Table 5 Hazard ratios of biochemical markers of bone turnover for the occurence of osteoporosis over the 10-year study period

	BTMs		Occurence of osteoporosis (L2–4)			Occurence of osteoporosis (femoral neck)		
	At baseline	Reference	HR	95% CI	Significance	HR	95% CI	Significance
Men								
Serum	Intact OC	+1SD	1.23	0.35–4.27		1.50	0.61–3.71	
	Total OC	+1SD	1.86	0.73–4.75		1.06	0.28–4.07	
	BAP	+1SD	0.95	0.23–3.93		1.61	0.73–3.59	
	PICP	+1SD	0.95	0.33–2.70		0.85	0.24–3.03	
	PINP	+1SD	2.80	1.18–6.63	*	1.09	0.32–3.69	
	ICTP	+1SD	0.74	0.17–3.25		1.10	0.26–4.58	
	β-CTX	+1SD	2.02	0.76–5.34		1.12	0.31–4.02	
	NTX	+1SD	0.95	0.29–3.08		0.64	0.09–4.54	
Urine	PYR	+1SD	1.79	0.79–4.06		2.11	0.98–4.53	+
	DPD	+1SD	2.86	0.78–10.50		1.53	0.63–3.73	
Women								
Serum	Intact OC	+1SD	0.78	0.47–1.29		0.99	0.64–1.53	
	Total OC	+1SD	1.52	0.92–2.52		1.32	0.90–1.93	
	BAP	+1SD	1.46	0.94–2.25	+	1.03	0.65–1.63	
	PICP	+1SD	1.13	0.69–1.84		1.00	0.62–1.64	
	PINP	+1SD	1.65	1.11–2.47	*	1.26	0.73–2.18	
	ICTP	+1SD	1.44	0.90–2.30		1.01	0.66–1.55	
	β-CTX	+1SD	1.80	1.27–2.56	***	1.21	0.76–1.91	
	NTX	+1SD	1.96	1.23–3.13	**	1.13	0.73–1.75	
Urine	PYR	+1SD	1.28	0.97–1.69	+	1.06	0.772–1.56	
	DPD	+1SD	1.40	1.06–1.84	*	1.23	0.84–1.80	

The hazard ratio was estimated using Cox proportional hazards modeling after adjustment for age and weight, and menstrual status of women, at the baseline

BTMs biochemical markers of bone turnover, *HR* hazard ratio, *CI* confidence interval, *OC* osteocalcin, *BAP* bone-specific alkaline phosphatase, *PICP* C-terminal propeptide of type I procollagen, *PINP* N-terminal propeptide of type I procollagen, *ICTP* C-terminal cross-linking telopeptide of type I collagen generated by matrix metalloproteinase, *β-CTX* β-isomerized C-terminal cross-linking telopeptide of type I collagen, *NTX* N-terminal cross-linking telopeptide of type I collagen, *PYR* pyridinoline cross-links of collagen, *DPD* deoxypyridinoline cross-links of collagen

$^{+}$ $P < 0.1$; * $P < 0.05$; ** $P < 0.01$, *** $P < 0.001$

addition, we had already measured serum free testosterone (FT) levels in male subjects from the present cohort, and found that the serum FT level could offer a useful predictor of bone loss within 3 years [40]. The use of these data might clarify relationships among endogenous sex steroids and BTMs in men and women, and provide some clues to the distinct gender differences in BTM levels.

Regarding the capacity of BTMs to predict bone loss, Garnero et al. [9] reported that BTMs could be useful for forecasting BMD changes in the forearm over 4 years. Others have found that BTMs can only poorly predict bone loss at the spine and hip [10, 11]. Iki et al. [12] found an association between CTX and bone loss at the hip during the first 3 years of follow-up in a female population-based cohort followed for 6 years. In a previous report, we clarified that urinary PYR in men and serum intact OC in women were significantly related to BMD changes at the spine over 3 years [17]. Nevertheless, the present study could not identify any significant associations between BTMs and rates of change in BMDs over 10 years. The influence of BTMs measured at one specific point during BMD change thus appears to be limited to within a relatively short period, such as up to 4 years.

As few reports have examined associations between BTMs and the incidence of OP, evaluating the usefulness of BTMs as predictors of future OP is difficult. However, the present study found that high PINP levels in both men and women and high levels of serum beta-CTX, serum NTX, and urinary DPD in women were significant predictors of future OP at the lumbar spine. This association with PINP, beta-CTX, and NTX in women remained significant after adding baseline BMD status as an adjustment factor. This means that these BTMs could predict the future occurrence of spinal OP in women independent of baseline BMD status showing either osteopenia or normal range BMD. This shows that high bone turnover becomes an important determinant of the occurrence of spinal OP, particularly in women.

We could not establish any BTMs as useful predictors of OP at the femoral neck. Although the reasons for site differences in the predictive capacity of BTMs are obscure, we have previously reported that the characteristics of the lumbar spine and femoral neck differ among individuals who rapidly lose bone [41]. These results suggest that the predictive capacity of BTMs might differ according to the site involved. Different strategies are therefore required to prevent OP of the lumbar spine and that of the femoral neck.

Several reports have found that the risk of osteoporotic fractures could be predicted by BTM levels independently of BMD. Prospective studies of postmenopausal French women have clarified that higher levels of bone resorption markers are associated with an increased risk of osteoporotic fractures [13–15]. In contrast, the present study could not identify any associations between osteoporotic fractures and BTMs. The sample size and characteristics of the present cohort might explain this difference. Our cohort comprised 400 participants aged 40–79 years, and the mean age was approximately 60 years, which might be too young to collect a sufficient number of individuals with new osteoporotic fractures. In fact, only 32 fractures (10 in men, 22 in women) were accumulated during 10 years in the present cohort. Further observation in larger cohorts, such as that in the above-mentioned ROAD study, might be required to confirm the absence of an association between BTMs and osteoporotic fractures.

Besides the small sample size, the present study shows several limitations. First, samples were not all taken at a fixed time. Circadian variability is known to affect BTM levels, with levels of most BTMs increasing at night and peaking between 02:00 and 08:00, then rapidly decreasing to a nadir between 13:00 and 23:00 [42]. Because we collected samples at the point when BTM levels would have been decreasing towards the nadir, our results might represent underestimations. Second, long-term storage might have influenced the BTM levels. In this study, serum and urine samples were immediately frozen in dry ice and then stored in a deep freezer at −80°C within 24 h. However, serum total OC, BAP, PINP, beta-CTX, and NTX were measured in baseline samples after 7 years, as technical methods for identifying these BTMs were unavailable in 1993. Storage for 7 years at −80°C might thus have influenced BTM values, although Seibel et al. [43] stated that BTMs should remain stable in serum and urine samples if stored at −70°C or below and at −20°C or below, respectively.

On the other hand, one advantage of the present survey was that various BTMs were measured in men and women who were randomly selected from the general population and followed for a decade, with a high degree of compliance. Another advantage was that the effects of various BTMs on changes in BMD, the presence of individuals who rapidly lose bone, and the occurrence of OP and osteoporotic fractures could be estimated directly.

In conclusion, we clarified that various BTMs, including markers of both bone resorption and bone formation, such as PINP, beta-CTX, NTX, and DPD in women, and PINP in men, could predict the occurrence of spinal OP. Among these, PINP, beta-CTX, and NTX in women could predict the occurrence of spinal OP, independent of baseline BMD status. We therefore speculate that BTM levels could help to predict OP at the lumbar spine, especially in women, but not OP at the femoral neck, the rate of change in BMD, or osteoporotic fractures.

