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Original Article

Analysis of the mechanical properties of food bolus masticated by denture wearers

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Masticatory performance of denture wearers was compared with that of the normal subjects by analyzing the behavior of the mechanical properties of the bolus. The index of the ability to comminute bolus was described as the total number of masticatory strokes until swallowing and therefore this was chosen as the first index. Principal Component Analysis (PCA) on the data of six parameters; 80% energy, elasticity, viscosity, hardness, adhesiveness, and cohesiveness, indicated that the cohesiveness was independent of the other parameters and should be evaluated as the second index of the ability to dilute bolus with saliva. Two factor scores of the other parameters were calculated using the standardized scoring coefficient obtained from PCA and factor analysis on the data of the normal subjects, which realized to compare two groups on the same plane of factor scores. The movement of factor scores on the factor plane would indicate the total behavior of mechanical properties of bolus and was chosen as the third index of the ability to knead bolus. Triangle Diagram (TD) was completed by using these three indices. On the TD, all the subjects were lower level at least in one index than the normal subjects in all the foods.

Key words: the denture wearers, food bolus, factor scores, mechanical properties

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Introduction

Removable prostheses are necessary to restore masticatory functions for patients who have lost their natural teeth. However, there are considerable differences of masticatory ability between denture wearers and normal subjects[1]. Various methods of evaluation for masticatory ability have been reported; the sieving methods[2-5], the evaluation with the color and the shape of chewing gum[6-9], the number of masticatory cycles[8,10,11,12], and the electromyographic activities of elevator muscles of the mandible[11,13,14]. Though the evaluations based on the tests with single food or with single method are easy to apply, they can not represent the whole masticatory performance[15]. It is inferred that investigating the mechanical properties of food bolus is appropriate for the direct observation of the masticatory efficiency. Nagatomi et al. have investigated the mechanical properties of boluses using three foods in the normal subjects[16]. Shiozawa et al. have investigated the relationship between the food texture and jaw muscle or tongue activity[17,18]. However, few researches have compared the mechanical properties of food bolus of denture wearers with those of the normal subjects. In this study, the change of the mechanical properties of bolus masticated by denture wearers was examined and the masticatory ability of denture wearers was evaluated in comparison with that of the normal subjects. As a result, three elements for evaluation were detected with comprehensive observation of the mechanical properties of boluses.

Materials and Methods

The experimental methods were according to the report of Nagatomi et al.[16] about masticatory behavior of the normal subjects.

1. Subjects

Eight denture wearers (four males and four females; aged from 58.8 to 67.5) were examined in this study. None exhibited any occlusal contacts with natural teeth in the bilateral molar areas; they corresponded to group B4 or C of Eichner's index[19]. The patterns of the remaining natural occlusal supports were shown in Table 1. The subjects provided their informed consent regarding their participation in this study and were explained the aim of the study. We received the approval for this study from the ethical review board of Tokyo Medical and Dental University (the approval number: 222. 2006.8.1).

2. Test food samples

Three types of foods with different textures were selected (Fig. 1): three pieces of rice crackers (Bourbon Petit Usu-Yaki, 2.4g, 30mm × 1mm, Bourbon Co., Japan), a piece of cheese (Candy type Cheese, 5.9g, 20mm × 10mm, Rokko Butter Co., Japan), and three pieces of peanuts (Ajitsuke rakkasei, 3.0g, 20mm × 10mm, Irita Shokai Co., Japan). As the research of Nagatomi et al.[16], these food samples were selected according to the criteria of Yanagisawa et al.[20]. They had stable textures and boluses of them were suitable for measurement.

Table. 1 Eichner's index of the patterns of remaining natural occlusal supports of each denture wearer subject
None exhibited any occlusal contacts with natural teeth in the bilateral molar areas.

Subject	Group
Sub.1	B4
Sub.2	C1
Sub.3	C1
Sub.4	C2
Sub.5	C2
Sub.6	B4
Sub.7	C2
Sub.8	C2

3. Experimental procedure

The RHEOMETER II (RE3305; YAMADEN Co., JAPAN) (Fig. 2 (a)) was used to measure the mechanical properties of food bolus. The data was analyzed using the software developed for this analysis (YAMADEN Co., JAPAN). Three analyses were performed on the bolus with this measuring device. Data of the six parameters; 80% energy, elasticity, viscosity, hardness, adhesiveness, and cohesiveness, which were commonly used for analyses of food texture[21], were obtained by these analyses.

1) Three analyses on the bolus

a) The axial compression test

The energy required to compress the bolus to 20% to the original height in the container by the plunger at a constant speed of 1mm/sec was measured by this test. This was termed 80% energy.

b) Creep test

The measurements were carried out under uniaxial compression at a constant speed of 10mm/sec. Each test food sample was allowed to creep under a constant load for 60 seconds. The data of elasticity and viscosity were obtained by the test.

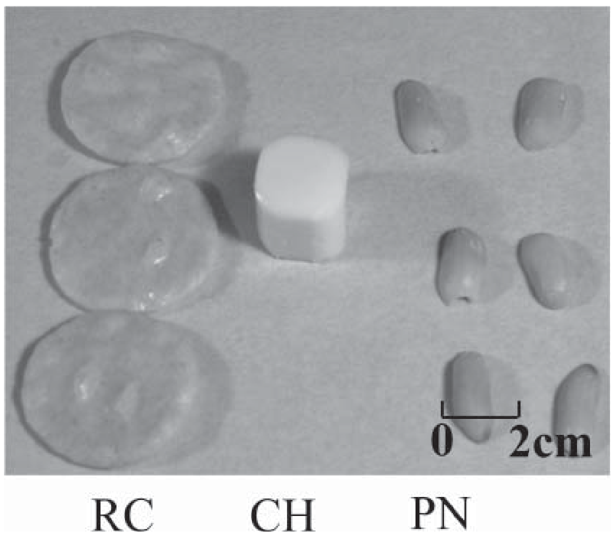


Fig. 1 Test food samples
Three types of food with different texture were selected. They were the same test foods used in the research of the normal subjects.

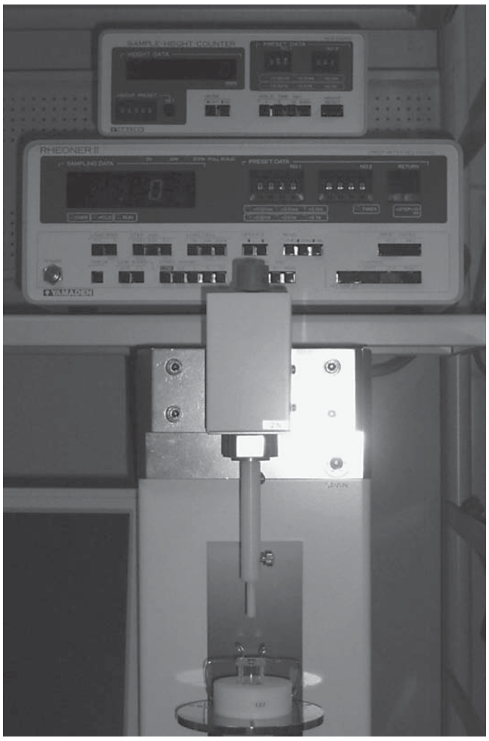


Fig. 2 (a) RHEOMETER II（YAMADEN, Japan）

c) Texture profile analysis

Each food bolus was compressed with the plunger to 33% to the original height of the container twice at a constant speed of 1mm/sec. Three parameters; hardness, adhesiveness, and cohesiveness, were obtained from this analysis.

2) Determination of the three points for measurement and the number of masticatory strokes at each point

The subjects were instructed to chew the test food sample naturally in order to determine the number of chewing strokes needed for swallowing. Swallowing during mastication was prohibited. The point of mastication just before swallowing was termed the last point (L point). The point when the bolus became measurable for the first time was termed the first point (F point). The middle point between the F point and the L point was termed the middle point (M point).

After determination of the three points, the subjects were instructed to chew the test food for the number of masticatory strokes determined for each point and to spit out the bolus from their oral cavities by the subjects own. Then the measurement was performed using the bolus spitted out. This trial was successively repeated three times at each point.

