Proposed Use of Adjusted Intake Based on Forage Particle Length for Calculation of Roughage Indexes[1]

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ABSTRACT

Effects of forage intake and particle length on chewing time were investigated. Two ratios of forage to concentrate, 33:67 and 50:50, and three lengths of forage particles were compared in two 3 × 3 Latin squares repeated a second year. Distribution of forage particle length was determined with an oscillating screen particle separator. Weighted mean particle lengths, .31, .43, and .51 cm, were measured for the three forages.

Actual intakes of forage dry matter and fibrous constituents were multiplied by mean particle length of the forage to obtain intakes adjusted (kg.cm) for particle length. Although there were no differences in intake of forage dry matter, or of neutral detergent fiber and acid detergent fiber between forage particle lengths, adjustment for particle length revealed that total chewing time was associated with mean particle length of the consumed forage. Total chewing time affected concentration of rumen volatile fatty acids, pH, and milk fat percentage between ratios of forage to concentrate.

Roughage indexes based on adjusted forage intake or intake of forage fibrous constituents are reported. The quadratic equation that described the roughage index ($\hat{Y}$) for the adjusted forage intake was $\hat{Y} = 365.2 - 69.6X + 4.73X^2$.

INTRODUCTION

The National Research Council (23) suggested a minimum of 17% crude fiber in the diet of lactating dairy cows. This suggested fiber does not consider absolute amount, source, or physical form. Feeding high energy diets containing 17% crude fiber or more was associated with physiological disorders (7, 22), depressed rumen pH and narrowed ratio of ruminal acetate to propionate (17, 28, 36), and reduced milk fat percent of dairy cows (7, 9, 21).

Balch et al. (5) reported that chewing time and milk fat percentage of dairy cows were reduced as grain replaced long hay in the diet. Furthermore, chewing time was reduced as particle size decreased. Chewing time was an indicator of roughage value. Roughage indexes for different diets have been reported (6, 24, 34). Sudweeks et al. (34) studied effects of forage and concentrate types and amounts on chewing time and derived roughage indexes for those forages and concentrates. A disadvantage of the method for measuring the roughage index is that it changes not only with forage quality (40), total dry matter, and forage intake (33), but with particle length as well. This makes it necessary actually to measure chewing activities for each total dry matter or forage intake and for the physical form of the forage to establish the roughage index.

The purpose of this study was to test an adjusted forage intake to predict roughage indexes and to study effects of adjusted forage intake on changes of ruminal volatile fatty acids and pH and milk fat percentage.

Experimental Procedure

Experimental diets consisted of alfalfa silage, chopped alfalfa hay, and a concentrate. First crop alfalfa at the late bud stage of maturity

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was cut, conditioned, and allowed to field wilt to 40% dry matter before chopping. Windrows were chopped at .48 cm theoretical length of cut plus 5.08 cm square recut screen and ensiled in 3.7 × 12.2 m concrete stave silos. Alfalfa hay was chopped at 2.54 cm theoretical length of cut. The concentrate was a basal corn grain mix with soybean meal, dry molasses, dicalcium phosphate, and trace mineral salt at 78, 15.4, 4, 1.5, and 1%. Vitamins A and D were added to provide 2200 IU each/kg of concentrate.

Six multiparous Holstein cows averaging 60 days postpartum with previous lactations of more than 8000 kg of milk were divided randomly into two groups, and each was assigned to a ratio of forage to concentrate in two 3 × 3 Latin squares. This design was replicated a second year. Treatments were: 1) ratio of forage to concentrate, 33:67 and 50:50 (dry matter), and 2) mean particle lengths of forage, .31, .43, and .51 cm. This was achieved by blending silage with chopped hay at ratios of 100:0, 67:33, and 33:67 (dry matter).

Each period included 14-day adjustment followed by 7-day collection. Experimental diets were offered ad libitum three times daily in amounts to assure 10% refusal. Feed refusals were recorded once daily prior to the a.m. feeding. The diet components were blended in a mobile mixer.

Distribution of forage particle length was determined twice and by replicates during each 7-day collection with an experimental oscillating screen particle separator developed by Finner et al. (13). Curves of particle distribution for the material retained on each screen were obtained with a Hewlett-Packard calculator plotter system and the University of Wisconsin-Madison's Univac 1110 computer. Mean particle length (MPL) for a particular sample was obtained by multiplying the percentage retained by weight on each screen times the mean particle length of the forage retained on that screen, and was summed over the screens plus the pan.