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Conflict of interest None.

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EDITORIAL

The concept and treatment of locomotive syndrome: its acceptance and spread in Japan

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In 2009, the average lifespan of a Japanese male was 79.6 years and that of a female was 86.4 years. This was the highest in the world; about 60 years ago, the average in the Japanese population was approximately 50 years. It is thus apparent that Japan has rapidly been becoming an aged society. In 2010 there were 29,440,000 individuals age 65 or older; this number will increase steadily, and is expected to reach 38,630,000 by 2042. By 2055 the elderly are expected to account for 40.5% of the country's total population.

A long life has been the dream of people; once realized, however, for many it has turned out to be a source of anxiety. One reason for this is the fact that many elderly require nursing care services; their number is increasing and presently stands at 4.5 million. The main causes necessitating such care are falls/fractures (9.3%) and joint disorders (12.2%), that is, 21.5% of all patients utilizing such services are suffering from locomotive organ disorders. These are disorders which make it difficult for people to walk on their two legs.

A recent analysis of profiles of orthopaedic patients requiring surgical operations in Japan showed that until the age of 40 the prevalence differed little among the age groups, but from age 50 or older it increased rapidly. The main disorders of the elderly are osteoporosis-related fractures, spondylosis, and osteoarthritis of the knee joints [1, 2]; estimated prevalence based on their cohort study in Japan is: radiographic knee osteoarthritis (≧2 on the Kellgren–Lawrence (KL) scale), 25.3 million; radiographic lumbar spondylosis (≧2 on the KL scale), 37.9 million; and osteoporosis (the criteria of the Japanese Society for Bone and Mineral Research, bone mineral density (hip) <70% of the young adult mean), 10.7 million. Many elderly have two or more of these disorders: 24.7 million have two disorders, the number with all three has been estimated at 5.4 million. At least 47 million had one of these disorders. These data indicate that most people have locomotive organ problems after reaching middle age.

When we realize that the aged population will continue to expand, it is clear that it is important for individuals and for society in Japan as a whole to take effective means of coping with the expected restricted walking ability after middle age. Recognizing such circumstances, the Japanese Orthopaedic Association (JOA) proposed the concept of locomotive syndrome in 2007 [3, 4]. This syndrome, or "locomo" in short, refers to those elderly who have come to need nursing care services because of problems of the locomotive organs, or have risk conditions which may require them to have such services in the future.

The countermeasures recommended against "locomo" are: preventing the deterioration of locomotive organs and the development of disorders, and maintaining and/or improving walking ability. The word "locomotive" also has the symbolic meaning of a locomotive engine, thus bringing to mind an active image and the impression that it can run for a long time if it is given regular maintenance.

The locomotive organs consist of three main elements: bones, which give the body a framework; joints and intervertebral discs, which enable the body to be mobile; and muscles and a nervous system, which move the body and/or regulate its motion. These elements work together by forming a kind of network. If these elements deteriorate beyond a specific point, they are diagnosed as osteoporosis-related fractures, osteoarthritis, spondylosis, sarcopenia,

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nerve disorders, etc. Figure 1 shows mutual relationships among locomotive organ disorder, gait disorder, and the requirement for nursing care. When an elderly person reaches the point where he finds it difficult to walk, he risks having to rely on nursing care from then on.

Among the signs and symptoms of "locomo" are pain, a limitation of the range of joint mobility, deformation, reduced balance capability and a slow pace of walking. In many cases, however, degeneration of the locomotive organs develops and progresses so slowly that people often fail to sense it. This makes it important for individuals to become aware of these signs and to recognize that they could be at risk of "locomo".

It is known that those experiencing difficulty in walking, climbing stairs, going shopping, putting on a pair of socks, or doing housework in their daily life have a significantly higher risk of requiring nursing care services than those who are able to do these things without difficulty. An individual can self-check as to whether he has "locomo" or not by taking a look at his daily activities; we have prepared a self-check list for this syndrome [3]:

1. You cannot put on a pair of socks while standing on one leg.
2. You stumble or slip in your house.
3. You need to use a handrail when going upstairs.
4. You cannot get across the road at a crossing before the traffic light changes.
5. You have difficulty walking continuously for 15 min.
6. You find it difficult to walk home carrying a shopping bag weighing about 2 kg (e.g., two 1-l milk packs).
7. You find it difficult to do housework requiring physical strength (e.g., use of a vacuum cleaner to clean the rooms, putting futons into and taking them out of the closet, etc.).

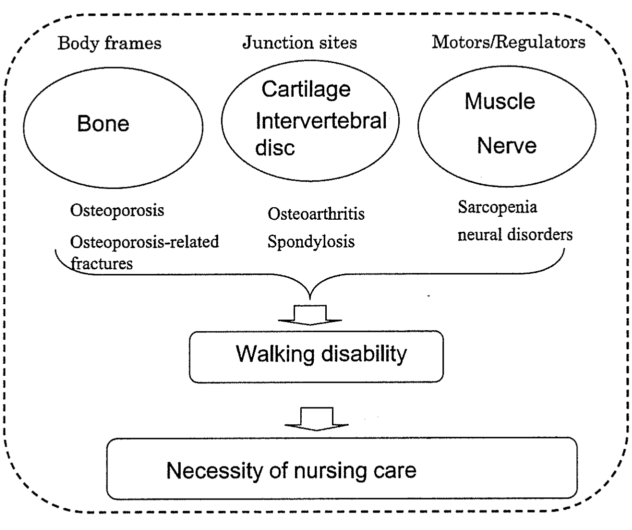

Fig. 1 The relationship among dysfunction of locomotive organs, walking disability, and need for of nursing care

Those who are described by any of the above categories may possibly have "locomo".

The key points in preventing the elderly from having problems with walking include reinforcing muscle strength, strengthening balance capacity, and avoiding heavy burdens on the knees and the lumbar spine.

The JOA recommends "standing on one leg with eyes open" and "half-squats" as beneficial locomotive exercises [3]. One-legged standing with eyes open is intended to enhance balance capability. A set of 1 min on each leg, and 3 sets a day are recommended. Squats are representative of muscle training for the lower half of the body. We recommend half-squats because it has a lower burden on the knees. One set is 5 or 6 squats, and 3 sets a day are recommended. These exercises are advantageous in that they can be used by an individual at home as long as care is taken not to fall down. Locomotive training at a home for the elderly has also been reported to significantly improve an individual's one-legged standing time, muscle strength of knee extension, and walking speed [5].

Various training regimens can be devised, depending on the walking ability of each person. If an individual wants to increase the extent of training, he can exercise more frequently and/or adopt more difficult ways, for example taking an arabesque posture on one leg and one-legged squats. If normal one-legged standing or half-squatting exercises are difficult, a desk or a chair can be used as support. If one is nervous about pain in the knee or the low back, the above-described training can be combined with therapeutic exercises for the knees and the lumbar spine. When the three key points described above are achieved, various other exercises such as Tai chi chuan can be effective.

This concept has been accepted and has spread quite rapidly in Japan since it was first proposed in 2007. Locomotive syndrome has been featured many times as a health program or a current issue on TV by NHK and other commercial broadcasting stations, and several medical journals have published a special issue on the concept. It also appears frequently in local government public relations news. Its rapid spread and recognition reflects that there have already been many people who are in trouble with nursing care because of locomotive syndrome. From now on, the JOA will promote this movement even further because it contributes to the health and welfare of the nation.