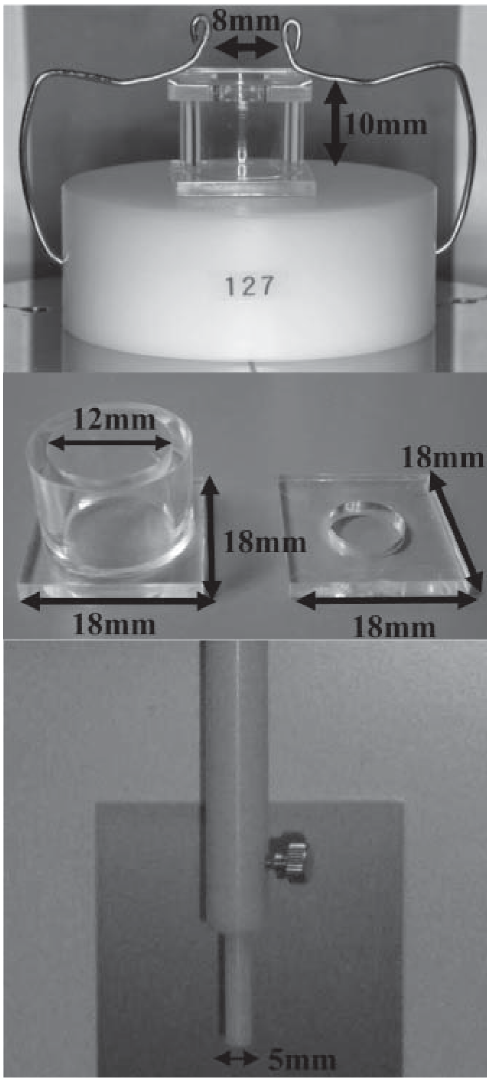


Fig. 2 (b) The measuring container and the cylindrical plunger

2) The container and the plunger

The food bolus spitted out by the subject was divided into two parts and they were approximately even amount. One was used for the axial compression test and the other was used for the creep test and the texture profile analysis. It was necessary to use the same bolus specimen to make the three analyses for the multivariable analysis on the six parameters. Each bolus was placed in the acrylic container. The container comprised three components: the acrylic bottom plate (18 mm × 18 mm), the ring (inner diameter, 12 mm; height, 10 mm), and the acrylic plate with the hole (diameter, 8 mm), which was the path for the acrylic plunger (diameter, 5 mm) for the measurement in the center of the plate (Fig. 2 (b)). They were placed in the thermostat bath (37°C) just before measurement. The container filled with bolus was fixed to the acrylic base with a wire to avoid movement during the measurement. Nagatomi et al. had investigated the mechanical properties of bolus with 12 normal subjects in the same way[16].

4. Statistical analysis

All the data of the normal subjects in the report of Nagatomi et al. had been quoted in this research[16]. The mean, standard deviation (SD), and coefficient of variation (CV) of six parameters were calculated. Statistical analysis was carried out by a one-way analysis of variance (ANOVA) followed by a Tukey multiple range test at a 5% level of significance to compare the mean data of six parameters at the F point with that at the M point, and that at the M point with that at the L point (SPSS 12.0J, SPSS Japan Inc.). The mean data of six parameters of denture wearers was compared with that of the normal subjects at each stage by the Welch's t-test ($p<0.05$). The mean of the masticatory strokes at each point of denture wearers and that of the normal subjects was also compared by the Welch's t-test ($p<0.05$).

As the preliminary analysis, Principal Component Analysis (PCA) (STATISTICA, StatSoft, JAPAN) was performed for the correlation matrix of six parameters. PCA was used for effective analysis on the texture of foods in other reports[22,23]. Two factor scores of each subject were calculated with the standardized scoring coefficients extracted by the factor analysis on five parameters in the normal subjects. The factor scores were calculated using the mathematical formulae given below.

X; Corrected data = (the data of the subject — the mean data of the normal subjects)/SD of the normal subjects

The score of factor 1 of the subject:

$$\sum_{i=1}^{5} X_i \cdot F1_i$$

Where, $F1_i$: the standardized scoring coefficient of factor 1 of parameter *i*.

The score of factor 2 of the subject:

$$\sum_{i=1}^{5} X_i \cdot F2_i$$

Where, $F2_i$: the standardized scoring coefficient of factor 2 of parameter *i*.

Triangle Diagram (TD)

Triangle Diagram (TD) was contrived for indicating the difference of masticatory performance between the denture wearers and the normal subjects with three indices (A, B, and C).

A represented the total number of masticatory strokes required for swallowing foods. B represented the cohesiveness at the L point. C represented the change of factor scores on the factor plane and was calculated as follows;

C = Number of masticatory strokes required from the F point to the L point/ (distance between the plot of the F point and of the M point + distance between the plot of the M point and of the L point)

All the values of A, B, and C of each denture wearer were normalized by the mean value of all the normal subjects respectively and were indicated as A', B', and C' on the TD.

Results

1. Total number of masticatory strokes

The mean number of masticatory strokes of all the denture wearers was significantly higher than that of the normal subjects at all the points in RC and in PN, and at the L point in CH ($p<0.05$) (Table 2(a)). All the subjects, except for Sub. 2 and Sub. 5, required the higher number of masticatory strokes than the normal subjects for chewing all the food samples. However, Sub. 2 required lower number of masticatory strokes than the normal subjects in the case of CH. Sub. 5 required the lower number of masticatory strokes than the normal subjects in the case of RC and CH. In the case of PN, all the subjects required the higher number of masticatory strokes at the F point than that of the normal subjects at the L point.

2. Preliminary analysis on six parameters

In the preliminary analysis, two factors were extracted from the PCA performed using the correlation matrix of the data. The parameters except for cohesiveness positively correlated with factor 1. On the other hand, only cohesiveness was correlated with factor 2. Therefore the data of cohesiveness and that of the other five parameters were analyzed separately.

3. Mechanical properties of food bolus

The data of the five parameters except for cohesiveness decreased as the normal subjects (Table 2(b) 1-3), but a delay in the progress of mastication was observed. The data of Sub. 4 and Sub. 6 revealed a notable delay in the progress of mastication in PN. The plots of the data of 80% energy were put up on behalf of five parameters in Fig. 3.

Table 2 (a) The number of masticatory strokes of each denture wearer at each point and the mean masticatory strokes of the denture wearers and the normal subjects
*: significantly higher than the mean masticatory strokes of the normal subjects by the Welch's t-test ($p<0.05$)

RC	F	M	L
Sub.1	38	57	76
Sub.2	40	48	56
Sub.3	27	42	57
Sub.4	42	54	108
Sub.5	20	25	30
Sub.6	46	68	90
Sub.7	26	38	50
Sub.8	28	42	56
DW (MEAN)	**33***	**47***	**65***
NS (MEAN)	**19**	**25**	**31**

CH	F	M	L
Sub.1	20	35	50
Sub.2	11	18	25
Sub.3	18	30	42
Sub.4	41	62	83
Sub.5	14	18	22
Sub.6	26	38	50
Sub.7	15	25	35
Sub.8	18	26	34
DW (MEAN)	**20**	**32**	**43***
NS (MEAN)	**13**	**21**	**28**

PN	F	M	L
Sub.1	32	46	60
Sub.2	40	48	55
Sub.3	32	39	46
Sub.4	100	121	142
Sub.5	35	39	43
Sub.6	66	99	132
Sub.7	35	44	53
Sub.8	30	35	40
DW (MEAN)	**46***	**59***	**71***
NS (MEAN)	**17**	**22**	**26**

Table 2 (b)-1 The mean of the data of six parameters, the standard deviation, and coefficient of variation at three points in RC
*: significantly different from the M point by Tukey HSD (p<0.05)
†: significantly different from the mean data of the normal subjects at the same point by Tukey HSD (p<0.05)

RC

		DW			NS		
		MEAN	SD	CV	MEAN	SD	CV
80%E (J/M^3)	F point	1.7E+04*	8.2E+03	0.47	1.6E+04*	1.1E+04	0.69
	M point	8.0E+03	3.8E+03	0.48	9.6E+03	7.0E+03	0.73
	L point	3.7E+03*†	3.4E+03	0.92	7.0E+03	6.1E+03	0.86
Elasticity (Pa)	F point	5.2E+04*	3.5E+04	0.68	5.7E+04*	4.3E+04	0.77
	M point	2.8E+04	2.2E+04	0.79	2.9E+04	2.1E+04	0.71
	L point	6.8E+03*†	7.2E+03	1.06	1.4E+04	6.6E+03	0.48
Viscosity (Pa・s)	F point	5.0E+06*†	1.8E+06	0.35	3.9E+05*	2.6E+06	0.72
	M point	2.1E+06	1.3E+06	0.62	2.3E+06	1.6E+06	0.68
	L point	9.2E+05*	7.8E+05	0.85	1.0E+06*	5.7E+05	0.56
Hardness (N)	F point	5.7E-01*	2.5E-01	0.44	6.7E-01*	4.6E-01	0.69
	M point	2.3E-01†	1.2E-01	0.50	4.0E-01	3.4E-01	0.85
	L point	1.3E-01	1.2E-01	0.91	1.9E-01*	1.2E-01	0.63
Adhesiveness (J/M^3)	F point	2.7E+03*	1.4E+03	0.52	2.6E+03*	1.5E+03	0.57
	M point	1.6E+03†	6.4E+02	0.39	2.5E+03	1.7E+03	0.65
	L point	1.1E+03	1.1E+03	0.92	1.6E+03*	1.2E+03	0.74
Cohesiveness	F point	4.4E-01*	6.4E-02	0.14	4.5E-01*	7.0E-02	0.16
	M point	5.2E-01	1.2E-01	0.23	5.4E-01	7.0E-02	0.13
	L point	5.7E-01	7.9E-02	0.14	5.9E-01*	6.0E-02	0.10

