基于基本体格检查提出综合肥胖

指数的分析与应用

The Analysis and Application of an Integrated Obesity Index Based on Basic Physical Examination

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摘要

本文利用基本体格检查获取的物理体格指标即身高，体重，腰围和臀围，在现有通用肥胖标准即身高体重指数，腰围臀围比例和体脂肪率的基础上，提出了综合肥胖指数。综合肥胖指数在应用方式简便可行的基础上力求全面完善，在一定程度上弥补了现行通用肥胖标准的局限性。首先,本文基于人体几何模型提出了综合肥胖指数的应用公式。而后，采用流行病学调查数据，将物理体格指标，性别，体脂肪率等变量带入模型进行数据分析，对综合肥胖指数与体脂肪率做线性回归得到综合肥胖指数的标准界限。应用所得标准对于样本人群患病率进行分析比较，通过数据分析比较了综合肥胖指数对于通用肥胖标准的误判概率修正意义，发现综合肥胖指数有明显优越性，将在一定程度上弥补现行通用肥胖标准在应用中的缺陷。

关键词：体格指标，肥胖指数，几何模型，线性回归，数据分析， 概率

Abstract

This paper proposes an Integrated Obesity Index (IOI) based on height, weight, waist, and hip, physical indexes that can be accessed through regular physical examinations, on top of common obesity standards, including Body Mass Index (BMI), Waist-Hip Ratio (WHR), and Body Fat Percentage (BFP). Integrated Obesity Index is aimed to be feasible and convenient under application, as well as comprehensive, compensating for the limitations of existing classifications of obesity. Thus, this paper proposes and examines the application formula of the IOI by establishing geometric models. Adopting the data from epidemiological survey, this papers brings physical indicators, gender, BFP and other variables into the model for data analysis, applies linear regression on the resulting images, and obtains the IOI cut-off point. By conducting comprehensive data analyses to various obesity classifications, the paper demonstrates that the IOI has significant advantages over BMI, WHP, or BFP and will compensate for the deficiencies of the existing obesity classifications to a certain extent in application.

Keywords: Physical Indexes, Obesity Index, Geometric Model, Linear Regression, Data Analysis, Probability

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Chapter 1 INTRODUCTION

With the continuous development of social economy and the improvement of living standards,obesity now becomes a leading cause of death worldwide, with increasing prevalence in adults and children, and is viewed as one of the most serious public health problems of the 21st century [1]. However, obesity is，estimated by WHO, the most easily overlooked chronic disease in mankind and certainly need more public attention.

1.1 Common Obesity Standard

The clinical definition and diagnostic criteria of obesity is diversified and dynamic for long time, widely used standard for obesity nowadays includes body mass index (BMI) and Waist-hip ratio (WHR) and Body Fat Percentage (BFP). The calculation of the above standard and the division of obesity list below [2]:

w = body weight（kg）, h = height（m）, BMI unit：kg/m2，the world-wide overweight standard for adult is BMI≥25，obese is BMI≥30[3] (table 1),yet different standard has to be taken in East Asia. The standard promulgated by Disease Control Department of the Ministry of Health of the People's Republic of China for Chinese mainland population is BMI≥24 for overweight and BMI≥28 for obese [4].

Table1：BMIObesity Index classification

BMI classification	
Underweight	<18.5
Normal range	18.5 – 24.9
Overweight:	>=25.0
Preobese	*25.0 – 29.9*
Obese:	>=30.0
Obese class I	*30.0 – 34.9*
Obese class II	*35.0 – 39.9*
Obese class III	*>=40.0*

$$\mathrm{WHR} = \frac{Waist}{Hip}$$

Waist here refers to the length of Waistline，measured on the intermediate level by Lowest rib and Ilium, Hip stands for hip circumference on the level of greater trochanter after legs closed [5]. waist and hip should use the same units， standard ratios of males and females are 0.9 and 0.85 respectively [6].

