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심박 및 심박변화를 통한 최대 지방 연소 시점의 추정

Preceding Research for Estimating the Maximal Fat Oxidation Point through Heart Rate and Heart Rate Variability

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Abstract - Increasing the oxidation of fat through exercise is the recommendable method for weight control. Preceding researches have proposed increase in the usage of fat during exercise in stabilized state and under maximum exertion through aerobic training. However, such researches require additional equipment for gas analysis in order to measure the caloric value or gas exchange of subjects during exercise. Such equipments become highly restrictive for those exercise and cause substantially higher cost. According to this, we have presented the method of estimating the maximal fat oxidation point through changes in LF & HF which reflects changes in heart rate and the autonomic nervous system in order to induce exercise for a less restrictive and efficient fat oxidation than existing methods. We have conducted exercise stress test on subject with similar exercise abilities, and have detected the changes in heart rate and changes in LF & HF by measuring changes in fat oxidation and measuring ECG signals at the same time through a gas analyzer. Changes in heart rate and HRV of the subjects during exercising was detected through only the electrocardiographic signals from exercising and detected the point of maximum fat oxidation that differs from person to person. The experiment was carried out 16 healthy males, and used Modified Bruce Protocol, which is one of the methods of exercise stress test methods that use treadmill. The fat oxidation amount during exercise of all the subjects showed fat oxidation of more than 4Fkcal/min in the exercise intensity from about 5 minutes to 10 minutes. The correlation between the maximal fat oxidation point obtained through gas analysis and the point when 60% starts to be relevant in the range from -0.01 to 0.01 seconds for values of R-R interval from changes in heart rate had correlation coefficients of 0.855 in Kendall's method and in Spearman's rho, it showed significant results of it being $p<0.01$ with 0.950, respectively. Furthermore, in the changes in LF & HF, we have determined the point where the normalized area value starts to become the same as the maximal fat oxidation point, and the correlation here showed 0.620 in Kendall and 0.780 in Spearma of which both showed significant results as $p<0.01$.

Key Words : Fat oxidation, Heart rate, VO_2max, ECG, Heart Rate Variability(HRV)

1. Introduction

With qualitative improvement in the standard of living, and development of science and technology physical activities of those living in the modern era has decreased and there is trend of increase in obesity, which is the cause of adult disease such as high blood pressure and diabetes.

Therefore, people in the modern era are spending more time on exercise and weight management from the perspective of looking after their health and prevention of illnesses. As the issue of obesity is becoming quite serious, diverse range of treatment methods including wide range of dietary treatment, exercise treatment, chemical treatment and surgical treatments are being proposed. In particularly, concurrent implementation of dietary treatment and exercise treatment is being recommended. In addition, researches on inducing fat oxidation through analysis of energy sources being used during exercise are being carried out actively.

The major calorie nutrient used as energy source when the human body is exercising includes carbohydrate, fat, and protein. Out of these nutrients, protein has a very low usage ratio of 5-10%, and carbohydrate and fat are major energy sources that are used[6]. Decision on utilization ratio on energy source is determined by the intensity and duration of exercise exerted onto the human body. In the case of long-term and low intensity exercise in which exercise continues for more than 30min, the ratio of fat being used as energy source gradually increase [10], and in the case of short-term and high

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intensity exercise the utilization of carbohydrate increases [3].

In order to find the point at which fat is being used as energy source maximally, researches on effective fat oxidation through exercise are being carried out actively both at home and abroad, and the American College of Sports Medicine (ACSM) is recommending 50-60% of Maximum Oxygen intake (VO_2max) as the exercise intensity in order to maintain and enhance health and cardiopulmonary function[2].

In addition, other researches on energy consumption during exercising, excessive oxygen consumption during recovery period following exercise, and ratio of energy mobilization prior to and following exercise in accordance with the exercise intensity have been continuing [7][15][20].

According to the results of the existing researches, the exercise intensity for maximal fat oxidation is 50-80% of the VO_2max and varies widely in accordance with gender and level of physical strength. There has been a report in the Astorino that the point at which the rate of maximal fat oxidation is the largest coincides with the point at which the ventilation threshold occurs[1]. Therefore, we have executed research that is aimed at non-restrictive measurement of the point of maximal fat oxidation on the basis of these existing researches. Obviously, although precise measurements need to be made in accordance with the existing restrictive methods, finding the non-restrictive maximal fat oxidation is required in accordance with the current activation and trend of sports.