The data of cohesiveness increased as mastication progressed in RC and PN, and it was almost constant in CH (Table 2(b) 1-3 and Fig. 4). Based on the Welch's t-test on the data for cohesiveness at the L point, there was no significant difference between the mean of cohesiveness of all the normal subjects and that of all the denture wearers in RC and CH, although a significant difference was observed in PN ($p<0.05$) (Fig. 5).

4. Factor score

The factor scores of each denture wearer were plotted on the factor plane obtained from the factor analy-

Table 2 (b)-2 The mean of the data of six parameters, the standard deviation, and coefficient of variation at three points in CH
*: significantly different from the M point by Tukey HSD ($p<0.05$)
†: significantly different from the mean data of the normal subjects at the same point by Tukey HSD ($p<0.05$)

CH

		DW			NS		
		MEAN	SD	CV	MEAN	SD	CV
80%E(N/M^3)	F point	4.6E+04*	1.9E+04	0.42	4.3E+04*	1.0E+04	0.24
	M point	2.7E+04	1.3E+04	0.46	2.4E+04	1.1E+04	0.44
	L point	1.2E+04*	9.5E+03	0.81	9.4E+03*	6.6E+03	0.71
Elasticity (Pa)	F point	1.6E+05*	7.8E+04	0.49	1.7E+05*	5.0E+04	0.29
	M point	9.2E+04	5.4E+04	0.59	1.1E+05	6.2E+04	0.56
	L point	2.0E+04*	4.0E+04	1.97	3.4E+04*	3.7E+04	1.10
Viscosity (Pa・s)	F point	2.4E+07*	1.1E+07	0.46	2.3E+07*	1.5E+07	0.64
	M point	1.5E+07	7.5E+06	0.49	1.2E+07	8.5E+06	0.74
	L point	7.6E+06*	1.0E+07	1.38	3.4E+06*	3.7E+06	1.10
Hardness (N)	F point	1.4E+00*	4.2E-01	0.30	1.4E+00*	3.1E-01	0.22
	M point	1.0E+00	4.9E-01	0.48	8.6E-01	3.8E-01	0.44
	L point	5.4E-01*	4.8E-01	0.89	3.4E-01*	1.9E-01	0.56
Adhesiveness (J/M^3)	F point	9.1E+03*†	3.8E+03	0.42	7.2E+03*	3.1E+03	0.43
	M point	6.2E+03	3.2E+03	0.51	5.1E+03	2.3E+03	0.45
	L point	2.7E+03*	2.0E+03	0.72	2.5E+03*	1.4E+03	0.56
Cohesiveness	F point	5.0E-01	6.4E-02	0.13	4.9E-01	7.0E-02	0.14
	M point	5.0E-01	5.0E-02	0.10	5.2E-01	7.0E-02	0.13
	L point	5.2E-01	7.3E-02	0.14	5.4E-01	7.0E-02	0.13

sis on five parameters except for cohesiveness with the normal subjects. Two factor loadings, which described the correlation between each parameter and two factors, were shown in each figure.

RC

At the L point, factor 1 of all the subjects was lower than that of the normal subjects. Moreover, except for Sub. 2 and Sub. 5, the plots at the L point of all the subjects converged in the area where the two factor scores were lower than those of the normal subjects (Fig. 6 (a)).

CH

Except for Sub. 2 and Sub. 5, factor 1 of all the subjects was lower than that of the normal subjects. The

Table 2 (b)-3 The mean of the data of six parameters, the standard deviation, and the coefficient of variation at three points in PN
*: significantly different from the M point by Tukey HSD ($p<0.05$)
†: significantly different from the mean data of the normal subjects at the same point by Tukey HSD ($p<0.05$)

PN

		DW			NS		
		MEAN	SD	CV	MEAN	SD	CV
80%E(J/M³)	F point	1.8E+04*	7.9E+03	0.45	1.5E+04*	7.4E+03	0.49
	M point	1.2E+04	7.0E+03	0.56	9.8E+03	6.5E+03	0.67
	L point	9.2E+03	6.3E+03	0.69	7.1E+03	5.0E+03	0.71
Elasticity (Pa)	F point	5.3E+04*	4.0E+04	0.75	6.2E+04	6.1E+04	0.99
	M point	3.1E+04	2.7E+04	0.86	3.7E+04	4.6E+04	1.23
	L point	7.7E+03*	6.8E+03	0.88	1.1E+04*	1.1E+04	0.99
Viscosity (Pa・s)	F point	2.9E+07*†	2.2E+07	0.77	1.6E+07*	1.4E+07	0.87
	M point	1.2E+07	7.7E+06	0.66	9.3E+06	8.3E+06	0.89
	L point	6.9E+06†	7.4E+06	1.08	3.3E+06*	2.4E+06	0.73
Hardness (N)	F point	9.3E-01*	4.5E-01	0.49	8.5E-01*	4.8E-01	0.56
	M point	6.1E-01	3.7E-01	0.61	6.1E-01	4.0E-01	0.66
	L point	3.8E-01	2.8E-01	0.74	3.9E-01*	2.4E-01	0.62
Adhesiveness (J/M³)	F point	2.1E+03	1.2E+03	0.57	2.9E+03	1.7E+03	0.58
	M point	1.8E+03	1.4E+03	0.79	2.2E+03	1.4E+03	0.62
	L point	1.1E+03†	9.4E+02	0.82	2.0E+03	1.5E+03	0.77
Cohesiveness	F point	3.8E-01†	5.6E-02	0.14	4.4E-01	8.0E-02	0.18
	M point	3.8E-01†	9.6E-02	0.25	4.5E-01	1.0E-01	0.22
	L point	4.7E-01*†	5.5E-02	0.12	5.3E-01*	8.0E-02	0.15

plots of Sub. 2 and Sub. 5 remained in the first quadrant on the plane in all the stages (Fig. 6 (b)).

PN

The scores of factor 1 for all the subjects were dispersed as compared with the scores obtained from the other food samples even at the L point. The scores of factor 2 of the subjects were almost same as those of the normal subjects. The plots of all the subjects surrounded the elliptical area of the factor scores of the normal subjects (Fig. 6 (c)).