BFP is currently the most accurate measuring standard for obesity. Yet it requires expensive method like underwater weighing, also known as hydrostatic weighing. Other methods include Near Infrared Analysis and Body displacement volume labeling etc., which just as costly as hydrostatic weighing. The index can also be deduced by BMI in the formula:

$$BFP\ (\%) = 1.2 \times BMI + 0.233 \times Age - 10.8 \times gender$$ [7]

The value of gender is 1 for male, 0 for female. Yet it is noted that although BMI for male and female stays constant, a 10% difference emerges in the BFP index. The value of BFP is also proportional to age increase with their weight constant [8]. Male with BFP over 25% and female with BFP over 30% are considered obese regarding to general standard [9] (table 2).

Table 2：BFP obesity Index classification

BFP classification		
Description	**Women**	**Men**
Essential fat	10–13%	2–5%
Athletes	14–20%	6–13%
Fitness	21–24%	14–17%
Average	25–31%	18–24%
Obese	32%+	25%+

1.2Analysis of Common Obesity Standards

Clinical statistics show that BFP is of the most accuracy among the above indexes for its most closely associated with the expected incidence of metabolic syndromes, yet the process sacrifices its ease of use at the same time [10]. Although BFP can also be deduced by BMI, yet the as a standard, it shows no improvement in accuracy. Therefore, those indexes with relatively more simplicity like BMI and WHR are taken as the most widely used standards for obesity. But both BMI and WHR have blatant limitations that are not to be ignored during model building:BMI only concerns the height and weight, ignoring the multiple components of body, such as fat and muscle with significantly difference in density. A large set of groups including bodybuilding enthusiasts who are relatively muscular is not suitable for this standard; on the other hand, WHR only focuses on the body's shape with has similar limitations.

In clinical applications of the underdeveloped areas, those potential patients and health care workers whose hardware condition far from configuration to detect patients BFP, always fail to combine the index of BMI and WHR at the same time to speculate obesity. In a certain extent, it may lead to neglection of potential obesity population, thus blocks effective treatment of metabolic syndromes with high potentially incidence.

In order to minimize the limitations of BMI, WHR and BFP in clinical applications that are mentioned above, to the following paragraphs would contain analysis of existing standards, establishment of a new model named **Integrated Obesity Index**(IOI) with appropriate mathematical approaches, The method is built on the balance of pursuit of maximum accuracy by considering both external contour and the composition of human body to integrate basic advantages of BMI, WHR and BFP and of the simplicity of data collection and the feasibility of application analysis, using only physical index such as height, weight, waist and hip which can be obtained from the basic physical examination.

In this paper, Chapter 2 would introduce the establishment of the new Integrated Obesity Index using human geometric model, and farther on to deduce the application formula of Integrated obesity index; Chapter 3 would state the prevalence of diabetes and metabolic syndromes with the database of *Jiangsu partition data from 2007 National Survey*[11] being adapted and introduce variables such as physical index, gender,body fat percentage into the model for data analysis, making a linear regression of IOI and BFP to obtain the standard boundary of IOI. Comparison between the application result and the prevalence of sample population, accuracy of IOI and the current common obesity index by comprehensive data analysis. Finally the potential applications value for groups and individuals are discussed; Chapter 4 would be the conclusion and lookouts.

Chapter 2MODEL ANALYSIS

2.1Geometry Model of Human Body

Over the years, researches have brought proportionality analysis into biological inquiry, using simplified geometric model to obtain a representative result. Therefore in this section, body structure of human being population would be simplified down to geometric level even if they are one of the most advanced organisms in the nature. The whole process is under the body would only be only constructed with trunk and extremities, which are accounted for most mass of the body. This paper presents a body geometry model considering the torso, upper limbs and waist, abdomen, respectively, as two sets of frustum, the lower limbs as a cone, as seen below (figure 1):

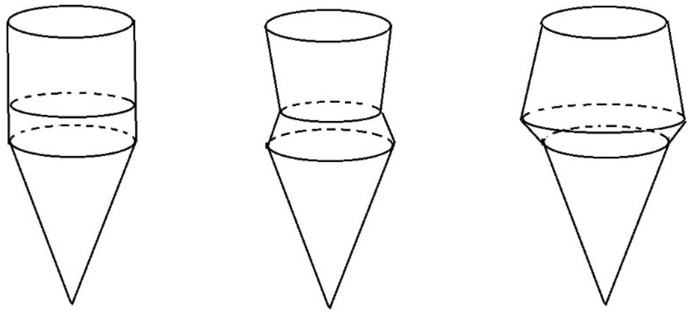


Figure 1: geometric shapes of human body

Height =H，Upper body length=h， h∝H and h/H=a(a is a constant).