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Factors involved in the presence of symptoms associated with rotator cuff tears: a comparison of asymptomatic and symptomatic rotator cuff tears in the general population

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Background: The mechanisms underlying symptom development in rotator cuff tears are still unknown. The purpose of this study was to identify the characteristics associated with symptoms of rotator cuff tears.
Materials and methods: We performed a medical checkup on residents of a mountain village. The subjects of this study included 211 individuals with 283 shoulders in which a full-thickness rotator cuff tear was observed through ultrasonography. We recorded the subjects' background and medical history and then performed physical examinations. The subjects were divided into 2 groups according to whether they had any pain or disabilities that they felt subjectively while performing their usual daily activities. We determined the prevalence of an asymptomatic rotator cuff tear and conducted a statistical analysis to compare any differences between the 2 groups.
Results: Of the 283 subjects, 65.4% with rotator cuff tears had no symptoms involving the shoulder. Asymptomatic rotator cuff tears were associated with a tear in the nondominant arm, a negative impingement sign, higher active forward elevation, and intact muscle strength in abduction and external rotation. A logistic regression analysis showed that a positive impingement sign, weakness in external rotation, and presence of a tear in the dominant arm were significantly associated with the presence of symptoms of rotator cuff tears.
Conclusions: In the general population, in approximately two-thirds of all rotator cuff tears, there are no symptoms, and the factors involved in the presence of symptoms associated with rotator cuff tears were identified to be a positive impingement sign, weakness in external rotation, and presence of a tear in the dominant arm.
Level of evidence: Level III, Cross-Sectional Study, Prevalence Study.

Keywords: Rotator cuff tear; asymptomatic; epidemiology; etiology; ultrasonography; population-based study

Institutional review board approval received from Gunma University Graduate School of Medicine (No. 20-36).

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A rotator cuff tear is one of the most common disorders affecting the shoulder. A patient with a symptomatic rotator cuff tear usually has pain, loss of muscle strength, and a limited range of motion in the shoulder. Traditionally, the tear itself has been believed to be a direct cause of these symptoms, but recent reports have shown that some individuals have asymptomatic rotator cuff tears.[1-4,7,9-11,13-15,17-20] In our previous study, 20.7% of 1,366 shoulders had full-thickness rotator cuff tears regardless of the presence or absence of symptoms in the general population. In addition, it was shown that 16.9% of 1,024 shoulders that were asymptomatic had rotator cuff tears.[22] However, little is known about either the mechanism of symptom onset or what factors render some tears asymptomatic and others symptomatic.

Our hypothesis was that there are factors differentiating asymptomatic from symptomatic rotator cuff tears. An asymptomatic rotator cuff tear could be considered to be a condition in which the body adapts to the rotator cuff tear through compensatory mechanisms, and this condition should thus be the goal of conservative medical management for rotator cuff tears. Therefore it is not only a diagnostic matter but also a therapeutic matter to know factors involved in the presence of symptomatic rotator cuff tears. The purpose of this study was to identify the characteristics associated with the symptoms of rotator cuff tears.

Materials and methods

This cross-sectional study was approved by the institutional review board of our institution, and all the subjects were informed that their data would be published and gave their consent to participate in this study. Cancer screening and a preventive health medical checkup were conducted for the residents of a mountain village, where agroforestry and tourism are the main industries. We randomly picked 683 of the residents and performed ultrasonography on both shoulders to diagnose rotator cuff tears.

In this study, the subjects were selected based on the following: (1) observation of a full-thickness rotator cuff tear through ultrasonography, (2) no restriction of both active and passive forward elevation less than 100°, (3) no history of surgical treatment of the shoulders, (4) no treatment of the shoulders at the time of this survey. On the basis of these criteria, this study included 211 individuals with 283 shoulders (139 subjects had a unilateral tear and 72 had bilateral tears), which comprised 81 men and 130 women with a mean age of 65.5 years (range, 34-87 years).

The ultrasonographic examinations were performed with the technique described by Middleton et al[8] by use of LOGIQ e (GE Healthcare, Buckinghamshire, England) with linear-array probes at 12 MHz. To avoid interobserver variation, all ultrasonographic examinations were performed by 1 experienced shoulder joint surgeon who was blinded to the other items in the evaluation. In accordance with the report by Takagishi et al,[16] discontinuity and thinning of the rotator cuff were considered to be indications of full-thickness rotator cuff tears. These diagnostic criteria have a sensitivity of 76% and specificity of 100% for the diagnoses of full-thickness rotator cuff tears.[16] Any suspected cases of partial-thickness rotator cuff tears were excluded from this study.

All of the subjects filled out a questionnaire regarding age, sex, dominant arm, heaviness of labor (subjectively classified by the subjects as light, intermediate, or heavy), any history of shoulder trauma, and whether they had any current symptoms involving their shoulders. We defined "current symptoms" as any pain or disabilities subjects felt subjectively while performing their usual daily activities within the 2 weeks before the survey. Subjects subsequently underwent physical examinations that evaluated the impingement sign, active forward elevation, and loss of muscle strength in abduction and external rotation. The investigation of the impingement sign was performed according to the technique of Neer[12] as follows: The patient is seated, while the examiner stands. The examiner prevents scapular rotation with one hand while using the other hand to raise the patient's arm in forced forward elevation, thus causing a greater tuberosity to impinge against the acromion.

Active forward elevation was measured with a goniometer as the angle between the thorax and the humerus at the scapular plane with the subject standing upright. The loss of muscle strength was evaluated by manual muscle testing based on the technique described by Daniels and Worthingham,[5] and any score lower than 5 indicated weakness. The evaluations for abduction were performed with the subject sitting and abducting the shoulder to 90° with the elbow extended. In addition, the evaluations for external rotation were performed with the subject sitting with the arm in neutral rotation at his or her side and the elbow flexed to 90°. All physical examinations were performed by the same examiner to avoid any interobserver error.

The subjects were divided into 2 groups according to their current symptoms involving the shoulders—those with a symptomatic rotator cuff tear (symptomatic group) and those with an asymptomatic tear (asymptomatic group). We determined the prevalence of the asymptomatic group and the percentage of subjects in the asymptomatic group according to decade of life ($\leq$49 years, 50-59 years, 60-69 years, and so on). In addition, the differences between the 2 groups in terms of age, sex, dominant arm, heaviness of labor, history of trauma, impingement sign, active forward elevation, and weakness in abduction and external rotation were evaluated. The Student t test was performed to compare age and active forward elevation, and Fisher exact probability tests were performed to compare sex, dominant arm, history of trauma, impingement sign, and weakness in abduction and external rotation. The Mann-Whitney U test was used to compare the heaviness of labor. Finally, a stepwise forward logistic regression analysis was used to identify the factors involved in the presence of symptoms of rotator cuff tears by use of the aforementioned factors as explanatory variables. All statistical analyses were conducted with the IBM SPSS Statistics 19 software program (IBM Japan, Ltd, Tokyo, Japan), and the critical value for significance was set at $P < .05$.

Results

The asymptomatic group accounted for 65.4% and the symptomatic group for 34.6% of the subjects, and according to decade of life, 57.9% of subjects in the asymptomatic group were aged under 50 years, 72.9% were aged 50 to

Table I Percentage of subjects in asymptomatic group by decade of life

	% of asymptomatic group	95% CI
All subjects	65.4% (185/283)	59.9%-70.9%
≤49 y	57.9% (11/19)	35.7%-80.1%
50-59 y	72.9% (35/48)	60.3%-85.5%
60-69 y	67.8% (59/87)	58.0%-77.6%
70-79 y	60.9% (67/110)	51.8%-70.0%
80-89 y	68.4% (13/19)	47.5%-89.3%

CI, confidence interval.