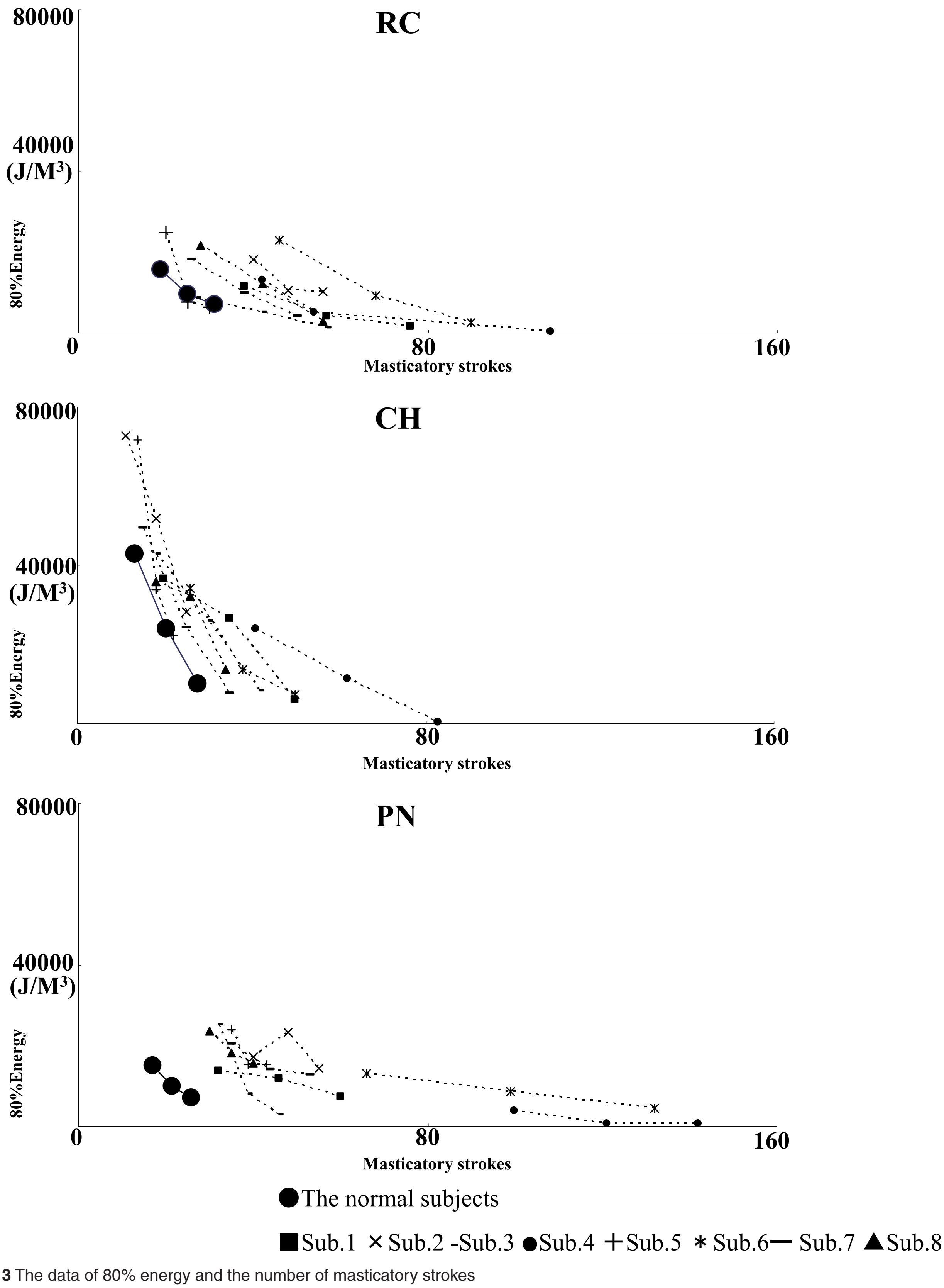


Fig. 3 The data of 80% energy and the number of masticatory strokes
The mean of the data of all the normal subjects at each stage was plotted and the plots of eight denture wearers at the three points were the mean of the result of three trials.

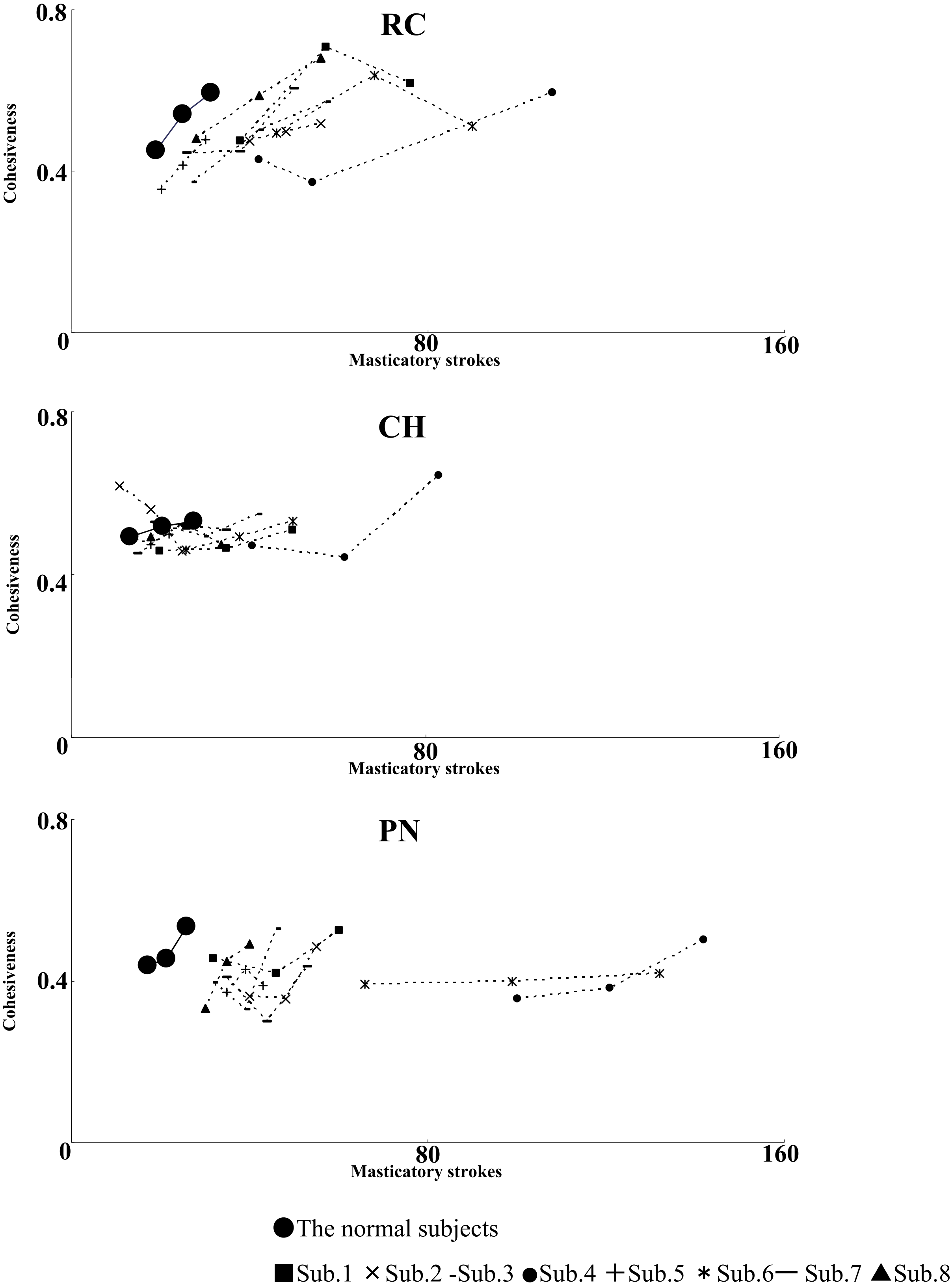


Fig. 4 The data of cohesiveness

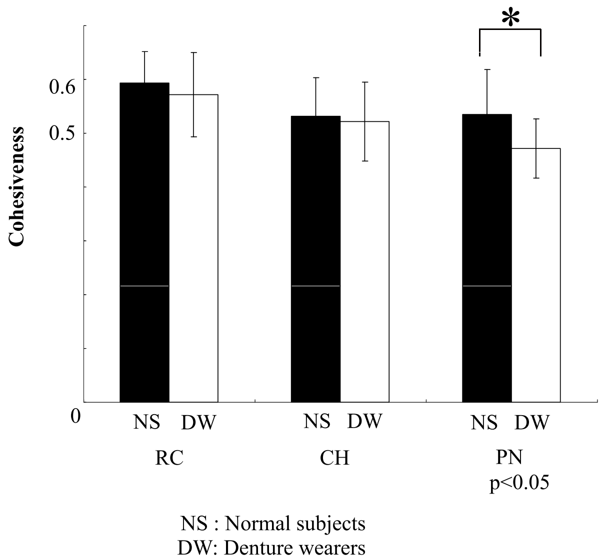


Fig. 5 Comparison of the data of cohesiveness at the L point between the denture wearers and the normal subjects by the Welch's t-test ($p<0.05$)

Discussion

1. Determination of the subjects and the test foods

The subjects corresponded to group B4 or C of Eichner's index. It was thought that the subjects who had no occlusal contacts in the molar area were ideal for this research. If they possessed the molar occlusal contact of tooth to tooth and could masticate there, the significant comparison with the normal subjects was thought to be difficult. Furthermore, it was reported that reduction of masticatory ability in denture wearers had been strongly related with the occlusal support in the molar area[24].