The above models assume that shoulder and hip circumference are two equal circles, which areas are S. Waist-to-hip ratio presented as WHR=K. So the waist size is shown as $S'=K^2S$. Approximate body volume can be obtained from the formula:

(1)

2.2Mathematical Interpretation of BMI

$$V_h = 8K + K \quad 3 \quad SH$$

With the formula , it's not hard to configure a cylinder with same volume of a human body (figure 2),

$$V_h = V$$

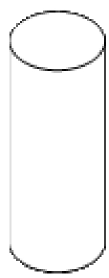


Figure 2： Cylinder geometry of human body

Which height is H，and ，

With t

In solid geometry ， so the base area of cylinder can be expressed

$S_h \; \mathrm{I} \; H$

with

$$BMI \; \mathrm{I} \; \frac{M}{S_b}$$

And $BMI = \frac{M(KG)}{H^2 Y m^2 Y}$， therefore

Which means of BMI values can be seen as the mass loaded on the bottom area.

According to the derivation and unit of BMI(kg/m^2) mentioned above, BMI can be treated as the mass loaded per unit area, which means BMI value is proportional related to the mass per unit area. Therefore, when endowed same height, the magnitude of BMI is proportional to the density of the individual. The density of fat is approximately 0.9g/ml, which is slightly less than the density of muscle (approximately 1.06g/ml) [12],from which it can be concluded that body fat percentage is inversely proportional to BMI, directly proportional to the degree of obesity. This conclusion is obviously not rigorous. Clinically it has been identified that the degree of obesity is lower if BMI value is smaller and the degree obesity is higher if BMI value is bigger.

This confliction shows the defection for using BMI. The conception of BMI is based on the assumption that the density of body is roughly the same. Therefore it is identified clinically the mass that human body can bear on one unit area holds the same[13]. By international standard, the cut-off point for overweight is BMI exceeding 25kg/m^2, whereas 25kg/m^2 is proportional to the mass value the body bears per unit area, also 25kg/m^2 can be simply recognize as the mass value on per unit area of a human body with standard density. In other words, if BMI of an individual is less than this, the mass which human body bears per unit area is lower. While the mass which human body can bear on relative unit area remains the same, which means the individual does not have so much cross-sectional area, the smaller cross-sectional area of an individual, the thinner it is, the lower the degree of obesity. Similarly, in order to withstand the mass on per unit area, for individuals who have higher BMI, the cross-sectional sections have to be enlarged, which means that the degree of obesity is higher.

The derivations above also reveal one limitation of BMI application: it ignores the differentiation of fat percentage and density of human bodies. In another word, for one whose BMI value exceeds, the value of overweight does not necessarily need to enlarge his cross-sectional area if his bearing ability exceeds the standard. Therefore it proves that the formula of bearing mass derived from IOI model in this paper is suitable for individuals with different density.

2.3 Integrated Obesity Index (IOI) derivation

In fact it is not difficult to assume that there are two individuals with same height (H), same mass (M) (namely the same BMI) and same cross-sectional area of hips(S), while with different WHR = K_1, K respectively (K_1<K) (due to different body fat percentage and density). The assumption states that the degree of obesity of the latter can be accurately represented by BMI, whose body fat percentage and density is equal to the standard value, so K is considered as the standard value for WHP.