Feed samples were collected weekly. Aliquots of all feeds were dried and ground or frozen and stored for later analysis. Dry matter content of silage samples was determined by toluene distillation (1) and oven drying at 65°C for hay, concentrate, and representative silage samples. Nitrogen content was determined by Kjeldahl (1). Ammonia nitrogen, lactic acid, and total volatile fatty acids were determined (12). Neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) were measured (16). Total nonstructural carbohydrates were measured (29).

Daily milk yields were recorded. Milk tests included fat by Babcock and protein by Kjeldahl nitrogen × 6.38. These analyses were conducted twice during the 7-day collection on a p.m.–a.m. composite sample.

Rumen fluid was taken by stomach tube 3 h after the a.m. feeding on the last 2 days of collection. The pH was measured by glass electrode immediately after sample collection. Approximately 50 ml rumen fluid was stored with .5 ml of 50% H_2SO_4 solution to stop bacterial action. Rumen volatile fatty acids and ammonia nitrogen were measured (12).

Total chewing, eating, and rumination times were determined by recording the action of individual cows every 5 min during 24 h.

The four Latin squares were pooled and analyzed (30). The model for the analysis of variance is in Table 1. Comparison with a single degree of freedom (df) was to test sources of variation in the analysis when the F test was significant. Orthogonal comparisons were: for square-year (3 df); 33:67 vs. 50:50 forage:concentrate; year 1 vs. year 2; and interaction of ratio of forage to concentrate by year; for treatment (2 df); linear effect and deviation from linear; and for the treatment* square-year (6 df), the three linear and three quadratic interactions.

RESULTS AND DISCUSSION

Composition of diet components is in Table 2. Total dry matter, silage, and hay intakes are

TABLE 1. Analysis of variance table.

Source	df
Square-year	3
Cow/square-year	8
Period/square-year	8
Treatments	2
Square-year × treatments	6
Residual	8

TABLE 2. Chemical composition of dietary components.

Feeds	Dry matter	%, Dry matter Crude protein	Neutral detergent fiber	Acid detergent fiber	Acid detergent lignin	Total non-structural carbohydrates	Ash
Silage[1]	46.2	20.6	45.3	39.2	7.2	2.5	11.1
Hay	88.8	15.0	54.9	42.7	8.3	6.0	8.0
Concentrate	90.5	15.6	8.2	5.1	3.1	57.7	5.1

[1] pH, 4.6; volatile fatty acids, 1.7%, and lactic acid, 4.3% of dry matter.

TABLE 3. Dry matter intake (kg/day).

	Ratio of forage to concentrate[1] 33:67			50:50				
MPL[4], cm	.31	.43	.51	.31	.43	.51	P^2	MSD[3]
Total	24.2	23.8	23.6	24.3	23.6	22.5	NS	2.5
Forage[A]	8.0	7.9	7.7	12.2	11.8	11.1	NS	2.3
Silage[A]	8.0	5.3	2.5	12.2	7.9	3.8	.05	2.7
Hay[A]	0	2.6	5.2	0	3.9	7.4	.05	2.3

[1] Dry matter.

[2] Significance within a ratio of forage to concentrate.

[3] MSD, mean standard deviation, ±.

[4] MPL, mean particle length of forage.

[A] 33:67 vs. 50:50 ($P<.05$).

TABLE 4. Intake (kg/day) of forage dry matter and fiber components.

	Ratio of forage to concentrate[1] 33:67			50:50				
MPL,[4] cm	.31	.43	.51	.31	.43	.51	P^2	MSD[3]
Forage[A]	8.0	7.9	7.7	12.2	11.8	11.1	NS	2.3
Neutral detergent fiber[A]	3.7	3.8	3.9	5.6	5.7	5.6	NS	1.2
Acid detergent fiber[A]	3.0	3.1	3.1	4.6	4.6	4.4	NS	1.0
Acid detergent lignin[A]	.6	.6	.6	.9	.9	.8	NS	.4

[1] Dry matter.

[2] Significance within a ratio of forage to concentrate.