Therefore, we have carried out preceding research aimed at estimating this point through changes in heart rate and Heart Rate Variability(HRV) on the basis of changes in fat oxidation through gas analysis in order to find this point. In this study, Changes in heart rate and HRV of the subjects during exercising was detected through only the electrocardiographic signals from exercising and detected the point of maximum fat oxidation that differs from person to person.

2. Method

2.1 Subject and Experimental Process

In this study, 16 experimental subjects were chosen among normal adult males who voluntarily wished to participate in the research. Subjects filled in the consent form along with explanations on the procedures of the experiment. Physical characteristics of the experimental subjects are given in the Table 1. This experiment was carried out at the Sports Medicine Laboratory of the Wonju Medical College of the Yonsei University with 16 healthy males, and used Modified Bruce Protocol, which is one of the methods of exercise stress test methods that use treadmill. During the experiment, treadmill (TM55, Quinton) and respiratory gas analyzer (True One 2400, Parvo Medics) were used to acquire the data on the changes in the respiratory gas of the subjects at every 15-second interval, and oxygen intake, respiratory exchange rate, exercise intensity and heart rate among these were taken.

Table 1 Physical characteristics of the experimental subjects

Variable	Mean±SD[1)]	Range
Age	27±2.21	24-32
Height(cm)	174.05±3.98	167-184
Weight(kg)	68.75±6.5	59-85
VO_2max ($mlkg^{-1}min^{-1}$)	46.14±6.17	33.61-55.96

1) SD : Standard Deviation

During the examination, blood pressure was measured at every 3-minute interval, and continuous electro cardiogram and heart rate, results of respiratory exchange rate, facial skin complexion of the subjects, and Ratings of Perceived Exertion (RPE) developed by Gunner Borg were comprehensively evaluated by using the cardiac stress monitor (Q-Stress, Quinton). If the findings corresponded to minimum of 4 items among all items, then such situation was set as the VO_2max in carrying out the experiment [4].

Module developed to obtain electrocardiographic signals during the exercise stress test was attached to the upper arm and electrodes were attached to both sides of the chest in order to acquire electrocardiographic signal of LEAD 1 simultaneously.

2.2 Design of the measurement system

Block diagram for electrocardiogram measurement of the module to obtain electrocardiographic signal used in this research is given in the Fig. 1.

The signal measured from ECG measuring part was converted from Analog to Digital with 8 bit resolution 240Hz sampling frequency using Microcontroller (MSP340F1611) and the signal was sent to PC via bluetooth system, which is a wireless communication system.

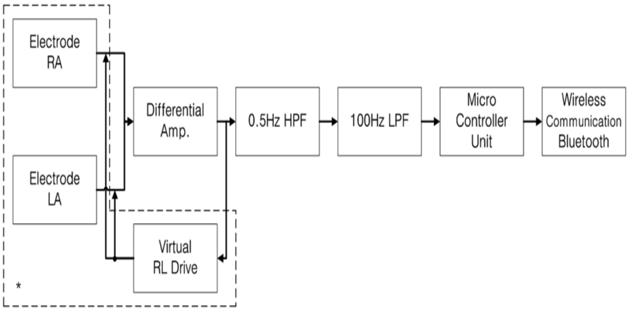

Fig. 1 Block diagram of the electrocardiogram measurement. Virtual RL Drive give a feedback to electrode RA and LA, so 2-Electrode ECG Module can minimize the effect of motion artifacts during exercise(*).

2.3 Fat Oxidation

The ratio of energy source mobilized during exercise under steady state can be calculated using respiratory factor and Lusk Table, and in this study, we have come up with fat kilocalorie (Fkcal) using the ratio of respiratory exchange rate and Lusk Table with oxygen intake obtained from exercise stress test using Modified Bruce Protocol[9]. In other words, we were able to calculate the ratio of carbohydrates and fat used during exercise by measuring CO_2 emission and oxygen intake during exercise.