According to the formula of volume：

(2)

(3)

Their volume will be converted into the cylinder with same height H(figure3)：

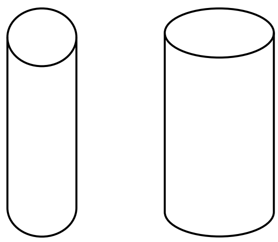


Figure 3：Cylinder geometry of human body

Two cylinders are obtained with same height but different bottom areas, which are:

(4)

$$S_b = \frac{V}{H} = \left[\frac{a}{3(K^2 + K)} + \frac{1}{3}\right]S \quad (5)$$

The actual masses acting on the bottom areas are (their ability to withstand the mass):

(6)

(7)

$$\lambda = \frac{M}{\left[\frac{a}{3(K^2 + K)} + \frac{1}{3}\right]S}$$

Then it is possible for the calculation of the standard coefficient of $\frac{S_b}{H^2}$=θ， then：

$$\lambda_1 \times H^2 \times \theta_1 = M \quad (8)$$

$$\lambda \times H^2 \times \theta = M \quad (9)$$

Then：

$$\frac{\theta_1}{\theta} = \frac{\lambda}{\lambda_1} = \frac{\left[\frac{a}{3(K^2 + K)} + \frac{1}{3}\right]}{\left[\frac{a}{3(K_1^2 + K_1)} + \frac{1}{3}\right]} \quad (10)$$

It is known： $BMI \times {}^{1}/_{\theta} = \lambda$

So

$$\lambda 1 = \lambda \times \frac{\frac{a}{3(K_1^2 + K_1)} + \frac{1}{3}}{\frac{a}{3(K^2 + K)} + \frac{1}{3}}$$

$$= BMI \times \frac{\frac{a}{3(K_1^{2} + K_1)} + \frac{1}{3}}{\left[\frac{a}{3(K^2 + K)} + \frac{1}{3}\right]\theta} \tag{11}$$

It has been described in the paper that is actually a value under standard condition, which means it could be seen as a constant. Then a new formula of the bearing mass comes with:

$$\delta = BMI \times \left[\frac{a}{3(K^2 + K)} + \frac{1}{3}\right] \tag{12}$$

In the formula, *a* is a constant. The majority of the vertical structure of the human body is complied with the golden ratio [13] , by ignoring the impact of the nuances of the vertical structure

$$a = \frac{5}{13}$$

on body volume, an unified standard would be taken as . So the new formula emerges as:

$$\delta = BMI \times \left[\frac{5}{39(K^2 + K)} + \frac{1}{3}\right] \tag{13}$$

In which $K = WHR$, $\delta = IOI$, namely the formula of **Integrated Obesity Index** (IOI) is:

$$IOI = BMI \times \left[\frac{5}{39(WHR^2 + WHR)} + \frac{1}{3}\right] \tag{14}$$

The new index (IOI) reflects the bearing mass per unit area, which combines the assessment of BMI and WHR and minimizes their limitations. If the magnitude of IOI for an individual is higher than the standard value, despite the ability of bearing mass is different, his the cross-sectional area can be regarded as being enlarged, so he has a higher degree of obesity. Similarly, if one's IOI value is lower than the standard value, despite the different ability of bearing mass, his cross-sectional area can be regarded being reduced, thus leading to a lower degree of obesity.

In the next chapter, the new index (IOI) will be applied to the sample population to determine the cut-off point of IOI obesity and to conduct analysis for validating. The application of IOI on the groups and individuals of sample population will also be introduced.

Chapter 3 DATA ANALYSIS

In this chapter we adapted the database of "National Survey on Prevalence of Diabetes and Metabolic Syndromes, Jiangsu area in 2007 [11]", introduced physical indexes, gender and body fat percentage into a model for data analysis and made linear regressions on the images. Based on the intersection of the fitting curve of body fat percentage and the linear regressions, the standard cut-off points of Integrated Obesity Index (IOI) has been obtained. Then we applied the standard to sample population for analysis, compared IOI with current common obesity index and finally discussed the potential value of application in groups and individuals.

3.1 Data pre-processing

We exported data from the database of "National Survey on Prevalence of Diabetes and Metabolic Syndromes, Jiangsu area in 2007 [11]" The total sample is 3449, in which 2206 are complete. After excluding the data of minor 2202 sample were validated.