[3] MSD, mean standard deviation, ±.

[4] MPL, mean particle length of forage.

[A] 33:67 vs. 50:50 ($P<.05$).

in Table 3. Total dry matter intake was not different (*P*>.05) between ratios of forage to concentrate. There was no difference (*P*>.05) in forage intake among ratios of silage to hay. In contrast, the difference in intake of forage from ratios of forage to concentrate was significant (*P*<.01). As designed, silage and hay intakes differed between ratios of silage to hay (*P*<.01) and forage to concentrate (*P*<.05). Intakes of NDF, ADF, and ADL were not different (*P*>.05) between ratios of silage to hay but differed (*P*<.05) among concentrate percents (Table 4).

Mean eating, ruminating, and total chewing times per 24 h are in Table 5. Diets containing 100% forage from silage were consumed faster than the other forage combinations; however, differences were not significant (*P*>.05). Similar to (32, 35), the high concentrate diets, 33:67 ratios of forage to concentrate, were eaten faster than the 50:50 diets (*P*<.01). Rumination time and total chewing time increased with each increment of chopped hay addition (*P*<.05). Total chewing time increased (*P*<.05) as mean particle length of the forage increased, as in (5, 20, 32), even though forage intake was nearly the same between ratios of silage to hay. This increase in rumination and total chewing time was linear (*P*<.05) over the mean particle lengths studied; the times were 356, 395, and 437 min/day rumination time and 578, 644, and 689 min/day total chewing time when mean particle lengths of the forage were .31, .43, and .51 cm. Increasing forage intake, with the same mean particle length, from about 8 to 12 kg dry matter per day increased total chewing time by 47, 85, and 61 min/day for forage with .31, .43, and .51 cm mean particle lengths. Others (15, 18, 20, 33, 39) reported similar trends of increased total chewing time with increased particle length. About 72% of the increase in total chewing time was from increased eating time.

Total chewing times in minutes per kilogram of forage intake and per kilogram of total intake of dry matter are in Table 5. Chewing time increased linearly as particle length increased (*P*<.05), 60, 67, and 77 min/kg of forage intake for the three particle lengths. However, total chewing time decreased (*P*<.05) from 77 to 59 min/kg forage as forage intake increased from 7.9 to 11.7 kg/day. Because this appears independent of forage particle length, a roughage index should be adjusted for particle length as well as intake.

A weighted mean particle length was estab-

TABLE 5. Actual forage dry matter intake (DMI) and chewing activities.

	Ratio of forage to concentrate[1]							
	33:67			50:50				
MPL,[4] cm	.31	.43	.51	.31	.43	.51	P^2	MSD[3]
Actual intake, kg								
Forage[A]	8.0	7.9	7.7	12.2	11.8	11.1	NS	2.3
Chewing activities								
Min/24 h								
Eating[A]	204	218	240	240	281	265	NS	45
Ruminating[A]	350	394	419	361	395	454	.05	79
Total chewing[A]	554	612	659	601	677	720	.05	100
Min/kg DMI								
Forage[A]	70.1	75.1	85.6	49.4	59.0	68.8	.05	15
Total[A]	23.1	25.0	28.1	24.7	28.7	32.1	.05	5

[1] Dry matter.

[2] Significance within a ratio of forage to concentrate.

[3] MSD, mean standard deviation, ±.

[4] MPL, mean particle length of forage.

[A] 33:67 vs. 50:50 (*P*<.05).

TABLE 6. Calculation of adjusted intake.

Forage to concentrate[1]	Actual forage intake, kg/day[A]	X	Mean particle length, cm	=	Adjusted intake kg.cm[A]
33:67	8.0		.31		2.6
	7.9		.43		3.4
	7.7		.51		3.9
50:50	12.2		.31		3.8
	11.8		.43		5.0
	11.1		.51		5.7
P[2]	NS		.05		.05
MSD[3]	2.3		.1		1.3

[1] Dry matter.

[2] Significance within a ratio of forage to concentrate.

[3] MSD, mean standard deviation, ±.

[A] 33:67 vs. 50:50 ($P<.05$).

lished for total forage intake within each period. Intake of forage dry matter was multiplied by mean particle length to obtain adjusted forage intake (Table 6). It was hypothesized that for the particular forage intakes, increasing mean particle length would increase chewing time but at a decreasing rate. The point below which particle length affected total chewing time was estimated to be 1 cm. Further research is necessary to substantiate this.