2.4 Data Analysis

2.4.1 R Peak and R-R interval(RRI) Detection

To detect R point, we have applied the modified variable threshold method as shown in Fig. 2. The modified variable threshold method takes a 250 point moving average filter while extracting the largest value every 200 samples from the ECG signals. Because the size of T points becomes bigger than point R as the exercise becomes more intense, in order to detect R point, we take an R point of a value more than the interval by setting a certain limited interval for preventing the wrong detection by T point or other noise.

In order to acquire changes in heart rate, interval between the R point is computed with R point detected from the electrocardiographic signal before converting and reconstituting them into continuous time-series data.

Firstly, if we set the location of the k-th R point on the electrocardiogram data by obtaining R point of electrocardiographic signal to be R(k), then interval time-series between the R point can be obtained by repeating I(k+1), ・・・ for the section between I(k)R(k) to R(k+1) for the section from R(k-1) to R(k). That is, if R(k-1) R(k) R(k+1) is the k-1, k, k+1 th detected R point, then the RRI can be expressed as follows:

$$I(k) = R(k) - R(k-1),\ I(k+1) = R(k+1) - R(k),\ \cdots \quad (1)$$

RRI series is used for observation of statistical characteristics of changes in heart rate main in the time domain. Heart rate series so obtained is not an same interval signal but have different interval as it is generated whenever heart rate is generated. Therefore, this signal cannot directly be subjected to power spectrum analysis by frequency analysis. In order to analyze the frequency of heart rate series, one must induce evenly spaced RRI from the heart rate series.

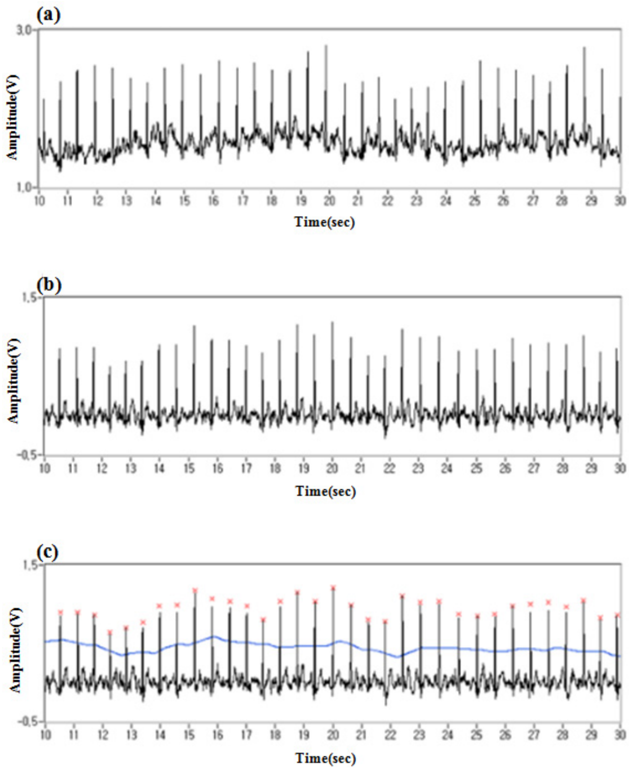

Fig. 2 Process of R Peak Detection. Detection an accurate R point in order to changes in heart rate, removed 60Hz power noise using notch filter on ECG signal(a). Eliminated baseline wandering using 20 point median filter of ECG Signal(b). ECG signal with Peaks detected(c).

2.4.2 Detection of Maximal Fat Oxidation Point in RRI

The detrend procedure removed the low frequency components from the original signal by applying 3rd order polynomial approximation method for the heart rate changes. Among these, the point at which the ratio of intervals of heart rate changes begins to correspond to more than 60% in the range from -0.01 to 0.01 seconds for values of R-R intervals is set as the point of maximal fat oxidation, with considerations for noise.

