識と技術が求められた．高齢社会に対応できる口腔保健の専門家が求められると同時に，チーム医療，とくに栄養補給チームの一員として貢献できる人材が求められていると考えられた．以上のことから，口腔ケアと摂食嚥下リハを担当する口腔保健の専門家（とくに歯科衛生士）には，口腔機能管理における専門的知識と技術のみならず，社会的ニーズに伴う高齢者に対する知識や技術，他の医療職との連携がさらに重要になる将来的医療環境に対応できる知識（とくに栄養学的知識）を習得させる教育プログラムが必要であると考えられた．

キーワード：口腔ケア/摂食・嚥下リハビリテーション/病院/保健施設

緒　言

口腔ケアは歯科疾患の予防として重要であり，さらに高齢者施設[1,2]や病院の要介護者[3,4]における呼吸器感染症の予防に効果的であることが知られている．また，摂食・嚥下リハビリテーション（以下，摂食嚥下リハ）による口腔機能の向上に伴い，口腔細菌が減少し，嚥下も正常になる．これらの結果，誤嚥性肺炎が予防される．このほか，栄養摂取を促進し宿主の体力回復や，体力回復の結果もたらされる感染防御能の増強による感染症の減少[5]や在院日数の短縮などが期待され，患者本人の意欲さらに高齢者では寿命延長[6]に対しても有効であるとされている．病院においては患者への口腔ケアおよび摂食嚥下リハのこのような効果に対する認識がひろまり，栄養補給チームとして対応する医療機関が増加している．これに応じて日本看護師協会では摂食嚥下障害看護の認定制度が導入されるようになった[7]．一方，医療における口腔領域の専門性の観点からみれば，口腔ケアと摂食嚥下リハをになう人材として第一に歯科衛生士があげられる．実際に，平成18年度の介護保険制度の見直しにより介護予防事業が創設され[8]，このなかでも歯科衛生士は高齢者や障害者などの要支援者に対し口腔機能の向上のために大きな役割を果すことが求められた．

そこで，この分野で貢献するべき歯科衛生士を育成するための教育プログラム開発の第一歩として，病院，施設および歯科医院を対象にアンケート調査を実施し，医療現場における口腔ケアと摂食嚥下リハの現状と課題を把握することにした．

対象および方法

平成18年に，福岡県内の医療機関に対して，質問用紙を郵送する方法でアンケート調査を行った．調査は，平成16年に秋房ら[9]が実施したアンケートをもとに行われた．平成18年は，平成16年に回答があった265病院および234高齢者・障害者施設（以下，施設），加えて新たに701歯科診療所（以下，歯科医院）を対象とした．回答を得た病院，施設，歯科医院の数はそれぞれ165（回収率62.2％），126（53.8％），303（47.0％）であった．

病院，施設および歯科医院に対するアンケートの設問と選択肢を表に示す（表1－3）．

統計解析は解析ソフトSPSS for Windows 11.01J（エスピー・エス・エス社）を用い，病院と施設に対するアンケート結果で平成16年度と平成18年度の比較を行う際にはχ^2検定を行った．また，歯科医院あたりの歯科衛生士の数における，全国と福岡の比較においてもχ^2検定を行った．このほか，歯科医院あたりのスタッフ数における，訪問歯科診療を行っている場合と行っていない場合の比較にはMann–WhitneyのU検定を行った．

結果および考察

Ⅰ．病院

平成16年度（以下，前回）および平成18年度（以下，今回）におけるアンケート調査は，回答者の職種を問う設問1に対する回答から，おもに看護師，医師，あるいは歯科医師によって記入されたことが分かる（表4）．そのため，医療従事者が回答した本アンケートの結果は，医療現場のニーズを反映するものであると考えられる．