59 years, 67.8% were aged 60 to 69 years, 60.9% were aged 70 to 79 years, and 68.4% were aged 80 to 89 years (Table I, Fig. 1). The mean age was significantly higher in those with bilateral tears than in those with a unilateral tear (70.0 years vs 63.2 years, $P < .001$).

There were significant differences between the 2 groups regarding the presence of a tear in the dominant arm, presence of the impingement sign, angle of active forward elevation, weakness in abduction, and weakness in external rotation (Table II).

A logistic regression analysis showed that the impingement sign, weakness in external rotation, and presence of a tear in the dominant arm were significantly associated with the presence of symptoms of rotator cuff tears. The odds ratios for the impingement sign, weakness in external rotation, and presence of a tear in the dominant arm were 10.18, 3.10, and 2.99, respectively (Table III).

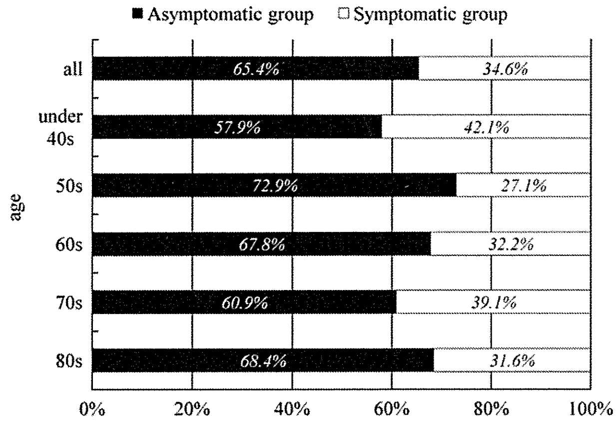

Figure 1 Percentages of patients in asymptomatic group and symptomatic group by decade of life. There was no significant difference between the percentages in the 2 groups by decade of life.

Discussion

Because there is a high prevalence of asymptomatic rotator cuff tears in the general population, the tear itself has been regarded as one type of normal degenerative change.[9,11,17,18] Some studies have evaluated the prevalence of asymptomatic rotator cuff tears using diagnostic imaging in asymptomatic healthy volunteers. The prevalence of asymptomatic full-thickness rotator cuff tears was 0% to 15% in studies using magnetic resonance imaging[2,10,13,15] and 6% to 23% in studies using ultrasonography,[1,3,7,9,11,14,17,18] and most of those reports showed that the prevalence of tears increases with age. However, these studies limited the subjects to volunteers without any symptoms in their shoulders, so the prevalence of symptoms in full-thickness rotator cuff tears in the general population remains unclear. Furthermore, the relationship between age and the presence of symptoms was ambiguous because of limitations in research design. According to the results of our study, 65.4% of 283 rotator cuff tears displayed no symptoms. These results are the first to show the prevalence of the appearance of symptoms in full-thickness rotator cuff tears in the general population.

There are several reports comparing asymptomatic and symptomatic rotator cuff tears, but there is no consensus as to what factors are involved in the presence of symptoms. Yamaguchi et al[20] performed bilateral shoulder ultrasonography in 588 patients who presented with unilateral shoulder pain and observed that in patients with bilateral rotator cuff tears in whom one tear was symptomatic and the other tear was asymptomatic, the symptomatic tear was significantly larger. They therefore determined that the size of the tear appears to be an important factor in the development of symptoms. In addition, Kelly et al[6] evaluated electromyographic patterns in 18 shoulders, of which 6 were normal controls, 6 had asymptomatic rotator cuff tears, and 6 had symptomatic rotator cuff tears. Their findings showed that the asymptomatic subjects demonstrated increased firing of the intact subscapularis, whereas symptomatic subjects continued to rely on torn rotator cuff tendons and periscapular muscle substitution. They determined that differential shoulder muscle firing patterns in patients with rotator cuff pathology may play a role in the presence or absence of symptoms. Moreover, Yamaguchi et al[21] reported that abnormal glenohumeral kinematics alone was not an independent factor, which could also account for the presence of symptoms. Our study shows that in comparison to symptomatic tears, asymptomatic rotator cuff tears showed a greater association with a negative impingement sign, preserved strength in external rotation, and presence of tear in the nondominant arm.

This study identified several characteristics associated with the symptoms of rotator cuff tears. However, our study had several limitations. First, it is a cross-sectional study, so diachronic changes with regard to the symptoms were not evaluated, and we did not really elucidate factors that cause symptom development. Second, with regard to the selection criteria, we excluded the subjects who had restriction of both active and passive forward elevation so as to exclude the patients with other potential causes of shoulder pain, such as osteoarthritis. However, we did not conduct diagnostic imaging other than ultrasonography; thus, we could

Table II Comparison of asymptomatic group and symptomatic group

	Asymptomatic group	Symptomatic group
Age (y)	66.8 ± 9.8	66.3 ± 10.6
Sex (male/female)	71/114 (38.4%/61.6%)	43/55 (43.9%/56.1%)
Dominant/nondominant arm*	96/89 (51.9%/48.1%)	71/27 (72.4%/27.6%)
Heaviness of labor (light/intermediate/heavy)	10/108/67 (5.4%/58.4%/36.2%)	11/50/37 (11.2%/51.0%/37.8%)
History of trauma (present/absent)	10/175 (5.4%/94.6%)	11/87 (11.2%/88.8%)
Impingement sign* (positive/negative)	11/174 (5.9%/94.1%)	41/57 (41.8%/58.2%)
Active forward elevation* (°)	150.7 ± 14.0	146.1 ± 15.8
Weakness in abduction* (present/absent)	31/154 (16.8%/83.2%)	40/58 (40.8%/59.2%)
Weakness in external rotation* (present/absent)	23/162 (12.4%/87.6%)	36/62 (36.7%/63.3%)

* $P < .05$.

Table III Results of logistic regression analysis

	Odds ratio	95% CI
Age	0.99	0.96-1.02
Sex	0.55	0.30-1.02
Dominant arm*	2.99	1.57-5.71
Heaviness of labor	0.82	0.50-1.36
History of trauma	1.09	0.37-3.16
Impingement sign*	10.18	4.57-22.69
Active forward elevation	0.99	0.97-1.01
Weakness in abduction	1.51	0.60-3.79
Weakness in external rotation*	3.10	1.21-7.95

CI, confidence interval.
* $P < .05$.

not exclude such patients completely. Third, regarding the definition of the symptoms involving the shoulder, we defined "symptoms" subjectively without any other objective assessment such as a visual analog scale. Fourth, we did not measure the sizes of the tears in this study. The information about tear size and which tendons were involved could potentially be a confounding variable.

Yamaguchi et al[20] followed up 58 patients with asymptomatic rotator cuff tears with ultrasound examinations and reported that 51% became symptomatic over a period of 2.8 years and 39% of those tears progressed in size during that time. Furthermore, Connor et al[2] studied asymptomatic shoulders in 20 elite overhead athletes. They showed that 40% of the dominant shoulders had partial- or full-thickness rotator cuff tears and none of the athletes interviewed 5 years later had had any subjective symptoms or had required any evaluation or treatment for shoulder-related problems in the ensuing period. In a continuous follow-up of the subjects in our study, we are now investigating whether asymptomatic rotator cuff tears remain asymptomatic and, in the case of symptom onset, what factors render these tears symptomatic. We strongly believe that the mechanisms underlying the development of symptoms will be revealed through a better understanding of asymptomatic rotator cuff tears, and this knowledge will thereby positively influence the treatment strategies for rotator cuff tears.