2.4.3 Detection of Maximal Fat Oxidation Point in LF & HF of HRV

In this study, we have used a interpolated RRI data for finding out the changes in heart rate has on the autonomic nervous system, and have detected the changes in Low Frequency (LF) area, the index which represents the activities of the sympathetic nerve and High Frequency (HF) area among parameters of HRV, which represents the activities of the parasympathetic nerve [12][16]. Here, we have set LF elements in a range of 0.04-0.15 Hz, and HF elements between 0.15-0.4 Hz. In addition, analysis of frequency domain was subjected to re-sampling procedure at 5 Hz by using the interpolated R-R interval.

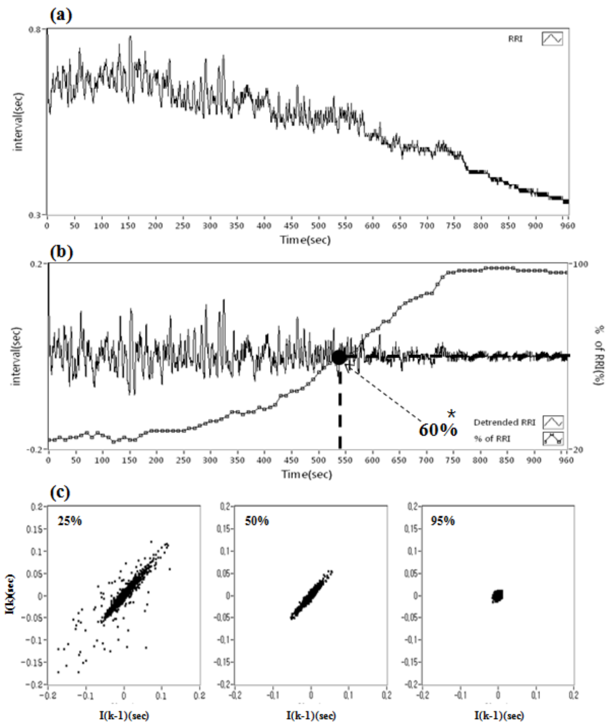

Fig. 3 RRI interval changes in the heart rate change during exercise(Subject 13). Detection of RRI on changes in heart rate(a). The signal of heart rate changes for which the low frequency components have been removed, ratio of the interval between R point and the immediately following R point, which is the range from -0.01 to 0.01 seconds for values of R-R intervals(*), among the signals was detected among the signals with duration of 1 minute at every 10 second interval (b). If R wave interval of RRI I(k) and I(k-1) are expressed scatter diagram, the range of interval values is from -0.01 to 0.01 percent (c).

Low frequency component of the heart rate changes for the signal that underwent re-sampling procedure by 3rd order polynomial approximation in this study in order to intercept signal distortion by low frequency component.

Similar to the analysis of time domain, signal with duration of 3 minutes was subjected to frequency analysis at every 10 second interval, and power spectrum was deduced in accordance with Auto Regression(AR) model by using the Burg method. Burg Method is one of minimum square deviation methods based on the method of minimizing deviation of frontal and rear aspect in the lattice structured Linear Predictor. In order to obtain each parameter of LF & HF in the power spectrum acquired with AR model, value of the area was computed through integral calculus by setting the range of frequency.

We have normalized the area value of the calculated LF & HF to 0-100%, and have determined the point where the normalized area of LF & HF becomes same as the maximal fat oxidation point as shown in Fig. 4.

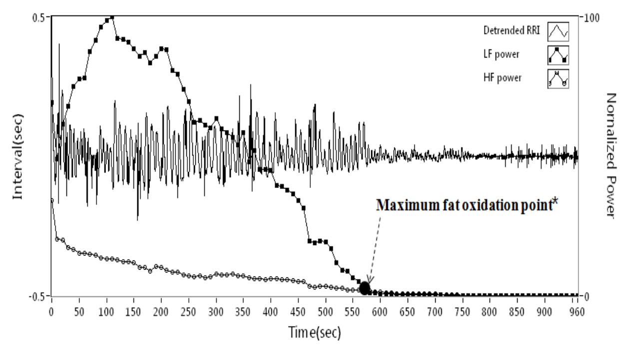

Fig. 4 Changes in LF & HF power during exercise(Subject 11). Normalized the area value of the calculated LF & HF to 0-100%, and have determined the point where the normalized area of LF & HF becomes same as the maximal fat oxidation point(*).