Yanagisawa et al. had developed the toughness index and classified foods into six types[20,25]. Nakagawa et al. had examined the validity of this index by investigating the activity mass of the masticatory muscles[13,14]. Three foods with stable textures were selected from the three types among the six types based on their reports. Boluses of these foods were thought to be suitable for measurement additionally. The foods belonged to the other three types were such as takuan (pickled Japanese radish), kamaboko (fish sausage), gumi jerry, gum, and meat. The mechanical properties of bolus of all these foods were thought to be difficult to measure. RC[12,26] and PN[11,24,27,28] were selected as the brittle food, and CH was selected as the adherent food[13,14,20,25,27,28] in this research. Though rice cake was reported as the adherent test food[17,18], the measurement of rice cake bolus was thought to be difficult. Moreover, RC, PN, and CH were often used in the previous researches. Then using these three foods had the advantage in comparison between the data of this research and that of the previous reports.

2. Mechanical properties of the food bolus at the L point

It was reported that the number of masticatory strokes until swallowing reflected the masticatory ability[12]. The number of masticatory strokes alone could be used as the index for evaluating masticatory performance if the deviation of mechanical properties of food boluses at the L point was small. However, CVs of the mechanical properties of five parameters except for cohesiveness of every subject at the L point (Table 2(b) 1-3) were considerably large, and therefore not only the number of masticatory strokes but also the mechanical properties of the bolus at the L point should be evaluated.

The result of the PCA performed on six parameters as the preliminary analysis showed that cohesiveness was independent of the other five parameters as in the case of the normal subjects[16] and it should be considered separately. The significant difference by the Welch's t-test in cohesiveness at the L point suggested that the ability to dilute the bolus with saliva of the denture wearers was inferior to that of the normal subjects in the case of PN. The ability to dilute bolus was discussed later. Comminuted chips containing oil droplet could not be mixed with saliva in PN though the other foods were thought to be easier to be diluted with saliva[12,29] than PN. For example, RC which is the same brittle food as PN, absorbed saliva in the oral cavity during mastication and was easy to be diluted with saliva.

3. Factor scores

The behavior of the two factor scores could be observed by plotting them in the factor plane. The tables of the factor loadings were shown in Fig. 6 (a), (b), and (c), for the axes of the factor plane consisted of the factor loadings which expressed the correlation between each factor and five parameters except for cohesiveness.

In RC, 80% energy, elasticity, and viscosity were highly correlated with factor 1 of RC according to the factor loadings. Adhesiveness and hardness were highly correlated with factor 2 (Fig. 6 (a)). There were three types of subjects in the change of the factor scores in

Factor loading

	Factor1	Factor2
80%Energy	0.79	0.38
Elasticity	0.9	0.29
Viscosity	0.76	0.52
Hardness	0.47	0.77
Adhesiveness	0.29	0.9

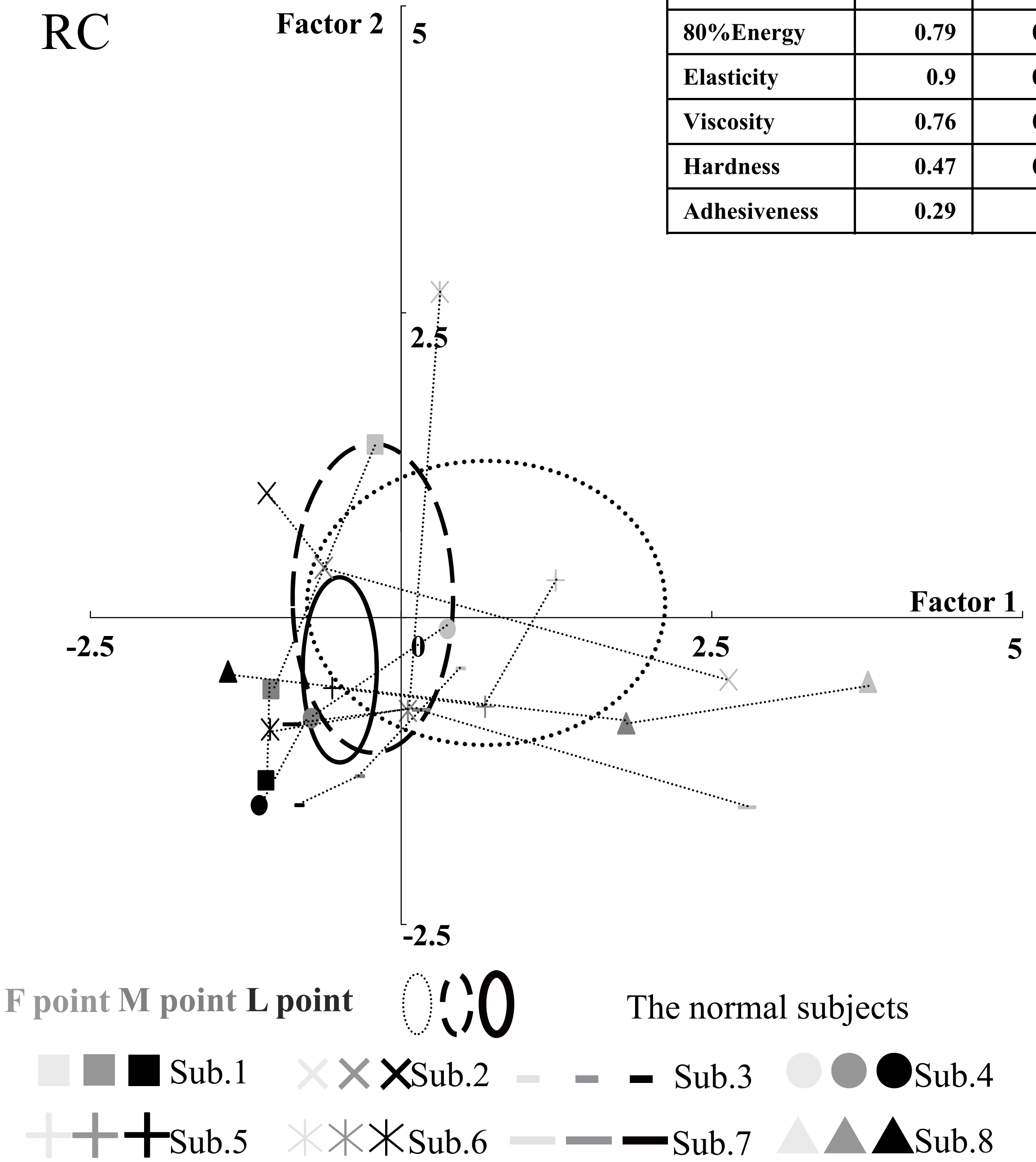
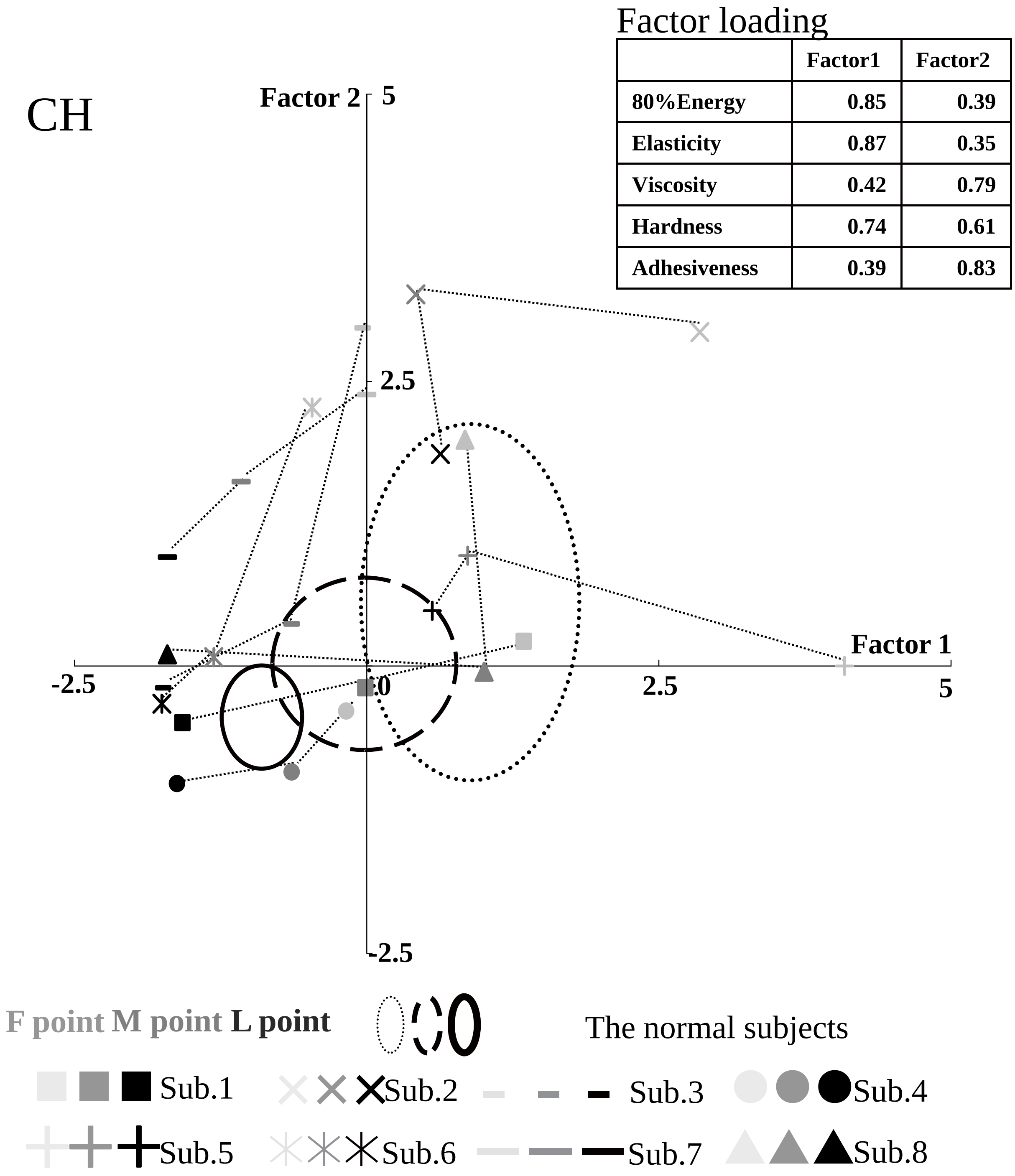