Conclusion

We performed a medical checkup on residents of a mountain village to identify the characteristics associated with symptoms of rotator cuff tears. In the general population, approximately two-thirds of full-thickness rotator cuff tears had no symptoms, and the factors involved in the presence of symptoms associated with rotator cuff tears were identified to be a positive impingement sign, weakness in external rotation, and presence of a tear in the dominant arm.

Disclaimer

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ORIGINAL ARTICLE

The effects of rotator cuff tears, including shoulders without pain, on activities of daily living in the general population

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Abstract
Background Few reports have so far evaluated the possible restrictions of activities of daily living (ADL) in patients with asymptomatic rotator cuff tears (RCTs). The purpose of this study was to examine the effects of RCTs, including shoulders without pain, on ADL in the general population.
Methods We performed medical checkups on 462 individuals (924 shoulders). All participants completed a questionnaire regarding their background and medical history. We then assessed their shoulder functions with the Simple Shoulder Test (SST) and performed US (US) examinations of both shoulders to diagnose RCTs. We divided participants into tear and nontear groups and performed statistical analysis to compare total SST scores and each SST item between groups. Furthermore, we performed the same examinations for participants identified as having shoulders without pain.
Results Among participants, those in the tear group showed significantly lower total SST scores than those in the nontear group. After examining each SST item, a significant difference was observed regarding the ability to sleep comfortably and to lift 3.6 kg to shoulder level. In shoulders without pain, the tear group showed significantly lower total SST scores than the nontear group. A significant difference was observed only regarding the ability to lift 3.6 kg to shoulder level.
Conclusions In the general population, ADL were restricted in participants with RCTs; they experienced night pain in the shoulder and muscle weakness during shoulder elevation. Furthermore, participants with RCTs, even if the condition itself did not induce any pain, tended to experience muscle weakness during shoulder elevation, thus resulting in restrictions of ADL.

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Introduction

A rotator cuff tear (RCT) is one of the most common disorders affecting the shoulder and cause pain and dysfunction. However, recent studies have found that there are cases of asymptomatic RCTs in which the patient exhibits no shoulder symptoms [1–10]. It is evident that patients with symptomatic RCTs tend to demonstrate restrictions in activities of daily living (ADL); however, few reports have so far evaluated the possible restrictions of ADL in patients with asymptomatic RCTs. We found no published reports examining what effects RCTs might have on ADL in the general population.

There are several methods to evaluate the effects of shoulder joint disorders on ADL. The Simple Shoulder Test (SST) as proposed by Lippitt et al. [11] is a self-assessment tool that evaluates 12 common shoulder functions; participants answer by circling “Yes” or “No”. These 12 questions are listed in Table 1. The SST is frequently used to evaluate ADL in cases of shoulder joint disorders because it is easy to perform but also sensitively reflects shoulder dysfunction attributed to shoulder joint

Table 1 Simple Shoulder Test

1. Is your shoulder comfortable with your arm at rest by your side?
2. Does your shoulder allow you to sleep comfortably?
3. Can you reach the small of your back to tuck in your shirt with your hand?
4. Can you place your hand behind your head with the elbow straight out to the side?
5. Can you place a coin on a shelf at the level of your shoulder without bending your elbow?
6. Can you lift 1 pound (0.5 kg) to the level of your shoulder without bending your elbow?
7. Can you lift 8 pounds (3.6 kg) to the level of your shoulder without bending your elbow?
8. Can you carry 20 pounds (9.1 kg) at your side with the affected extremity?
9. Do you think you can toss a softball underhand 10 yards (9.1 m) with the affected extremity?
10. Do you think you can toss a softball overhand 20 yards (18.3 m) with the affected extremity?
11. Can you wash the back of your opposite shoulder with the affected extremity?
12. Would your shoulder allow you to work full time at your regular job?

disorders. It does not bias the examiner into a particular direction, and it has excellent reproducibility [11–21].

The purpose of this study was to examine the effects of RCTs on ADL in the general population, including shoulders without pain, using the SST.

Materials and methods

This cross-sectional study was approved by the institutional review board of our institution. A medical checkup, which was intended to help prevent the occurrence of lifestyle-related disease and promote early detection of cancer, was conducted for the residents of a mountain village, where agriculture, forestry, and tourism remain the most important sources of income. Consent was obtained from 544 individuals participating in the study. First, all participants filled out a questionnaire regarding age, gender, presence of shoulder pain at the present time, history of shoulder joint trauma, history of surgery, history of outpatient hospital care, and then the range of motion of active and passive forward elevation of the shoulder joint was measured. We then assessed shoulder functions with the SST. We also conducted ultrasonographic (US) examinations of both shoulders in order to diagnose RCTs. US examinations were performed with the technique described by Middleton et al. [22] using LOGIQ e (GE Health Care, USA) with linear-array probes at 12 MHz. To avoid interobserver variation, all US examinations were performed by one experienced shoulder joint surgeon who was blinded to the other items in the evaluation. In accordance with the report by Takagishi et al. [23], discontinuity and thinning of the rotator cuff were considered to be indications of full-thickness RCTs. Any suspected cases of partial-thickness RCTs were considered to be nontears. According to the US findings prior to surgery on 58 shoulders, which were performed by the shoulder joint surgeon who conducted the US examinations in this study, in cases that underwent arthroscopic rotator cuff repair in our institute from January 2010 to August 2011 after being diagnosed with RCTs, outcomes of 91.8% sensitivity, 77.8% specificity, 95.7% positive predictive value, 63.6% negative predictive value, and 89.7% accuracy were obtained (unpublished data).

Participants were selected based on the following criteria:

1. All target evaluation items could be obtained;
2. individuals with both an active and/or passive forward elevation $\geq$100°, with the purpose here being to exclude any cases of shoulder joint contracture, such as frozen shoulders, with the limit angle selected based on reports by Bunker et al. [24] and Zuckerman et al. [25];
3. No history of trauma and surgery to the shoulder joints;
4. No treatment on the shoulders at the time of this survey.

Based on these inclusion criteria, 52 patients lacking all evaluation items, five observed with a limited range of motion, 11 with a history of trauma and surgery to the shoulder joints, and 14 undergoing treatment for shoulder pain during the investigation were excluded. With regard to the five patients in whom a limited range of motion was observed, no RCT was observed on US examinations, so they were not considered to be cases demonstrating a secondary contracture accompanying an RCT. Moreover, there were two patients with an active forward elevation of $\leq$100° and a passive forward elevation of $\geq$100°, and an RCT was observed in both patients based on US examinations. These 2 cases were diagnosed as pseudoparalysis accompanied by an RCT and were thus included in this study because they had normal elbow flexion strength and demonstrated no neurological abnormalities due to a suspicion of either cervical spine disease or a central nervous system disorder. Therefore, the study comprised 462 participants with 924 shoulders; 171 were men and 291 were women, with a mean age of 61.3 (28–87) years.

As a statistical analysis, we first divided all participants into a tear and a nontear group, depending on the existence of an RCT, and conducted a comparative examination using the Mann–Whitney *U* test to ascertain that a difference existed between the two groups in the total SST score.

In addition, to examine factors that determined the two groups with respect to each SST item, we performed a logistic regression analysis using the existence of a tear as an objective variable and each SST item as an explanatory variable. It is known that the prevalence of RCTs increases with age [3, 4, 6, 7, 9, 10, 12]; therefore, age was used as a regulator in the examination, and the effect of age on ADL was excluded.