2.4.4 Statistical Analysis

SPSS 12.0, Windows was used for processing of data for the study and the level of all statistical significances were set at $p<0.05$. We have made a statistical analysis of the time value of maximal fat oxidation amount from the changes in fat oxidation amount detected through data obtained from gas analyzer on 16 subjects, and the time value of maximal fat oxidation amount detected through changes in heart rate and LF & HF proposed by this study. Since the nonparametric method, unlike the parametric method, does not have any particular premises and deals with order rather than actually measured values, computation can be made easily. In addition, it is possible to respond relatively less sensitively to the measurement errors. Wilcoxon signed rank test, by outputting test statistics quantity by simultaneously considering the signs and sizes of each of the pairs of differences, has greater test capability than the sign test that only considers sign. Therefore, we have examined the significance of each comparative variable through Wilcoxon Signed Rank Test among nonparametric methods of Paired T-Test.

3. The Experimental Results

3.1 Relationship of Fat and Carbohydrate Oxidation

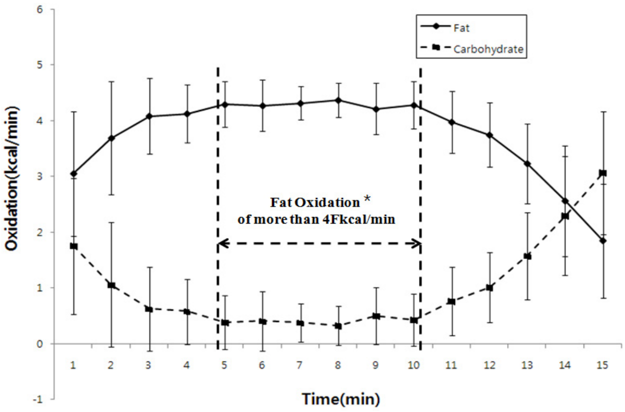

Fig. 5 Average changes and standard deviation of fat oxidation and carbohydrate in 16 experimental subjects during exercise. changes in average oxidation amount of fat and carbohydrates of all the subjects during exercise that intensifies in 3 minute intervals. Fat oxidation amount during exercise of all the subjects showed fat oxidation of more than 4Fkcal/min in the exercise intensity from about 5 minutes to 10 minutes, and carbohydrates showed inverse proportionate changes. As the intensity of exercise got gradually higher, the oxidation amount of carbohydrates increased gradually(*).

Table 2 shows the changes in average oxidation amount of fat and carbohydrates of all the subjects during exercise that intensifies in 3 minute intervals.

As a result of conducting Paired Samples Correlations on oxidation of fat and carbohydrates which has occurred during exercise, we have seen Correlation Coefficient equaling −1, P(0.000)< 0.05. Therefore, we have statistically confirmed that the relationship between two oxidation points change with the correlation of inverse proportion.

3.2 Maximum of Fat Oxidation Point

3.2.1 Change of Heart Rate

Time of maximal fat oxidation of each experimental subjects detected through gas analysis and RRI during exercise are given in the Table 4. %VO_2max at the time of maximal fat oxidation through gas analysis was 36.50±4.67% and %VO_2max at the time of maximal fat oxidation detected from RRI was 37.16±4.63%.

Table 2 Change of average and standard deviation of fat oxidation and carbohydrate

Subject	Fat Oxidation (Fkcal/min)		Carbohydrate (Fkcal/min)	
	Average	Standard Deviation	Average	Standard Deviation
1 min	3.051	1.115	1.754	1.219
2 min	3.690	1.020	1.057	1.119
3 min	4.086	0.674	0.622	0.750
4 min	4.128	0.519	0.578	0.583
5 min	4.292	0.410	0.384	0.478
6 min	4.272	0.457	0.405	0.527
7 min	4.316	0.298	0.377	0.348
8 min	4.370	0.310	0.322	0.351
9 min	4.212	0.460	0.496	0.512
10 min	4.281	0.426	0.430	0.468
11 min	3.977	0.557	0.761	0.610
12 min	3.746	0.575	1.012	0.629
13 min	3.230	0.720	1.571	0.777
14 min	2.560	0.991	2.295	1.068
15 min	1.845	1.021	3.065	1.098