Although there were no differences ($P>.05$) in actual forage intake or intake of forage constituents between ratios of silage to hay, after adjustment for mean particle length of the forage, adjusted intakes were different ($P<.05$) between ratios of forage to concentrate and silage to hay (Table 7).

Intakes of adjusted forage, NDF, ADF, and ADL are in Table 7. Comparisons between mean particle length of forages showed a linear effect ($P<.01$) for all constituents. Adjusted forage and ADF intakes were: 3.2, 4.2, and 4.8 kg.cm, and 1.2, 1.7, and 2.0 kg.cm for forage with .31, .43, and .51 cm mean particle lengths.

TABLE 7. Intake of adjusted forage and fiber components (kg.cm).

	Ratio of forage to concentrate[1]							
	33:67			50:50				
MPL,[4] cm	.31	.43	.51	.31	.43	.51	*P*[2]	MSD[3]
Forage[A]	2.6	3.4	3.9	3.8	5.0	5.7	.01	1.3
Neutral detergent fiber[A]	1.1	1.6	2.0	1.7	2.4	2.9	.01	.7
Acid detergent fiber[A]	.9	1.3	1.6	1.4	2.0	2.3	.01	.6
Acid detergent lignin[A]	.2	.3	.3	.3	.4	.4	.01	.1

[1] Dry matter.

[2] Significance within a ratio of forage to concentrate.

[3] MSD, mean standard deviation, ±.

[4] MPL, mean particle length of forage.

[A] 33:67 vs. 50:50 ($P<.05$).

After forage intake was adjusted for mean particle length, total chewing time differed ($P<.05$) among intakes from 554 min/day for an adjusted forage intake of 2.6 kg.cm to 720 min/day for 5.7 kg.cm. Effect of adjusted forage intake on total chewing time was quadratic ($P<.05$). This may suggest that cows pass larger particles at higher intakes. Concentrate of the diet was not included in adjustment calculations because the contribution of concentrate to total chewing time was small and appeared to be of little practical consequence (35, 38). The basal concentrate mix for this experiment was devised to hold fiber contribution to a minimum. This may not be true if concentrate mixtures of higher fiber are used.

Total chewing time per kilogram of forage intake increased as mean particle length increased for both ratios of forage to concentrate. When adjustment was applied, total chewing time decreased from 222 to 134 min/kg.cm (Table 8) as adjusted forage intake increased from 2.6 to 5.7 kg.cm. Chewing efficiency (11) increased from 277 to 473 g of adjusted forage dry matter per hour for the lowest and highest intakes. Effect of increasing intake of adjusted forage on total chewing time per kilogram, independent of concentrate, was a negative linear response ($P<.05$). The trend was the same for all fibrous constituents of forage ($P<.05$).

Further, for us to study the relationship of total chewing time per kg.cm of intakes of adjusted forage, NDF, ADF, and ADL, individual cow data were used to obtain the best fit. Linear regression analyses were of total chewing time per kg.cm of adjusted-intake (Y) as a function of adjusted-intake (X) (Figures 1 through 4). The quadratic equation best fit the data; linear and quadratic components were significant at .01 and .05 probabilities. Correlation coefficients were −.86 for adjusted forage intake and −.9 for all fibrous constituents of forage.

Total chewing time per kg.cm of adjusted forage, intakes of NDF, ADF, and ADL decreased as intake increased, approaching the minimum with a trend asymptotic to the X axis.

Although total chewing time appears a good measure of roughage characteristics of the diet (6, 24, 34), the roughage benefit is mediated probably through its effect on salivation. Saliva production has a marked effect on rumen pH, volatile fatty acids, and ratio of acetate to propionate (14, 17, 28, 36) as well as milk fat percentage (8). Total daily salivary secretion increased linearly with increasing dry matter intake (27, 41). However, the volume of saliva secreted per kilogram of dry matter consumed decreased with increasing intake (3, 4, 27). Total saliva production in cows varied between 110 to 178 liters/day (3). Total chewing time is associated closely with saliva production (6).