Some analyzed data of human body indexes are abnormal, examples are shown in table 3：

Table 3：Examples of Data Anomalies

height（CM）	weight（KG）	BMI	waist（CM）	hip（CM）	WHR	body fat percentage（%）
169	86	30.1	92	112	0.82	4.8
158	48	19.2	73	89	0.82	33.4

The first one obviously is obese according to his height, weight, waist and hip alone, where his BMI=30.1 and WHR=0.82. But the actual body fat percentage is low, indicating most likely a measurement error or a data input error. The second one with normal physical index and height/weight had high body fat percentage, which might be a special individual case.

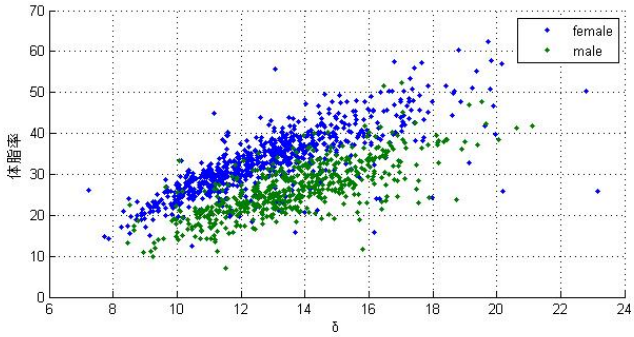
Considering the fact that the causes of the abnormal data mentioned above are difficult to verify, this paper remains such data for analysis in order to ensure scientific rigor.

3.2Cut-off points of IOI and Validation

The formula has been deduced in last chapter：$\delta = BMI \times [5/39(K^2+K)+1/3]$， in which K=WHR， δ=IOI， namely **Integrated Obesity Index**. However in order to apply this formula in prediction of the prevalence of diabetes and metabolic syndromes in practical applications, it is also need to validate the new index as well as draw up cut-off points of IOI for those who are "in the high risk of abnormal metabolism", namely "obese or overweight people", delimitating in all demographic people.

We will compare the new index, IOI with BMI to find out its advantages and disadvantages as BMI is currently the most widely used standard for obesity.

According to previous discussion clinical statistics shows that BFP is most representative, namely this index is most associated with the expected incidence of metabolic syndromes, although it cannot be widely used due to complexity and high cost. In order to verify whether the new index can reflect the different degrees of obesity we made an image of IOI (δ) and body fat



percentage in Figure 4.

It can be seen clearly from the figure that IOI has positive linear correlation with body fat percentage. Meanwhile there is a clear boundary between male and female scatterplot, which correspond to the previous point that levels of body fat are epidemiologically dependent on sex: if the degree of obesity is same the male body fat content is 10% lower than the female.

In order to explore the superiority of the new index in application, as comparison we also made the image of the correlation between WHR and BFP and one between BMI and BFP.

Figure 4：The image of IOI(δ) and body fat percentage

The image of the correlation between WHR and BFP is shown as following (Figure5)：

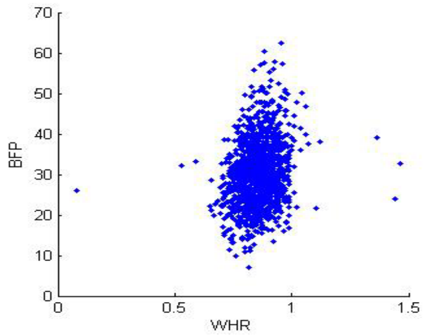


Figure 5：The image of the relationship between WHR and BFP

In the image of the relationship between WHR and BFP we can find a linear relationship, which indicates that WHR has certain influence on BFP. So IOI, in which WHR is taken into account, is more reasonable and more comprehensive comparing to the application of BMI alone.