口腔ケアの実施状況を問う設問2に対する回答から，多くの病院では口腔ケアが実施されていることが明らかとなった（表4）．また，その開始時期を問う設問3に対する回答から，口腔ケアは「急性期から」，あるいは「症例によっては急性期から」開始されていることが分かった（表4）．これらのことから，病院では口腔ケアの重要性，とくに誤嚥性肺炎の予防，あるいは患者の予後に与える影響などが十分認識されていることが示唆された[10-12]．口腔ケアの担当者を問う設問4に対する回答から，その担当者は「看護師」が最も多く，「看護助手」，「歯科衛生士」，「言語聴覚士」，「介護福祉士」，「歯科医師」がこれに続き，前回よりも口腔ケアを担当する職種が拡大する傾向が認められた（χ^2検定，$p<0.001$，図1）．看護師が口腔ケアを担当している場合，口腔ケアを専門的に学ぶ機会が少ない看護師の負担になっていると推察できる．口腔ケアの専門家である歯科衛生士の割合が増加したことは（図1），看護師の業務軽減だけでなく，専門的な口腔ケアを受けることができる患者が増加したことを意味し，望ましい傾向であると考えられる．一方，口腔ケアの実施に関わる言語聴覚士が増加したことに関しては（図1），専門的な口腔ケアが遂行されている保証がなく，医療現場での口腔ケア業務のあり方について再考が必要であると思われた．

摂食・嚥下リハビリテーション（以下，摂食嚥下リハ）に関して，その担当部局の有無を問う設問5に対する回答から，摂食嚥下リハを実施する「専門外来や担当部局がある」，あるいは「担当部局はないが担当可能」と回答した病院が，前回の調査結果と比較して有意に増加したことが認められた（χ^2検定，$p<0.01$，表4）．それを担当する職種を問う設問6に対する回答から，摂食嚥下リハは「看護師」が最も多く担当し，「言語聴覚士」，「医

表1　病院に対するアンケートの項目

ご回答いただく方は、できるだけ口腔ケアおよび摂食・嚥下リハビリテーションを理解している方にお願いいたします。
貴院における口腔ケアおよび摂食・嚥下リハビリテーションについてお尋ねします。

設問1　このアンケートにご回答していただく方の職種は次のどれですか。
① 医師・歯科医師　② 看護師　③ 介護職　④ 事務職　⑤ その他

設問2　入院患者に対して、口腔ケアを行っていますか。
① 口腔内を評価して、口腔ケアを実施している　② 口腔ケアの自立ができない方に対して行っている　③ 行っていない

設問3　設問2で①もしくは②と答えた病院にお尋ねします。入院患者に対する口腔ケアの開始時期はいつですか。
① 急性期から積極的に行う　② 症例によっては急性期から行う　③ 原疾患の状態が落ち着いてから始める
④ 要望があった場合に行う

設問4　設問2で①もしくは②と答えた病院にお尋ねします。口腔ケアを担当する職種は次のうちどれですか。(複数回答可)
① 医師　② 歯科医師　③ 看護師　④ 保健師　⑤ 看護助手　⑥ (管理) 栄養士　⑦ 介護福祉士
⑧ 理学療法士　⑨ 作業療法士　⑩ 言語聴覚士　⑪ 歯科衛生士　⑫ 歯科助手　⑬ その他

設問5　全ての病院にお尋ねします。摂食・嚥下リハビリテーションを担当する部局はありますか。
① 専門外来がある　② 担当部局がある　③ 担当部局はないが対応可能である　④ 対応しない

設問6　設問5で①、②、③のいずれかと答えた病院にお尋ねします。摂食・嚥下リハビリテーションを担当する医療スタッフの職種は次のうちどれですか。(複数回答可)
① 医師　② 歯科医師　③ 看護師　④ 保健師　⑤ 看護助手　⑥ (管理) 栄養士　⑦ 介護福祉士　⑧ 理学療法士
⑨ 作業療法士　⑩ 言語聴覚士　⑪ 歯科衛生士　⑫ 歯科助手　⑬ その他

設問7　全ての病院にお尋ねします。入院患者に対する摂食・嚥下リハビリテーションの開始時期はいつですか。
① 急性期から積極的に行う　② 症例によっては急性期から行う　③ 原疾患の状態が落ち着いてから始める
④ 入院期間中に行うことはまれである

設問8　全ての病院にお尋ねします。摂食・嚥下リハビリテーションに係る人材は十分に確保できていますか。
① 将来的にも十分である　② 現状は対応できているが将来的に不足が予測される　③ 現状に対する対応に不足がある
④ 人材が不足している (量・質)

設問9　全ての病院にお尋ねします。口腔ケアと摂食・嚥下リハビリテーションを総合的に行うことができる人材を雇用したいと思いますか。
① 雇用したい　② 条件によっては雇用したい　③ 対象者がほとんどいないので雇用の必要性を感じない
④ 現状で十分対応できているので雇用する必要がない