Table 3 Paired Samples Correlation

	N	Corrleation	Sig. (2-tailed)	T
Fat Oxidation-Carbohydrate	15	−1.000	0.000	6.737

3.2.2 Change of LF & HF

These are changes in the autonomic nervous system which was examined indirectly through changes in LF & HF of the analysis of frequency area among parameters of HRV during exercise. The power of LF & HF, the index of the sympathetic nerve and parasympathetic nerve of the autonomic nervous system reduces as the intensity of the exercise increases, and showed a significant reduction around 500 seconds as shown in Fig. 4. In order to verify the correlation of each points detected through two methods, we have analyzed the correlation using nonparametric method, and its result is as shown in Table 6.

As a result of making an analysis of the correlation using the method of Kendall and Spearman, in case of using changes in heart rate, correlation coefficients were 0.620 and 0.780, and then in case of using LF & HF, correlation coefficients were of 0.855 and 0.95, thereby displaying significant correlations in both cases.

Table 4 Detection of time of maximal fat oxidation through gas analysis and Heart rate

Subject	Gas Analysis		Heart rate	
	Time of maximal fat oxidation (sec)	$\%VO_2$ max	Time of maximal fat oxidation (sec)	$\%VO_2$ max
Sub 1	630	47.49	630	47.49
Sub 2	615	42.07	610	41.19
Sub 3	615	39.61	600	33.31
Sub 4	600	28.47	620	36.98
Sub 5	630	34.25	620	34.10
Sub 6	570	35.88	560	33.55
Sub 7	525	33.84	540	34.79
Sub 8	555	34.05	570	38.03
Sub 9	555	33.90	580	45.14
Sub 10	555	36.09	570	36.85
Sub 11	510	33.85	530	37.46
Sub 12	525	31.82	500	31.83
Sub 13	525	38.16	540	30.53
Sub 14	585	38.49	600	36.88
Sub 15	540	42.22	550	41.11
Sub 16	495	33.86	500	35.35
Mean±SD	564.4 ±43.77	36.50 ±4.67	570 ±41.47	37.16 ±4.63

Table 5 Detection of time of maximal fat oxidation through Gas Analysis and LF & HF

Subject	Gas Analysis		LF & HF	
	Time of maximal fat oxidation (sec)	$\%VO_2$ max	Time of maximal fat oxidation (sec)	$\%VO_2$ max
Sub 1	630	47.49	640	49.75
Sub 2	615	42.07	600	39.42
Sub 3	615	39.61	610	37.60
Sub 4	600	28.47	630	37.72
Sub 5	630	34.25	570	31.64
Sub 6	570	35.88	550	31.82
Sub 7	525	33.84	490	32.38
Sub 8	555	34.05	560	35.20
Sub 9	555	33.90	550	34.49
Sub 10	555	36.09	590	41.92
Sub 11	510	33.85	570	42.60
Sub 12	525	31.82	530	37.23
Sub 13	525	38.16	500	35.54
Sub 14	585	38.49	580	39.44
Sub 15	540	42.22	490	42.98
Sub 16	495	33.86	420	30.39
Mean±SD	564.4 ±43.77	36.50 ±4.67	555 ±58.08	37.51 ±5.13

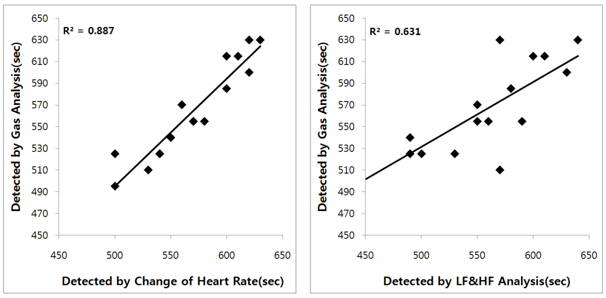

Fig. 6 Comparing the maximal fat oxidation point through gas analysis during exercise and the maximal fat oxidation point of changes in heart rate(a) and LF & HF(b).

Furthermore, in order to validate the points detected through changes in heart rate and LF& HF, we have used Wilcoxon Signed Rank Test among nonparametric method of Paired T-test, and as a result of analysis, each was detected as p=0.115(>0.05) and p=0.299(>0.05) as shown in Table 7.