The image of the correlation between BMI and BFP is shown as following (Figure 6)：

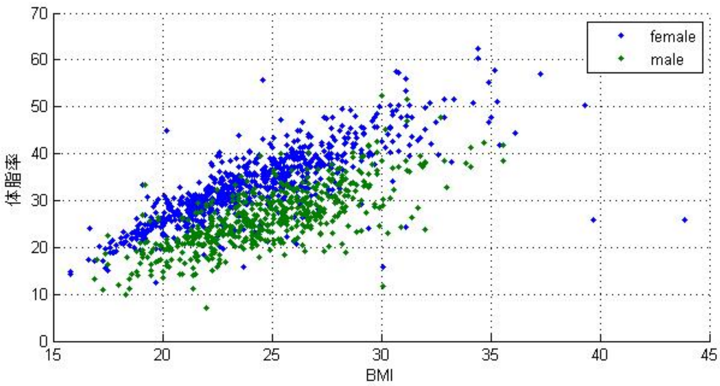


Figure 6：The image of the relationship between BMI and BFP

In the image of correlation between BMI and BFP the degree of concentration of dots for male and female is weaker than in the image of correlation between BFP and IOI. In the Chapter 1 we have mentioned the formula of the conversion between BMI and body fat percentage: BFP% = 1.2×BMI + 0.233×Age - 10.8×Gender, the gender value of male is 1 and female is 0. Although this formula has taken into account the difference between male and female body fat percentage, it is generally considered that the value of BFP derived from BMI index is not more superior than the value of BMI, which simply because with different body fat percentage male and female at the same age and same BMI cannot be considered the same. In another words, the standard of BMI used the same both for male and female cannot exactly correspond to the different body fat percentage. Therefore after a reasonable deriving, the advantage of the new formula is that the same IOI value for male and female can exactly correspond to the different body fat percentage.

Previous research shows that there is a certain relationship between age and BFP [8]. In this paper we made the image of correlation between age and BFP shown in Figure 7:

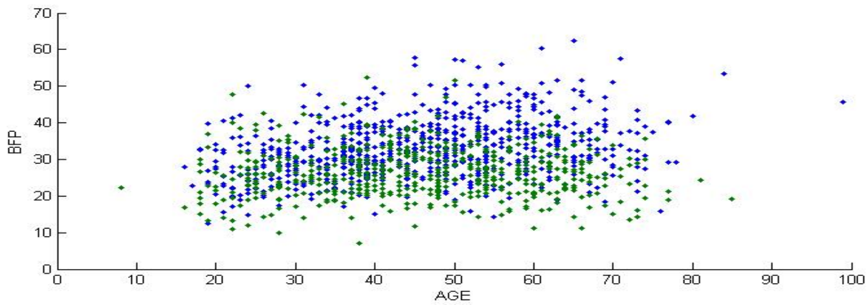


Figure 7: The image of the relationship between age and BFP

Thus, there is a certain correlation between age and body fat percentage. Precedent studies have showed that the correlation between age, race, etc. and BFP is quadratic and nonlinear[8]. The influence of age on body fat percentage is limited, that body fat changes insignificantly with age to a certain degree. The changes of the values of BFP in the same age of men and women from 20 to 80 year-old are within 5.So these variables are negligible compared to the impact of gender on BFP. Therefore, we will ignore age and other possible variables in the following discussion of BMI and IOI in order to unify the variables and ensure that the new index is simple and practical in future application.

Based on the above conjecture and the fact thatcurrently the standard of BFP is the most widely accepted standard of obesity, in this paper we try to find out the relationship between IOI and BFP by linear regression at the same time we will verify this conjecture.

Establishing the formula of IOI and BFP:

$$\mu = \theta_1 + \theta_2 \delta$$

（BFP=μ，IOI=δ，θ_1、θ_2 are constants）

Based on the standard of Mat lab, after we make linear regression between IOI and BFP in women we find that:

BFP(μ)=7.40696751989167e-05+2.57702105517688*δ（δ=IOI）

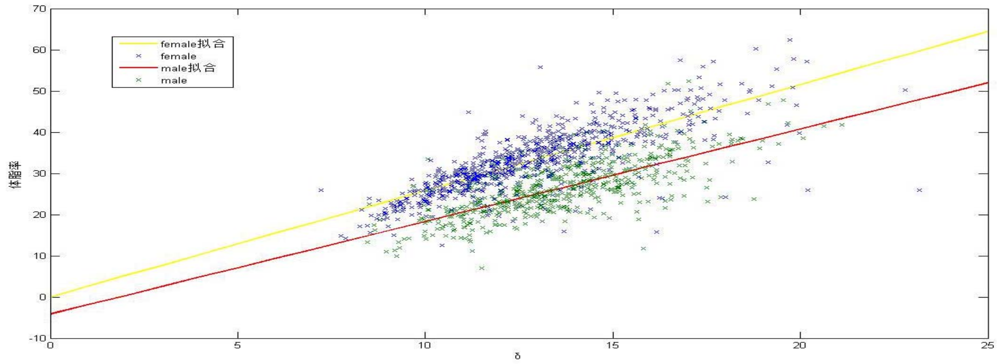
From STATS we can get the value：R^2=1.0；F=1.1877>f=0.0000；p=0.0235<alpha=0.05;

This shows that the accuracy of this fitting is high.

Similarly, after we make linear regression between IOI and BFP in men we find that:

BFP(μ)= -4.12403059011801+2.24440311074324*δ（δ=IOI）

From STATS we can get the value：R^2=0.5446；F=646.9094>f=0.0000；p=20.1748>alpha=0.05；Here, the value of p is more than the default value of alpha， suggesting the accuracy is not high enough, but the degree of the fitting is acceptable from the image, so we temporarily consider that it is correct, we will make a detailed analysis afterwards .An image processed by Mat lab



could

Figure 8 :The linear regression relationship between BFP and IOI.

be found in Figure 8.

Based on the compartmentalization of BFP for the diagnosis of obesity mentioned above the standard of obesity in men is BFP≥25% and in women is ≥30%, we make an image in which μ=25% for men and μ=30% for women, showing overlapping with the fitting image(Figure 9):

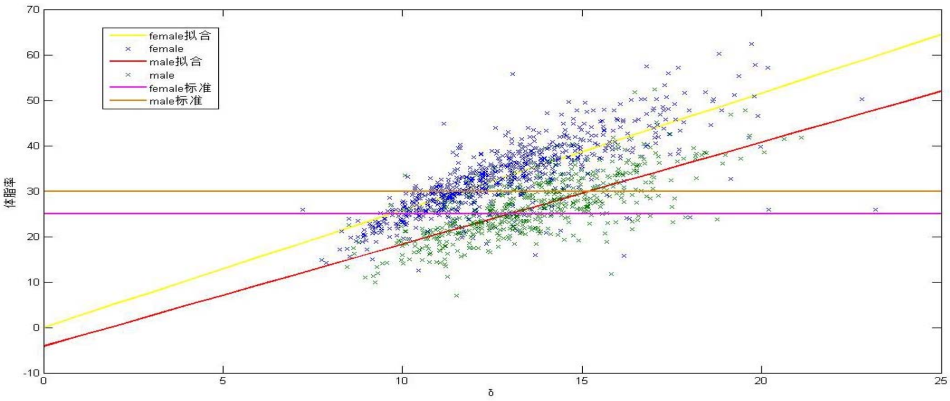


Figure 9： The fitting image of the relationship betweenIOI and BFP and the intersectionimage of BFP standard line.

Solving the linear algebraic equations:

$$\begin{cases} \mu=30 \\ \mu= 7.40696751989167e\text{-}05+2.57702105517688*\delta \end{cases}$$

$$\begin{cases} \mu=25 \\ \end{cases}$$

μ= -4.12403059011801+2.24440311074324*δ

Obtaining the intersection:

Women:（11.641319681909112092203653436247, 30.0）

Men：（12.976292204689393049677560999142, 25.0）

Therefore, this paper shows that **women will be considered as obesity if their IOI>=11.64 and men will be considered as obesity if their IOI>=12.97.**

Similarly, after we make a linear regression between BMI and BFP we find that(figure 10)：