Next, the participants who had no present pain in the shoulder joint, including pain on motion according to the questionnaire findings, and who also answered "Yes" to both SST items of question 1: "Is your shoulder comfortable at rest?," which evaluates the presence of pain at rest; and question 2: "Does your shoulder allow you to sleep comfortably?," which evaluates the presence of pain at night, were thus defined as having "shoulders without pain." These participants were then examined in the previously described manner with respect to the total SST score and each item. Statistical analysis was carried out using the IBM SPSS Statistics 19 (IBM Japan, Ltd., Tokyo, Japan), and the critical values for significance were set at <5%.

Results

Examination of all participants

Of the 924 shoulders, 99 belonged to the tear group [mean age 70.5 (46–87) years] and 825 to the nontear group [mean age 60.2 (28–86) years]. Total SST score was 10.6 (3–12) in the tear group and 11.3 (5–12) in the nontear group, with the total SST score in the tear group being significantly lower ($P < 0.001$) (Fig. 1). Upon examination of each SST item, there was a significant difference with respect to two items: question 2 "ability to sleep comfortably" [odds ratio (OR) 0.41, 95% confidence interval (CI) 0.19–0.88, $P = 0.022$], and question 7 "lift 3.6 kg to shoulder level" (OR 4.21, 95% CI 2.25–7.88, $P < 0.001$).

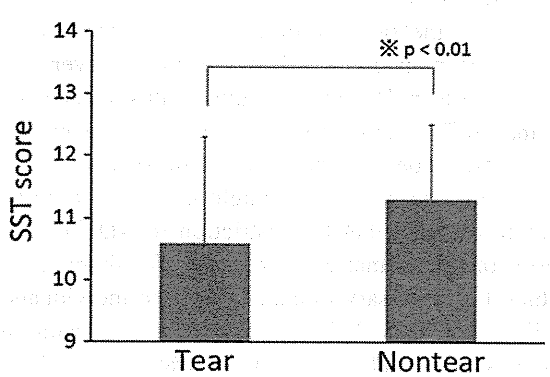

Fig. 1 Comparison of Simple Shoulder Test (SST) total scores between all shoulders. SST score was significantly lower in the tear group (*$P < 0.001$)

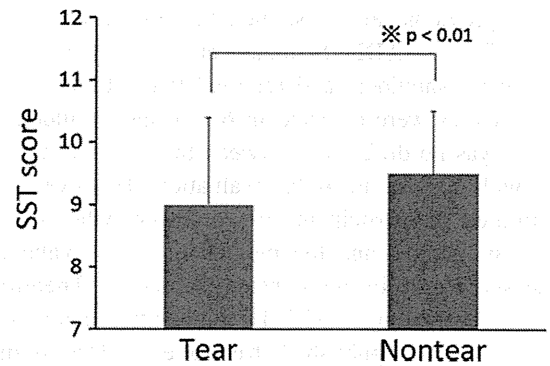

Fig. 2 Comparison of Simple Shoulder Test (SST) total scores between shoulders without pain. SST score was significantly lower in the tear group (*$P < 0.001$)

Examination of shoulders without pain

A total of 708 shoulders had no pain, 57 of which belonged to the tear group [mean age 71.1 (56–87) years] and 651 to the nontear group [mean age 60.5 (28–86) years]. The total score for SST questions 3 through 12 (maximum score 10 points) was 9.0 (3–10) in the tear group and 9.5 (5–10) in the nontear group, with the total SST score in the tear group being significantly lower ($P < 0.001$) (Fig. 2). There was a significant difference among the questions only in respect to question 7, "lift 3.6 kg to shoulder level" (OR 4.60, 95% CI 1.91–11.09, $P = 0.001$).

Discussion

Several published reports have evaluated the SST score for ADL in patients with RCTs. Lippitt et al. [11] studied 50 shoulders with RCTs and reported that the patients had an impaired ability to sleep comfortably, lift 3.6 kg to shoulder level, and throw a ball 18.3 m overhand. Duckworth et al. [26] studied 123 shoulders with full-thickness RCTs and reported that the total SST score was 5 points on average and that many restrictions were found with respect to the ability to sleep comfortably, lift 3.6 kg to shoulder level, throw a ball 18.3 m overhand, wash the back of the opposite shoulder, and do regular work. Harryman et al. [27] studied 333 shoulders with full-thickness RCTs and reported that the total SST score was 4.4 points and that many restrictions were found in respect to the ability to sleep comfortably, lift 3.6 kg to shoulder level, and throw a ball 18.3 m overhand. The results of these studies agreed on the fact that RCTs restrict ADL. However, all of these studies examined symptomatic RCTs and did not evaluate RCTs in their entirety, including asymptomatic RCTs.

A few previous reports studied the effects of asymptomatic RCTs on ADL. Schibany et al. [5] studied 212 asymptomatic shoulders and reported that, although full-thickness RCTs were detected in 6% of the shoulders by US, there was no difference between the tear and nontear groups with respect to ADL evaluation. However, that study limited its participants to volunteers who had no shoulder symptoms, and the method of ADL evaluation was measured only by the constant subscores. Therefore, no detailed evaluation of ADL limitations that includes all RCTs has yet been published. Keener et al. [15] studied 196 participants with asymptomatic RCTs and 54 with an intact rotator cuff presenting with a painful RCT in the contralateral shoulder. The authors stated that participants with an intact rotator cuff had greater but clinically insignificant SST scores than those with an asymptomatic tear. However, it was not a population-based study intended for the general population, and therefore the individual SST items were not considered in detail. In our study, we considered each SST item in the investigated group of participants to be representative of the general population. The results of the overall examination confirmed ADL to be restricted in participants with RCTs; specifically, participants were prone to suffer night pain in the shoulder joint and muscle weakness during shoulder elevation. In addition, in the examination of shoulders without pain, detailed evaluations by SST confirmed that when there was a RCT, ADLs were restricted; specifically, participants were prone to suffer muscle weakness when engaging in shoulder elevation motions. These are the first-ever results from an inclusive study on RCTs in the general population to identify how RCTs affect ADL, regardless of whether or not participants exhibit any symptoms. Tashjian et al. [21], however, reported that patients with rotator cuff disease who are treated without surgery and had a 2-point change in the SST score experienced a clinically important change in self-assessed outcome. In our study, we found ADL to be restricted by evaluating each SST item, but further studies will be required to confirm whether any clinically important difference actually exists when evaluating participants by the total SST score.

Regarding the relationship between asymptomatic RCT and muscular strength, Moosmayer et al. [4] studied 420 shoulders of asymptomatic volunteers aged between 50 and 79 years and reported that the strength of flexion significantly decreased in the group with RCTs. Kim et al. [1] also studied 237 asymptomatic shoulders and reported the abduction strength to significantly decrease in shoulders with a large to massive full-thickness RCT. The ADL restriction identified in our study with respect to shoulders without pain was the inability to lift 3.6 kg to shoulder level. It is believed that this restriction can be attributed to muscle weakness during shoulder elevation motions, and as a consequence, no inconsistency is considered to exist between these reports and our study.