Fig. 6 (a) The factor scores on the factor plane of RC
The plane was with factor 2 on the Y-axis and factor 1 on the X. The factor loadings of factor 1 and factor 2 by the factor analysis on the boluses of the normal subjects were shown next to the plane. The 1SD distribution of factor scores of the normal subjects was indicated by the ellipse area. The plot of the subject was the mean of factor scores form three trials.

RC. The first type of subjects would make unhomogeneous bolus containing various size particles, then only factor 1 of them decreased. The second type of subjects had already made homogeneous bolus at the F point and only adhesiveness decreased until the L point. The last type of subjects decreased two factors simultaneously as the normal subjects[16]. Unlike these seven subjects, the score of the factor 2 increased as



	Factor1	Factor2
80%Energy	0.85	0.39
Elasticity	0.87	0.35
Viscosity	0.42	0.79
Hardness	0.74	0.61
Adhesiveness	0.39	0.83

Fig. 6 (b) The factor scores on the plane of CH

mastication progressed only in Sub. 2. Homogeneous bolus could not be formed and particles of RC still remained in the bolus even at the L point.

In CH, elasticity, 80% energy, and hardness were highly correlated with factor 1, and adhesiveness and viscosity were highly correlated with factor 2. CH was softened by the temperature of the oral cavity. Therefore the bolus of the subjects, such as Sub. 4 and Sub. 6 who had required the large number of masticatory strokes until the L point, was softened and factor 1

Factor loading

	Factor1	Factor2
80%Energy	0.81	0.35
Elasticity	0.18	0.95
Viscosity	0.62	0.68
Hardness	0.78	0.43
Adhesiveness	0.88	0.15

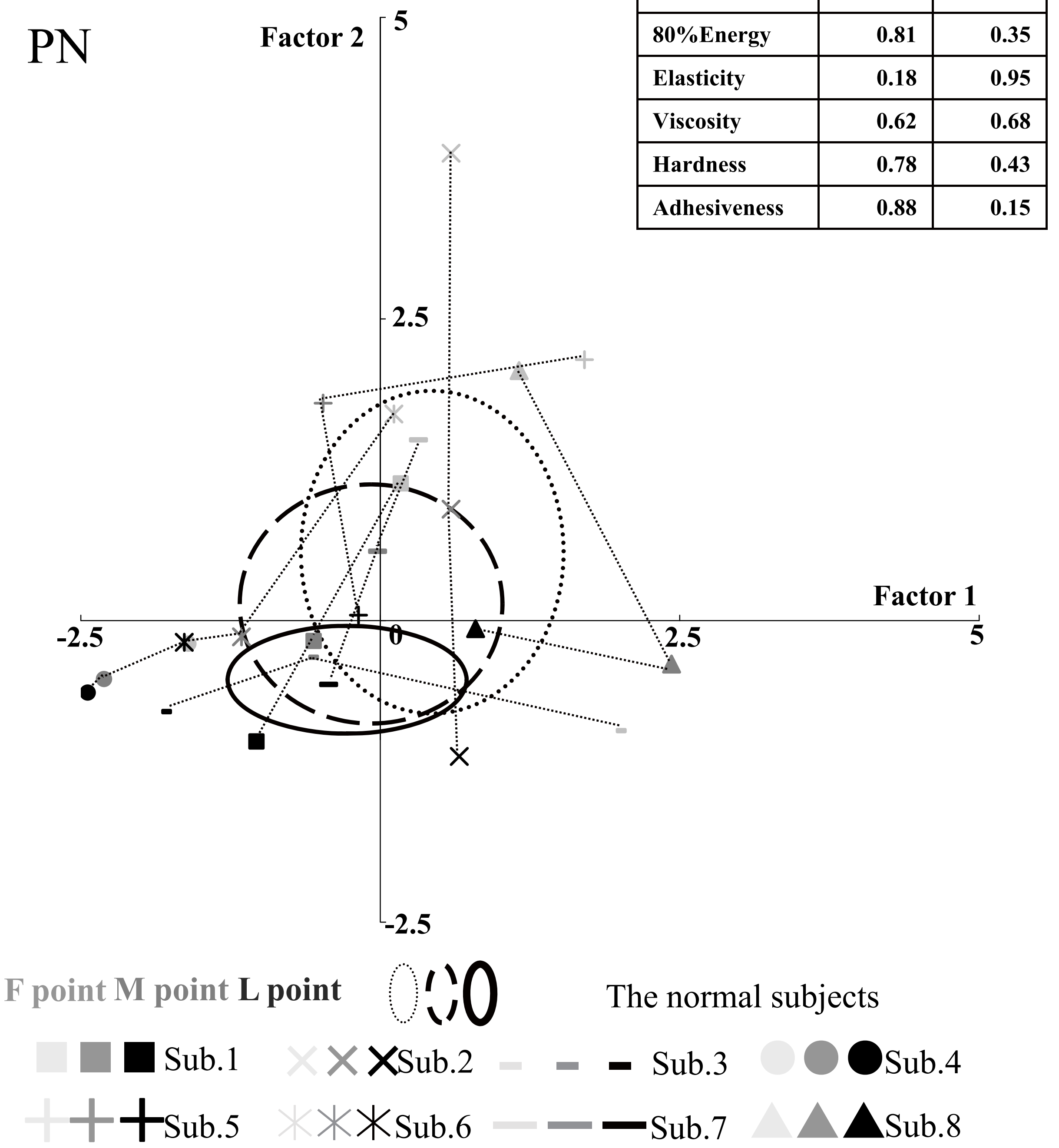


Fig. 6 (c) The factor scores on the plane of PN

of them resulted in the low scores. On the other hand, the scores at the L point of Sub. 2 and Sub. 5 remained high. The small number of masticatory strokes of these two subjects resulted in the decrease of the effect of the temperature in the oral cavity. At the L point in the other subjects, the scores of factor 1 were lower than the normal subjects. On the other hand, the scores of factor 2 were dispersed at the L point. For adhesiveness was highly correlated with factor 2, this result indicated that the bolus formation of CH might be difficult for denture wearers because of its adhesiveness (Fig. 6 (b)).

In PN, adhesiveness, 80% energy, and hardness were highly correlated with factor 1 and elasticity was highly correlated with factor 2. Three subjects (Sub. 1, Sub. 3, and Sub. 4) decreased the scores of both factor 1 and factor 2 lower than the mean score of the normal subjects. In the other subjects, the score of either factor 1 or 2 was larger than the mean score of the normal subjects. The bolus of PN did not absorb saliva unlike RC. Moreover, it was not influenced by the temperature in the oral cavity unlike CH. The dispersion of scores reflected the difficulty in the formation of homogeneous bolus (Fig. 6(c)). PN was successfully swallowed after decrease of adhesiveness by kneading and diluting bolus with saliva. The dispersion of factor 1 in PN, which was strongly related with adhesiveness, occurred with the individuality in the amount of secreted saliva through mastication. PN, which is containing oil droplet, was hard to be diluted with saliva. Because adhesiveness increased after comminution, the variation in the speed of comminution depending on the individual ability resulted in the dispersion of the score.