TABLE 8. Total chewing time (minutes) per kg.cm of adjusted intake.

	Ratio of forage to concentrate[1]							
	33:67			50:50				
MPL,[4] cm	.31	.43	.51	.31	.43	.51	P^2	MSD[3]
Forage[A]	222	177	171	162	138	134	.05	43
Neutral detergent fiber[A]	503	372	341	357	291	277	.01	113
Acid detergent fiber[A]	609	460	431	430	360	346	.05	131
Acid detergent lignin[A]	3434	2440	2248	2339	1880	1866	.01	750

[1] Dry matter.

[2] Significance within a ratio of forage to concentrate.

[3] MSD, mean standard deviation, ±.

[4] MPL, mean particle length of forage.

[A] 33:67 vs. 50:50 ($P<.05$).

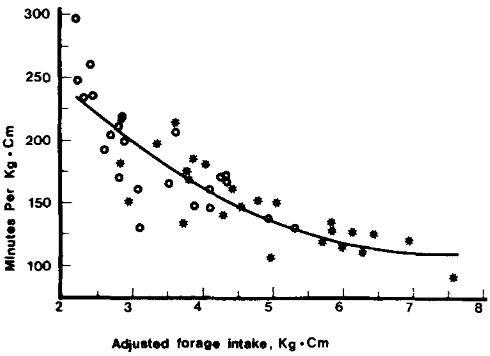

Figure 1. Relationship of chewing time with adjusted forage intake: ○, 33:67 forage to concentrate ratio; ✱, 50:50 forage to concentrate ratio; ———, predicted; correlation, −.86; regression equation, $Y = 365.2 - 69.6\ X + 4.73X^2$, total chewing time per kg.cm of adjusted intake as a function of adjusted intake (X).

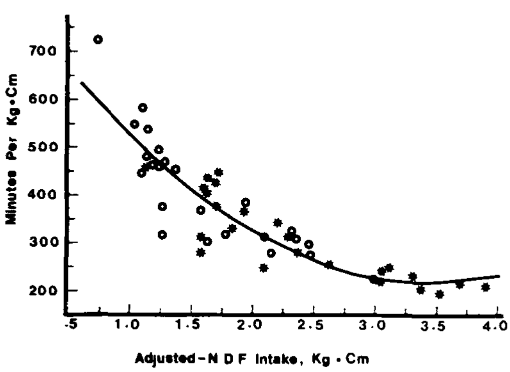

Figure 2. Relationship of chewing time with adjusted neutral detergent fiber intake (NDF): ○, 33:67 forage to concentrate ratio; ✱ 50:50 forage to concentrate ratio; ———, predicted; correlation, −.9; regression equation, $Y = 838.5 - 363.4\ X + 53.4X^2$, total chewing time per kg.cm of adjusted intake (Y) as a function of adjusted intake (X).

Poutiainen (26) showed that as chewing time increased, volume of saliva increased. Therefore, buffering capacity in the rumen from salivary contribution was altered greatly by diet. Increasing total saliva production produced a greater buffering activity in the rumen and increased the ratio of acetate to propionate (19, 37).

Molar percentages of acetate and propionate were affected ($P<.01$) by concentrate and mean particle length of the forage (Table 9). Acetic acid increased ($P<.05$) with an increase in total chewing time. When individual acetates (Y) were regressed on adjusted forage intake (X), response was linear with a correlation coefficient of .6 ($P<.01$). The linear regression equation was $Y = 55.84 + 1.62X$. The same treatment effect was found by Sudweeks (32) with increasing particle length of corn silage from .62 to 1.91 cm and by DePeters et al. (10) with increasing forage intake. Molar percentage of propionate decreased from 26.3% for the

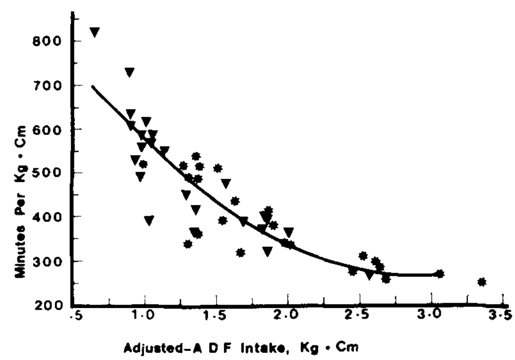

Figure 3. Relationship of chewing time with adjusted acid detergent fiber (ADF) intake: ▼, 33:67 forage to concentrate ratio; ✱, 50:50 forage to concentrate ratio; ———, predicted; correlation, −.86; regression equation, $Y = 977.8 - 490\ X + 84.2X^2$, total chewing time per kg.cm of adjusted intake (Y) as a function of adjusted intake (X).