Our study has several limitations. The first is that this study was not conducted with an examination of tear size, and we did not determine which tendons were involved. Yamaguchi et al. [9] noted that RCT size appeared to be an important factor in symptom development. As mentioned previously, Kim et al. [1] reported that abduction strength significantly decreased in shoulders with a large to massive full-thickness RCT. Harryman et al. [27] also demonstrated that patients who had an infraspinatus as well as a supraspinatus tendon tear tended to have a significantly worsened ability to use the arm overhead compared with those who had only a supraspinatus tear. It is therefore possible that ADL restrictions may differ depending on the size and extent of the tear. Second, ADL evaluation was done only by SST in this study. Some other evaluation methods on ADL in cases of shoulder joint disorder have been reported. In this study, evaluation was done by the STT in view of the fact that it allows evaluation of ADL in a larger number of participants within limited time constraints. The third point concerns the diagnosis of partial-thickness RCTs using US, the diagnostic criteria for which remain controversial. Therefore, in this study, partial-thickness RCTs were considered to be nontears. Fourth, with regard to the selection criteria, we excluded any participants who had restrictions in both active and passive forward elevation so as to exclude patients with other potential causes of shoulder pain, such as osteoarthritis. However, no other type of diagnostic imaging was conducted other than US, and thus we could not exclude such patients completely. Fifth, this was a cross-sectional study, and a longitudinal examination was not conducted. Yamaguchi et al. reported that about 50% of asymptomatic shoulders with RCTs became symptomatic within an average of 2.8 years [8]. Mall et al. [2] also reported that larger tears are more likely to develop pain in the short term than are smaller tears, so it is possible that observations over time may reveal changes in the degree of ADL restriction.

Until now, the purpose of conservative treatment for RCTs was to maintain a painless condition even in the presence of a tear. However, results of this study demonstrate that RCTs cause restriction in ADL, even if the condition itself does not induce pain. In the case of RCTs without pain, the individual might not visit a medical institution, thinking that the restriction in ADL is merely the result of the normal aging process. We therefore consider that it is necessary to explain to such individuals the possibility that their RCTs, which cause no pain, may nevertheless eventually result in restriction in ADL. In addition, specialists who treat RCTs should be mindful of this phenomenon and try to provide optimal treatment to improve the quality of life for such patients.

In conclusion, we evaluated the effects on ADL caused by RCTs using the SST in a general population. Total SST score was significantly lower when participants had RCTs, which thus led to the onset of various types of dysfunctions: "sleep disturbances due to shoulder pain" and an "inability to lift 3.6 kg to shoulder level." Total SST score was also significantly lower in shoulders without pain when there was an RCT, thus leading to the occurrence of a dysfunction; namely, an "inability to lift 3.6 kg to shoulder level."

Conflict of interest The authors did not receive and will not receive any benefits or funding from any commercial party related directly or indirectly to the subject of this article.

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TECHNICAL NOTE

Comparison of ultrasound speed in articular cartilage measured by different time-of-flight methods

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Abstract The purpose of this study was to investigate whether different time-of-flight (TOF) methods including amplitude-related methods, which determine tissue borders from the reflected wave itself, and the cross-correlation method, which requires reference signals to determine borders, influence speed of sound (SOS) values for articular cartilage. Left femoral condyle samples from a 6-month-old pig and a 3-year-old pig were used. Radiofrequency signals from the cartilage surface and cartilage–bone interface were acquired using the ultrasound transducer for nine points in each sample. TOF was calculated by three amplitude-related methods (peak amplitude, peak envelope, signal phase) and a cross-correlation method. Cartilage thickness was measured microscopically, and SOS was calculated at each point. Mean (± standard deviation) SOSs in cartilage from the 9-point measurement by the four TOF methods were 1488 ± 51, 1488 ± 48, 1487 ± 54, and 1466 ± 51 m/s (for peak amplitude, peak envelope, signal phase, and cross-correlation methods, respectively) for the 6-month-old pig, and 1709 ± 107, 1717 ± 104, 1713 ± 105, and 1695 ± 138 m/s, respectively, for the 3-year-old pig. Paired *t* testing identified no significant differences between the amplitude-related methods and the cross-correlation method, although SOS values yielded by the amplitude-related methods tended to be higher than those from the cross-correlation method. These results suggest that amplitude-related methods of TOF measurement and the cross-correlation method are equivalently applicable to articular cartilage SOS measurement when a wave is clearly reflected from cartilage. TOF methods should thus be considered in studies on SOS measurement.

Keywords Articular cartilage · Ultrasound speed · Time-of-flight method · Cartilage thickness

Introduction

Articular cartilage maintains a function of load absorption through its composition and shape. In osteoarthritis of the knee, cartilage degenerates and becomes worn due to many factors, including aging and exposure to mechanical stress for long periods. In clinical practice, plain radiography is typically used to evaluate the condition of osteoarthritis. This does not show an actual image of the cartilage but evaluates the distance between femoral and tibial bone surfaces, as well as the presence of osteophytes and sclerosis of subchondral bone [1]. A key limitation of this evaluation is that cartilage thickness on the femur cannot be differentiated from that on the tibia, or from the meniscus located between the femur and tibia. Direct evaluation of cartilage has thus been studied using magnetic resonance imaging (MRI). MRI allows morphological evaluation of articular cartilage, such as determination of thickness and volume [2], and identification of cartilage degeneration [3].

Ultrasonography has also been investigated for applications allowing direct evaluation of articular cartilage. Degenerative changes in cartilage have been evaluated ultrasonographically [4, 5], along with cartilage surface roughness [4, 6]. In addition to these evaluations of changes in cartilage quality, ultrasonography has been used to

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visualize articular cartilage and evaluate cartilage thickness morphologically [7–11]. In those studies, the speed of sound (SOS) in cartilage has been regarded as the setup parameter for ultrasound devices in calculating cartilage thickness. Theoretically, however, for the calculation of cartilage thickness or volume using ultrasonography, the SOS in articular cartilage itself should be used, since SOS can differ among tissues and thus affect the calculations. Toyras et al. [12] performed simulation calculations for SOS, thickness, and error in dynamic modulus based on experimental results for bovine cartilage and the results from a previous study of human cartilage, suggesting that a constant SOS can be utilized to obtain a clinically acceptable accuracy for cartilage thickness and Young's modulus. Conversely, relatively variable mean values for SOS in human articular cartilage (1658 m/s [13], 1892 m/s [14], and ca. 1580 m/s [15]) have been reported. In fact, SOS in articular cartilage has been considered to be a candidate for detecting cartilage degeneration [13, 16] since this value is known to be influenced by cartilage degenerative changes, such as composition [12, 17], material properties [12, 18], and orientation of collagen fibrils [19]. However, such variability in SOS could originate from individual differences among samples, errors in measurement methods [20], or differences in measurement methods.

For the measurement of SOS in articular cartilage, in general, two measurement steps are necessary. One is measurement of articular cartilage thickness, and the other is time-of-flight (TOF) measurement, representing the time needed for ultrasound to travel between the cartilage surface and the cartilage–bone interface. For TOF measurement, a cross-correlation method [21], which detects the border on the basis of similarities between the standard wave and the reflected wave, has been used in past studies of SOS in articular cartilage [15, 22]. In this method, however, TOF values theoretically depend on selection of the standard wave. Wave selection can be subjective, but the criteria for selection have not been described. In addition, ultrasound reflection from articular cartilage has been reported to change with degeneration [16], and the ideal standard wave can thus differ according to the condition of the articular cartilage. On the other hand, a relatively simple and unambiguous method of detecting the signal peak of the reflected radiofrequency wave as the border [10, 23] has also been used. With these methods, the border of the tissues is determined from the reflected wave itself and requires no reference signal. Even though these methods define TOF in different ways, no studies have yet clarified whether these different methods yield divergent results. We performed SOS measurements for articular cartilage using ultrasound amplitude-related methods for TOF measurement as well as the cross-correlation method, and then compared the results in order to investigate the influence of the different TOF methods on SOS values and the feasibility of amplitude-related methods.