4. Selection of the elements for Triangle Diagram (TD)

Three elements, which expressed the masticatory performance of comminution, kneading, and diluting bolus with saliva were designed. In other words, they were the total number of masticatory strokes from the beginning of mastication to just before swallowing, cohesiveness of which behavior was independent of the other five parameters, and the change of factor scores on the factor plane with the progress of mastication which expressed the overall behavior of the five parameters; 80% energy, elasticity, viscosity, hardness, and adhesiveness.

1) Total number of masticatory strokes required for swallowing foods

The total number of masticatory strokes required for swallowing foods was shown in Table2 (a). Though the mechanical properties of bolus were investigated in this study, there was no information about the comminution before bolus formation except for the total number of masticatory strokes required for swallowing. Moreover, as it was usually used for the index of masticatory ability in other reports[12], it could be used for the comparison between the results in this research and those in the previous studies. Then it was selected as the index. It was expressed as A.

2) Cohesiveness of boluses at the L point

The PCA revealed that cohesiveness was independent of the other parameters. In the normal subjects, the raw data of cohesiveness at the L point converged to the approximately constant range in all the three types of foods[16]. It was inferred to be located at the lowest range of cohesiveness appropriate for swallowing. It was reported that ability to make bolus and to decrease adhesiveness was related to the saliva secretion[26,30]. The mechanical properties of bolus got close to that of water by being diluted with saliva. As cohesiveness of water is 1.0, the cohesiveness of bolus increased toward 1.0 in the progress of mastication. Since the data of cohesiveness was almost constant for all the three test foods at the L point in the normal subjects[16], it could be the standard value for the ability to dilute the bolus with saliva. It was expressed as B.

3) The change of factor scores on the factor plane with mastication

The additional investigation was attempted regarding five parameters except for cohesiveness. The movement on the factor plane was thought to indicate the overall behavior of the mechanical properties of bolus and the moving distance was thought to be equal to the magnitude of the change. Therefore the rate of the number of masticatory strokes to the distance from the plot of the F point to that of the L point through the M point was expressed as C. It represented the ability to make swallowable bolus.

4) Triangle Diagram (TD)

TD was drawn to show the difference between the values of three elements of each denture wearer and the average value of all the normal subjects in each element at the same time.

(1) The TD of RC

There was little difference between all the denture wearers and the normal subjects in C'. Except for Sub. 5, A' of all the denture wearers was higher than that of the normal subjects. The difference in A' indicated that the ability of the denture wearers to comminute food was inferior to that of the normal subjects. Little difference in C' was detected and this fact indicated that almost all subjects could knead and dilute the bolus as well as the normal subjects. Because RC had the property of water absorption, it was thought to be easier for the denture wearers to knead and to dilute the bolus of RC than the boluses of the other foods.

On the other hand, A' and C' of Sub. 5 were almost same as those of the normal subjects although B' remained lower. From this result of the TD, the ability of

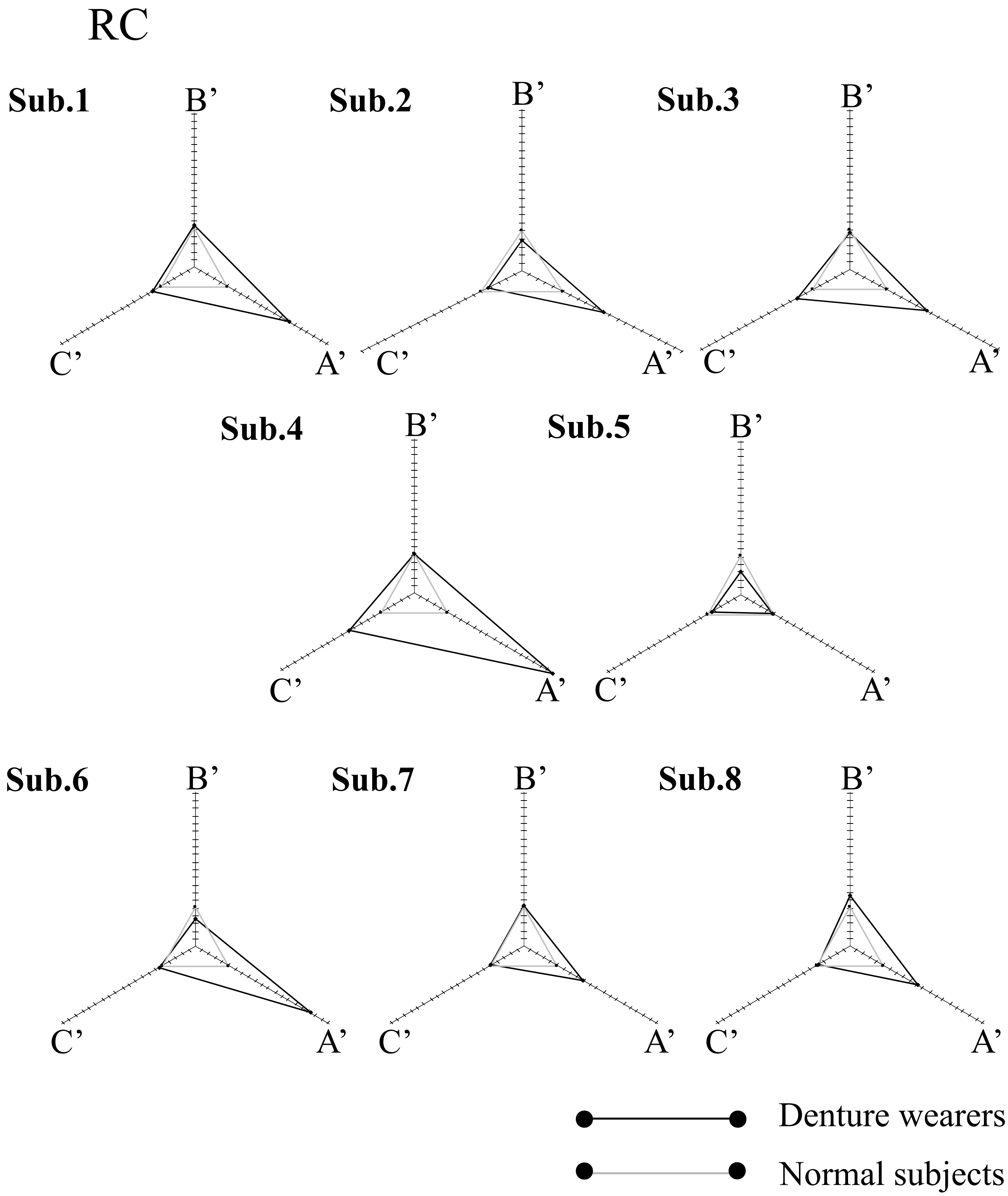


Fig. 7 (a) Triangle Diagram of RC
The mean of the normal subjects was indicated as the apex of the equilateral triangle and one scale on each axis represented 1SD.