Table 6 Analysis of correlation of detected time of maximal fat oxidation in accordance with nonparametric method

	Kendall tau-B		Spearman rho	
	Correlation coefficient	P-value	Correlation coefficient	P-value
Gas Analysis -Change of Heart rate	0.855	p<0.01	0.950	p<0.01
Gas Analysis -LF&HF Analysis	0.620	p<0.01	0.780	p<0.01

Table 7 Wilcoxon signed Ranks test detected time of maximal fat oxidation

(a) Between Gas Analysis and Change of Heart rate

		N	Mean Rank	Sum of Ranks	Sig. (2-tailed)
Wilcoxon signed rank test	Negative Ranks	5[a)]	6.50	32.50	
	Positive Ranks	10[b)]	8.75	87.50	
	Ties	1[c)]			0.115
	Total	16			

a) Change of Heart rate < Gas Analysis

b) Change of Heart rate > Gas Analysis

c) Change of Heart rate = Gas Analysis

(b) Between Gas Analysis and LF-HF Analysis

		N	Mean Rank	Sum of Ranks	Sig. (2-tailed)
Wilcoxon signed rank test	Negative Ranks	10[a]	8.80	88.00	
	Positive Ranks	6[b]	8.00	48.00	
	Ties	0[c]			0.299
	Total	16			

a) LF & HF Analysis < Gas Analysis

b) LF & HF Analysis > Gas Analysis

c) LF & HF Analysis = Gas Analysis

4. Conclusion

In this paper, in order to detect the maximal fat oxidation point during exercise through changes in heart rate and LF & HF, we have checked the changes in fat oxidation amount through gas analysis during exercise, and have compared and validated the changes in fat oxidation amount through gas analysis of changes in heart rate and LF & HF.

Exercise stress test was carried out in order to detect the time of maximal fat oxidation that differs in each of subject with similar level of exercise capability with 16 normal adult male with level of maximum oxygen intake at 46.14 ±6.17 ml kg-1min-1,which is the index for exercise capability, as subject.

Firstly, changes in the quantity of fat oxidation during exercising were looked into. Lee at. al. reported that the maximum of fat oxidation could generate under exercise intensity of 50%VO_2max[22]. As a result of measuring fat oxidation with indirect calorie measuring methods during bicycle ergometer exercise for 120, 60, and 30 minutes in 25, 65, and 85%, respectively, in studies conducted by Romijn and others, the highest ratio of calorie through fat was during the lowest intensity of exercise. However, its lipid oxidation rate was 65% during a 30 minute workout, which was the highest among exercise of the intensity of VO_2max [18].

The time of maximal fat oxidation through gas analysis in this study is 564.4±43.77 seconds after commencement of exercise in accordance with modified Bruce Protocol, which corresponds to 36.50±4.67% VO_2max, and there was not much difference from the results of preceding research [17][18] with average person as subjects. As you can see in Fig. 5, among exercises gradually increasing its intensity in 3 minute intervals, the fat oxidation amount in changes of fat and carbohydrate oxidation amount was the highest between about 5 minutes to 10 minutes, and the carbohydrate oxidation amount was the lowest to the contrary. With the gradual increase in the intensity of exercise, the quantity of oxidation of carbohydrate increases while that of fat decreases. This appears to be the result of the fact that, with respect to the respiratory exchange rate at low intensity, oxygen intake due to aerobic metabolism is larger than the quantity of generation of CO_2 and as the intensity increases, quantity of generation of CO_2 increases rapidly with increase in the ratio of an aerobic metabolism for the purpose of generation of larger quantity of energy necessary for exercise.

Next, the changes in autonomic nervous system which reflects changes in sympathetic nerve and parasympathetic nerve identified through changes in heart rate during exercise was as shown in Fig. 4. As the intensity of exercise increased, the activity of the autonomic nervous system in its initial stable condition started to gradually deteriorate. The human body is always controlled by the autonomic nerve to maintain balance with the inner environment regarding changes in inner or external environments, and we can assume the extent such sympathetic nerve and parasympathetic nerve was controlled by the relevant autonomic nerve through changes in LF & HF. Both sympathetic and non-sympathetic nerves are activated in order to maintain Homeostasis, thereby resulting in large and complicated changes in heart rate. However, as one exercises, the heart rate increases and this is adjusted mainly by the balance between the involution of activities of parasympathetic nerves and acceleration of activities of sympathetic nerves [8][19].