設問10　全ての病院にお尋ねします。口腔ケア担当者として習得して欲しい技術や知識は次のどれですか。(複数回答可)
① 高齢者に対しての知識　② 社会福祉に対する知識　③ 介護技術　④ 栄養学的な知識　⑤ カウンセリング能力
⑥ 口腔清掃に対する技術　⑦ 入れ歯に対する知識　⑧ その他

設問11　全ての病院にお尋ねします。摂食・嚥下リハビリテーション担当者として習得して欲しい技術や知識は次のどれですか。(複数回答可)
① 高齢者に対しての知識　② 社会福祉に対する知識　③ 介護技術　④ 栄養学的な知識　⑤ カウンセリング能力
⑥ スクリーニングテスト能力　⑦ 摂食介助技術　⑧ 摂食嚥下訓練能力　⑨その他

表2　施設に対するアンケートの項目

ご回答いただく方は、できるだけ口腔ケアおよび摂食・嚥下リハビリテーションを理解している方にお願いいたします。

設問1　このアンケートにご回答していただく方の職種は次のどれですか。
① 医師・歯科医師　② 看護師　③ 介護職　④ 事務職　⑤ その他

設問2　貴施設の入所者の方々に対して、専門家による口腔ケアや摂食・嚥下リハビリテーションは必要ですか。
① 大変必要である　② 必要である　③ あまり必要でない　④ 必要でない

設問3　設問2で「①大変必要である②必要である」と答えた施設にお尋ねします。日常的に口腔ケアの介助が必要な方に対して、口腔ケアの介助を行っていますか。
① 積極的に行っている　② 必要に応じて行っている　③ 行っていない

設問4　設問3で①もしくは②と答えた施設にお尋ねします。口腔ケアの介助を担当する職種は次のうちどれですか。（複数回答可）
① 医師　② 歯科医師　③ 看護師　④ 保健師　⑤ 看護助手　⑥ （管理）栄養士　⑦ 介護福祉士
⑧ 理学療法士　⑨ 作業療法士　⑩ 言語聴覚士　⑪ 歯科衛生士　⑫ 歯科助手　⑬ その他

設問5　全ての施設にお尋ねします。摂食・嚥下リハビリテーションを行っていますか。
① はい　② いいえ

設問6　設問5で「① はい」と答えた施設にお尋ねします。摂食・嚥下リハビリテーションが必要な入所者は何名ですか。
全入所者＿＿＿名中＿＿＿名

設問7　設問5で「① はい」と答えた施設にお尋ねします。摂食・嚥下リハビリテーションを担当する職種は次のうちどれですか。（複数回答可）
① 医師　② 歯科医師　③ 看護師　④ 保健師　⑤ 看護助手　⑥ （管理）栄養士　⑦ 介護福祉士
⑧ 理学療法士　⑨ 作業療法士　⑩ 言語聴覚士　⑪ 歯科衛生士　⑫ 歯科助手　⑬ その他

設問8　全ての施設にお尋ねします。口腔ケアと摂食・嚥下リハビリテーションを総合的に行うことができる人材を雇用したいと思いますか。
① 雇用したい　② 条件によっては雇用したい　③ 対象者がほとんどいないので雇用の必要性を感じない
④ 現状で十分対応できているので雇用する必要がない

設問9　全ての施設にお尋ねします。口腔ケア担当者として習得して欲しい技術や知識は次のどれですか。（複数回答可）
① 高齢者に対しての知識　② 社会福祉に対する知識　③ 介護技術　④ 栄養学的な知識　⑤ カウンセリング能力
⑥ 口腔清掃に対する技術　⑦ 入れ歯に対する知識　⑧ その他

設問10　全ての施設にお尋ねします。摂食・嚥下リハビリテーション担当者として習得して欲しい技術や知識は次のどれですか。（複数回答可）
① 高齢者に対しての知識　② 社会福祉に対する知識　③ 介護技術　④ 栄養学的な知識　⑤ カウンセリング能力
⑥ スクリーニングテスト能力　⑦ 摂食介助技術　⑧ 摂食嚥下訓練能力　⑨ その他