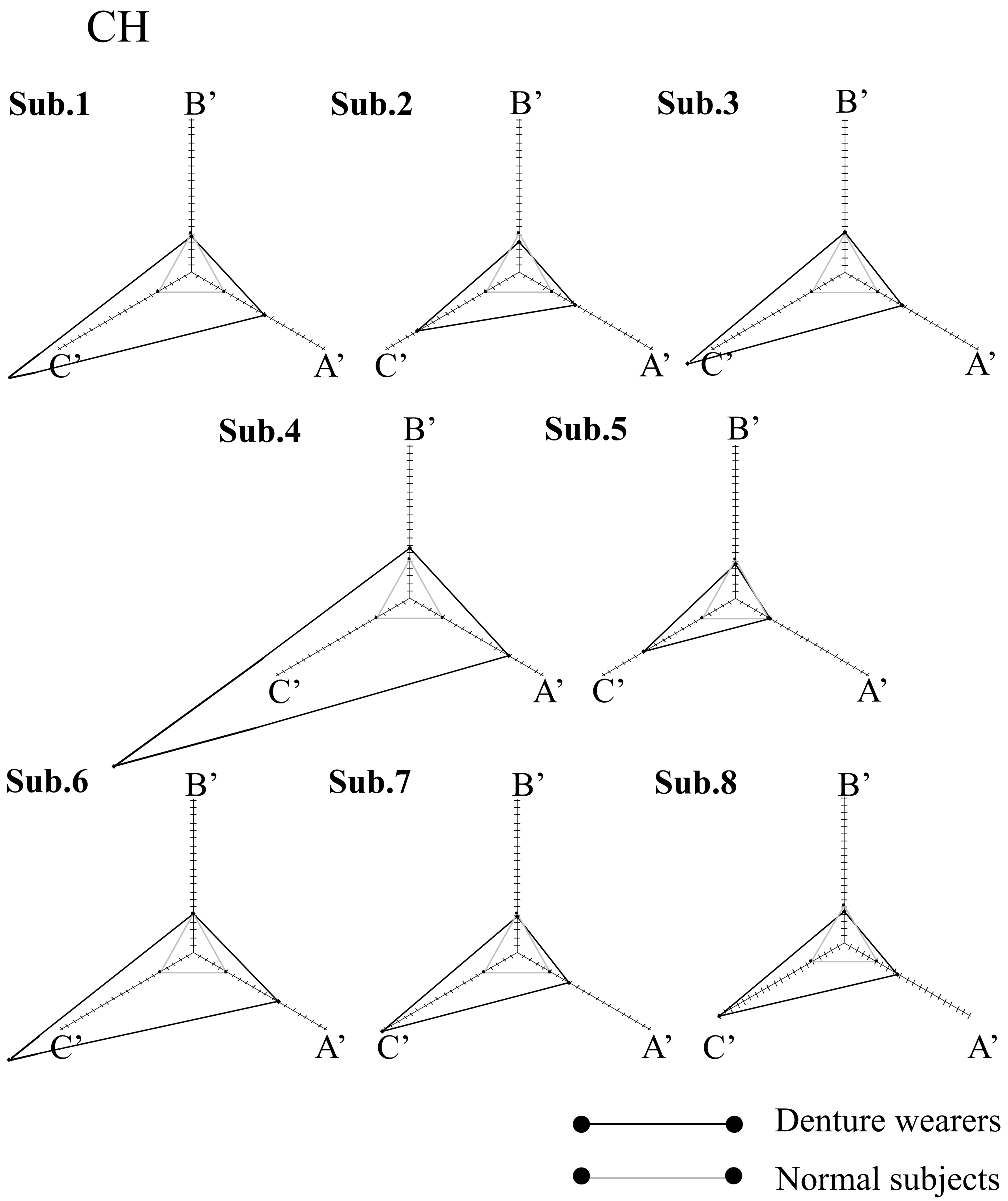


Fig. 7 (b) Triangle Diagram of CH

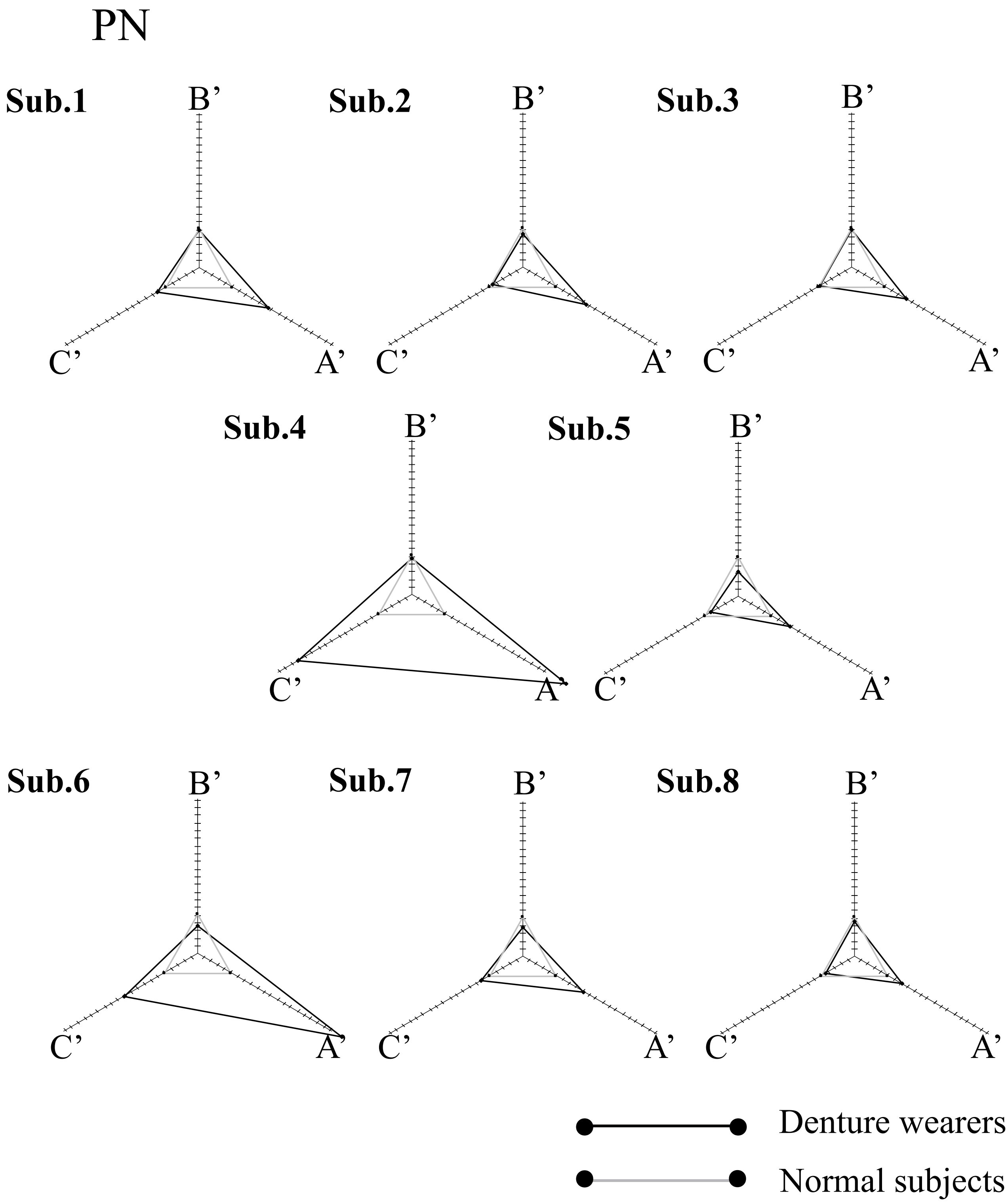


Fig. 7 (c) Triangle Diagram of PN

Sub. 5 to comminute and to knead the bolus of RC was adequate although the diluting function of Sub. 5 was inferior to that of the other subjects (Fig. 7 (a)).

(2) The TD of CH

C' of the denture wearers was larger than that of the normal subjects. The denture wearers would have difficulty in kneading CH for large adhesiveness (Fig. 7 (b)).

(3) The TD of PN

Though C' of the subjects without Sub. 4 and Sub. 6 was almost same as the normal subjects, A' of all the subjects was higher than that of the normal subjects. Large A', which included the ability to comminute food before bolus formation, indicated that these subjects had difficulty in comminution of the bolus of PN before the F point. Both A' and C' of Sub. 4 and Sub. 6 were large. These two subjects had poor ability to comminute and to knead the bolus. The result that B' of all the denture wearers were lower than the normal subjects on the TD showed that diluting the bolus of PN with saliva was more difficult than diluting the bolus of the other foods for denture wearers (Fig. 7(c)).

General overview

Every denture wearer had at least one inferior index in all the three foods to the normal subjects. This result on the TD of three foods indicated the function of masticatory performance such as comminution in RC and PN, kneading in CH, and diluting in PN. The function of the denture wearers did not achieve the same level as the normal subjects.

Conclusion

1. The data of the cohesiveness demonstrated the unique trend and it should be evaluated independently of the other five parameters; 80% energy, elasticity, viscosity, hardness, and adhesiveness.

2. The change of mechanical properties of the bolus during mastication with denture wearers could be compared with that of the normal subjects by using the standardized scoring coefficients derived from the factor analysis on the parameters of the normal subjects for the first time.

3. The measurement of single parameter by using single food was not sufficient for the comprehensive evaluation of mastication.

4. It was suggested that at least three indices were required for comparing the total masticatory function of denture wearers with that of the normal subjects. They were cohesiveness, the total number of masticatory strokes, and the moving rate of the factor scores on the factor plane.

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