Changes in LF & HF Power which represent sympathetic nerve and parasympathetic nerve detected in the frequency analysis of changes in heart rate started to decline at a fast pace in its power of LF & HF around approximately 500 seconds as the intensity of the exercise gradually increased. This showed significant results that changes in fat oxidation amount per minute is maximum at around 8 minute after starting the exercise through gas analysis.

Previous researches proposed that at heart rate lower than 100 beat/min, it is accomplished by the involution effect of the activities of the parasympathetic nerves and heart rate increases due to acceleration of sympathetic nerves at intensity higher than this[19]. In addition, there is a report that the time at which the contribution by the sympathetic and parasympathetic nerves change substantially corresponds to the anaerobic threshold (AT) [11][14][21]. Along with this, there was a study reporting that the point having the largest percentage of maximal fat oxidation in the study done by Astorino matches the point where ventilator occurs[20].

Therefore, we have proposed a method of estimating the maximal fat oxidation point through detecting changes in LF & HF which appears in the changes in heart rate and changes in the autonomic nervous system without going through gas analysis upon exercise, and the maximal fat oxidation point using changes in heart rate was detected as 37.16±4.63%VO_2max in 570±41.47 seconds, and was detected as 37.51±5.13%VO_2max in 555±58.08 seconds in case of using LF & HF.

The correlation between the maximal fat oxidation point by each subject obtained through gas analysis and the point when 60% starts to be relevant in the range from -0.01 to 0.01 seconds for values of R-R intervals from changes in heart rate proposed by this study had correlation coefficients of 0.855 in case of Kendall's tau-B method of each nonparametric method, and in case of Spearman's rho, it showed significant results of it being $p<0.01$ with 0.950, respectively. Furthermore, in the changes in LF & HF, we have determined the point where the normalized area value starts to become the same as the maximal fat oxidation point, and the correlation here showed 0.620 in case of Kendall and 0.780 in case of Spearma of which both showed signifi cant results as $p<0.01$.

We have seen that the correlation coefficient in case of using changes in heart rate appeared to be a bit more significant regarding detection of maximal fat oxidation point through two methods proposed by this study. However, we were able to check that the average of the maximal fat oxidation point detected through changes in heart rate was higher than the average of the maximal fat oxidation point detected through gas analysis, and check that the average of maximal fat oxidation point detected through changes in LF & HF was estimated to be lower. Moreover, we have verified that not only the estimation using changes in heart rate but also estimation of the maximal fat oxidation point using changes in LF & HF was also very useful as detecting maximal fat oxidation point showed more accurate results through changes in LF & HF rather than changes in heart rate in subject no. 3, 8, 9, 12, and 14. In addition to that, we have checked that there was no difference in resulting values between two methods since it showed insignificant results with each significant probability was $p=0.115$ (>0.05), $p=0.299$ (>0.05) respectively as a result of making an analysis through Wilcoxon signed rank test. Therefore, we have proven that both changes in heart rate and changes in LF & HF are both useful in detecting the maximal fat oxidation point.

In conclusion, the detection of maximum fat oxidation point through changes in heart rate and LF & HF is possible to detect maximum fat oxidation point through the existing gas analysis in this thesis, and as gas analysis of O_2/CO_2 takes the measurement of just electrocardiogram, it has the convenience of being able to obtain desired results as comfortable as possible. Therefore, we will be able to give real-time feedback on exercise to the user during exercise as the maximal fat oxidation point is estimated through accurate real-time measurement of parameter of changes in heart rate during exercise in the future, and this can be used in a variety of ways for overcoming obesity. Additionally, for such research, development of system for execution of exercise through the method presented in this study and to actually compute changes in the body fat would be necessary.

Reference

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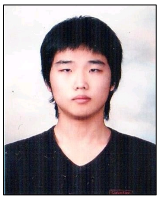

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