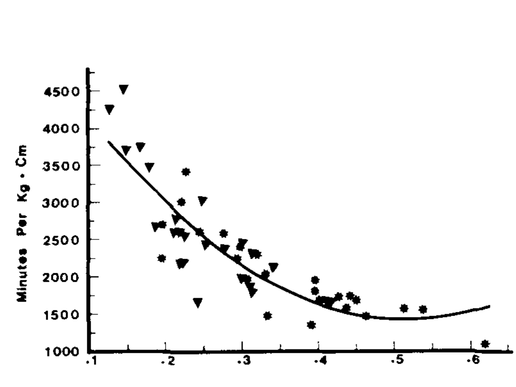

Figure 4. Relationship of chewing time with adjusted acid detergent lignin (ADL) intake; ▼, 33:67 forage to concentrate ratio; ✱, 50:50 forage to concentrate ratio; ———, predicted; correlation. .9; regression equation, $Y = 5651.7 - 16401X + 15918X^2$, total chewing time per kg.cm of adjusted intake (Y) as a function of adjusted intake (X).

TABLE 9. Rumen volatile fatty acids (VFA's), pH, and milk fat percentage.

	Ratio of forage to concentrate[1]							
	33:67			50:50				
MPL,[4] cm	.31	.43	.51	.31	.43	.51	P^2	MSD[3]
Rumen VFA's								
(Molar %)								
Acetic[A]	57.4	60.2	62.1	63.8	65.6	65.5	.01	3.7
Propionic[A]	26.3	23.3	22.1	18.7	18.1	17.7	.05	4.1
Butyric	11.4	11.8	11.1	11.4	10.2	11.4	NS	1.2
Total VFAs (mM/liter)[A]	90.8	91.7	87.3	108.4	99.8	90.8	.05	14
Acetic:propionic[A]	2.2	2.6	2.9	3.4	3.6	3.7	.05	.6
pH[A]	6.4	6.4	6.4	6.5	6.6	6.6	NS	.16
Milk fat (%)[A]	2.9	3.0	3.0	3.3	3.5	3.3	NS	.5

[1] Dry matter.

[2] Significance within a ratio of forage to concentrate.

[3] MSD, mean standard deviation, ±.

[4] MPL, mean particle length of forage.

[A] 33:67 vs. 50:50 ($P<.05$).

lowest adjusted forage intake to 17.7% for the highest (Table 9). Rumen butyrate was not affected by concentrate or by forage mean particle length. Total volatile fatty acids were affected ($P<.05$) by concentrate and mean particle length.

Differences in concentration of total volatile fatty acids between concentrate percents, 89.9 vs. 99.6 mM/liter ($P<.05$) possibly could be explained by differences in fermentability of the diets. Diets that increase chewing time and saliva flow may lower the concentration of volatile fatty acids because saliva flow would have a dilution effect and increased turnover rate of rumen liquid (31). This statement does not hold true across ratios of forage to concentrate. However, when data were compared between mean particle lengths of forage, independent of concentrate, effect was linear ($P<.05$). The concentration of volatile fatty acid decreased from 99.7 to 88.1 mM/liter as total chewing time increased from 578 to 690 min/24 h. Even with higher concentrations of volatile fatty acids, rumen pH was higher for the 50:50 ratio of forage to concentrate (6.6 vs. 6.4) than for the 33:67 ratio ($P<.05$).

Milk fat was affected ($P<.05$) by concentrate, 2.9 vs. 3.4%, but not by mean particle length of forage.

CONCLUSION

Adjusted forage intake was closely associated with total chewing time over a range of forage intakes from 7.7 to 12.2 kg/day having a range in mean particle length from .31 to .51 cm. Intake adjustment based on mean particle length at forage intakes of this experiment could be applied to calculate the roughage index of forages cut at different lengths.

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