師」,「(管理) 栄養士」,「作業療法士」などがこれに続き，前回の調査結果と比較して摂食嚥下リハに関与する職種が拡大していることが伺えた（χ^2検定，$p<0.001$，図2）．摂食嚥下リハの実施に関与する職種の拡大は，その実施がチーム医療，とくに栄養補給チーム医療によってなされているためだと考えられる．しかしながら，関与する職種が拡大されているにもかかわらず，口腔保健の専門家である歯科医師や歯科衛生士においては摂食嚥下リハに関与する割合がそれほど高くなっていなかった．その背景には，他の医療従事者が摂食リハに関する歯科

表3　歯科医院に対するアンケートの項目

院長先生についてお尋ねいたします。
年齢　①　20歳代　②　30歳代　③　40歳代　④　50歳代　⑤　60歳以上
性別　①　男性　②　女性　医院開設後＿＿＿＿＿＿年
医院開設住所地　＿＿＿＿＿＿市・郡　＿＿＿＿＿＿町・村

設問1　貴医院のご専門は次のどれですか。(複数回答可)
①　一般歯科　②　小児歯科　③　歯周病科　④　予防歯科　⑤　審美歯科　⑥　口腔外科　⑦　在宅訪問　⑧　その他

設問2　貴医院のスタッフの内訳をお答え下さい。当てはまる職種名の欄に人数を入れて下さい。
①　歯科医師　②　歯科衛生士　③　歯科助手　④　歯科技工士　⑤　受付　⑥　その他

設問3　現在歯科衛生士を雇用している方にお尋ねします。主な業務内容は何ですか。(複数回答可)
①　診療補助　②　保健指導（ブラッシング指導など）　③　予防処置（スケーリング・PMTC・フッ化物応用など）
④　在宅訪問（口腔ケア）　⑤　その他

設問4　全ての歯科医院にお尋ねします。スタッフとして歯科衛生士が必要だと考えますか。
①　とても必要だ　②　必要だ　③　あまり必要ではない　④　全く必要ない

設問5　全ての歯科医院にお尋ねします。4年制教育を受けた歯科衛生士は必要だと思いますか。
①　とても必要だ　②　必要だ　③　あまり必要ではない　④　全く必要ない

設問6　設問5で①または②と答えた方にお尋ねします。4年制教育を受けた歯科衛生士にどのような新たな能力を期待しますか。(複数回答可)
①　より高度な技術力　②　より多くの知識　③　研究能力　④　リーダー的な存在　⑤　患者さんへの対応能力　⑥　その他

設問7　設問5で③または④と答えた方にお尋ねします。必要性を感じない理由で、該当する番号に○を付けて下さい。(複数回答可)
①　2．3年制教育で十分だと思うから　②　給与面を考慮する必要があるから　③　高度な技術力は必要ないから
④　多くの知識は必要ないから　⑤　研究能力は必要ないから⑥　その他

設問8　全ての歯科医院にお尋ねします。今後在宅訪問歯科診療をお考えですか。
①　是非やりたい　②　やりたい　③　あまりやりたくない　④　やりたくない　⑤　現在行なっている

設問9　全ての歯科医院にお尋ねします。訪問診療における口腔ケア担当者として習得して欲しい技術や知識は次のどれですか。(複数回答可)
①　高齢者に対しての知識　②　社会福祉に対する知識　③　介護技術　④　栄養学的な知識　⑤　カウンセリング能力
⑥　口腔清掃に対する技術　⑦　義歯に対する知識　⑧　その他

医師や歯科衛生士の能力は認めてはいるものの，嚥下リハに関する能力を疑問視している可能性があるためと考えられる．このような点を踏まえ，摂食嚥下リハに口腔保健の専門家が関与することの重要性を医療現場や社会に対して啓蒙し，さらにチーム医療の一員として摂食嚥下リハに携わることができる口腔保健の専門家を育成することが必要であると思われた．摂食嚥下リハの開始時期を問う設問7に対する回答から，「急性期から」，あるいは「症例によっては急性期から」摂食嚥下リハを実施する病院が過半数を占め，前回と比べ有意に増加していたことが分かった（χ^2検定，$p<0.01$，表4）．急性期からの摂食嚥下リハの実施が増加したことは，経口栄養摂取が患者の予後やQOL向上に重要であるとの認識が浸透したためと思われた．また，摂食嚥下リハに係る人材