Materials and methods

Cartilage sample preparation

The animal care and use committee at our university approved all procedures used in this investigation. Knee joints of a 6-month-old pig and a 3-year-old pig were obtained from a slaughterhouse (Tokyo Shibaura Zouki, Tokyo, Japan), as we assumed that cartilage SOS might differ between pigs at different ages and could affect the differences in SOS among TOF methods. Porcine femoral condyle articular cartilage was used in this study since the cartilage size and shape are relatively similar to those of human cartilage. After slaughter, the whole bodies of the pigs were kept at 3°C in a refrigerated room. On the third day, the hind limbs were detached and sent to our facility at the same temperature. In our facility, limbs with intact knee joints were packed in plastic bags, degassed, sealed hermetically, and stored at –20°C. On the day of the experiment, soft tissues including the joint capsules and ligaments were removed after the limbs were thawed in normal saline solution (Otsuka Pharmaceutical, Tokyo, Japan) at room temperature. Osteochondral blocks from the left medial femoral condyles were acquired by cutting the bone with a band saw (SWD-250; Fujiwara Sangyo, Miki, Japan) and then fixing on a custom-made acrylic sample holder (50 × 50 × 13 mm; Murai & Co., Tokyo, Japan) with resin (GC-Ostron; GC, Tokyo, Japan). During preparation, samples were continuously cooled and moistened using normal saline solution. The osteochondral block was then trimmed using a diamond saw (Minitom; Struers, Westlake, OH, USA) to achieve a sample cartilage surface size of 10 mm × 10 mm. The position of trimming was adjusted so that the cartilage surface and sample holder were concentric, and so that the edges and sides of the cartilage surface were parallel to the side surfaces of the sample holder.

Acoustic measurements

Acoustic measurements were performed using a custom-made apparatus (Fig. 1). The sample holder with the porcine osteochondral block affixed was positioned in 20°C water in a water tank with the cartilage surface facing upward. A stage underneath with three micrometers (accuracy, 10 μm) allowed horizontal movement of the sample. Two micrometers were perpendicular to each other in the horizontal plane for position adjustment by parallel

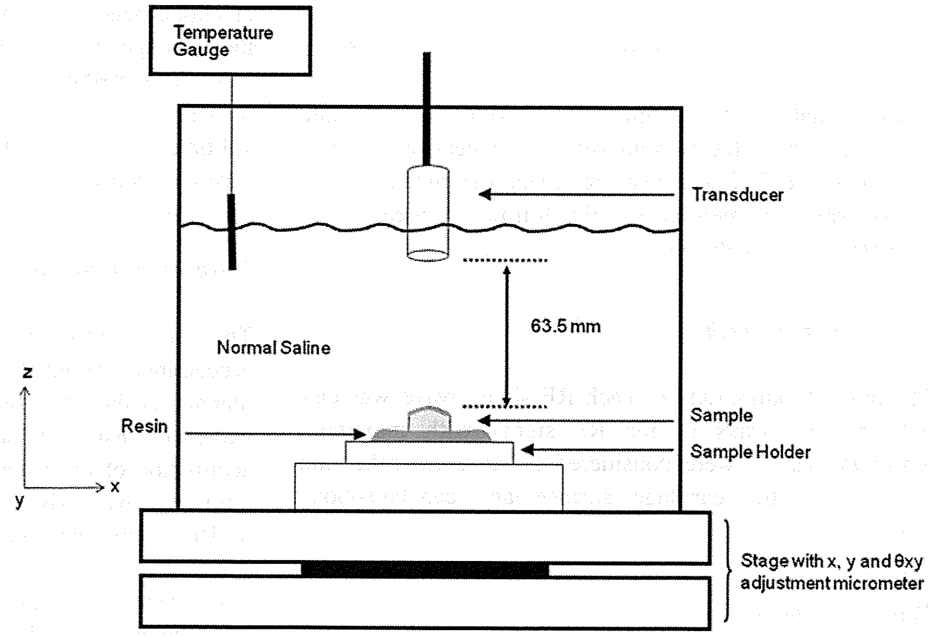

Fig. 1 Schematic showing the custom-made apparatus for acoustic measurement. The trimmed cartilage sample on the sample holder is positioned in a water tank, and a stage underneath uses micrometers to allow sample movement and rotation in the horizontal plane. The transducer is adjusted to be fixed at the focal distance (63.5 mm)

movement (*x* and *y* axes). The third micrometer enabled circular movement (θxy) in the horizontal plane. An ultrasound transducer was also placed over the sample independently from the sample in the water tank, and the holder of the transducer had a *z*-adjustment device so that the distance between the cartilage surface and the transducer surface could be kept at the transducer focus distance (63.5 mm).

Ultrasound measurements were performed using the A-mode pulse-echo method and a focused non-contact ultrasound transducer (V311-SU; Olympus NDT, Waltham, MA, USA) (center frequency = 7.3 MHz, 3.4–11.2 MHz, −3 dB; transducer tip diameter = 16 mm; element diameter = 13 mm; radius of curvature = 63.5 mm). Acoustic pulses were excited electrically using a pulser/receiver board (NDT-5800; Olympus NDT). Echoes of the transmitted pulse were recorded with the transducer and pulser/receiver board. A bandpass filter (1.0–20.0 MHz) was used to enhance the ultrasound signal-to-noise ratio. The signal was digitized at a 1000-MHz sampling frequency using an oscilloscope (DPO4034; Tektronix Japan, Tokyo, Japan).

For acoustic measurement, edges of the 10 mm × 10 mm cartilage surface and the center point of the surface were first identified by moving the water tank stage horizontally under the fixed ultrasound beam. The cartilage surface was then scanned with the ultrasound transducer by moving the stage to identify the top cartilage surface point (point C) (Fig. 2a). The ultrasound beam was, theoretically, the most closely perpendicular to the cartilage surface at this point, as the cartilage of the femoral condyle has a convex surface. After identification of the coordinates for this point as (A, B), eight additional points 1 mm apart from each other around this point were identified and set as radiofrequency (RF) signal acquisition points, along with point C (Fig. 2b). The *x*–*y* coordinates of the eight points for the top surface point were thus (A + 1, B + 1),

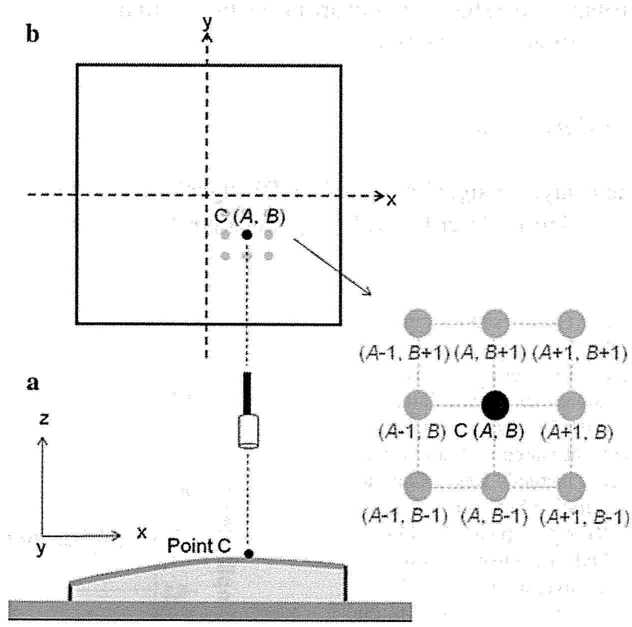

Fig. 2 Schematic showing radiofrequency signal acquisition points. **a** Top point of the cartilage surface (point C). **b** With point C as the center point, radiofrequency signals were acquired at nine points, each 1 mm apart