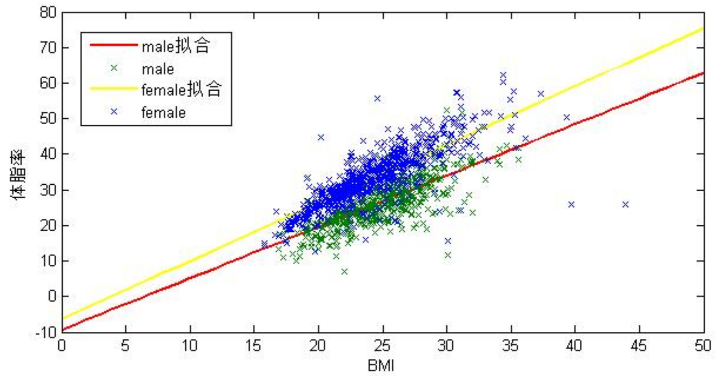


Figure 10： The linear regression relationship between BMI and BFP.

Women:μ=-6.37157579867540+1.63537111354473*BMI

Men:μ=-9.31845436900497+1.44367588279567*BMI

We make an image in which μ=25% for men and μ=30% for women, showing the overlapping with the fitting image (Figure 11)：

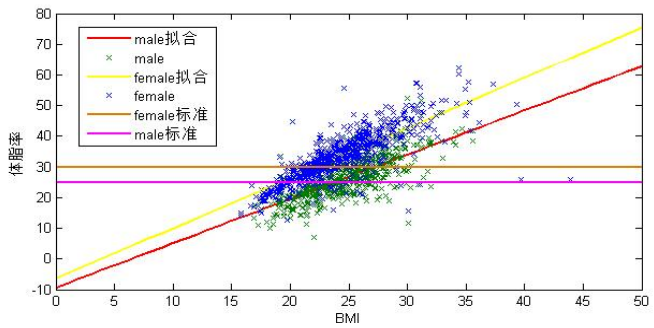


Figure 11： The fitting image of the relationship betweenBMI and BFP and the intersectionimage of BFP standard line.

The intersections were (22.240563929149149408312059284, 30.0) and （23.7715783563187199169597848304, 25.0）respectively.

After the comparison of these results mentioned above we obtain the following results:

Based on STATS, the value generating from the linear regression between BMI and BFP is roughly the same as the value coming from the linear regression between IOI and BFP. The values of p in men are approximately 20, much larger than the default alpha=0.05.

In the preprocessing of data, there are two cases mentioned above in which data are abnormal, both of which are collecting from men. Considering that the living habits of men differ from those of women, the probability of male body to be extreme is greater than that of women (such as to have significantly higher content of muscle than normal). Therefore, we consider p≈20 as a relatively accurate and controllable estimate valuein this paper. In addition, the similar value of p can be obtained by two different paths, reflecting the acceptable accuracy. At the end of this paper, we also proposes a possible method to optimize the cut-off points for male population, which may compensate for the low fitting of the linear regression among male population .

Because the values of IOI corresponding to the different standard of body fat obesity in men and women are different, once again it shows that previously the measurement of BMI may be misleading for it was initially introduced to measure the female body [9]. Comparing the new index of IOI with BMI, we find that the change of the difference between men and women will be controlled within 0.1, validating previous achievements as well as confirming the accuracy of the new index.

3.3 Correlation between IOI and Prevalence on Sample Population

We applied the IOI cut-off points(for female IOI=11.64，for male IOI=12.98) to statistical sample population and obtained results shown on Table 4.

Table 4 ： The statistics of the prevalence of diabetes in **IOI** non-obese / **obese population**

category	normal		obesity	
	Number	percentage	Number	percentage
diabetes	42	4.90%	118	8.79%
IGT	3	0.35%	17	1.27%
normal	813	94.76%	1207	89.95%
Total	858	100.00%	1073	100.00%

We could find from above table that the prevalence of diabetes and IGT (Impaired glucose tolerance is a pre-diabetic state of hyperglycemia that is associated with insulin resistance and may precede type 2 diabetes mellitus by many years [15].) in overweight/obese population is nearly twice high as the prevalence in normal body population, which corresponds to the calculation by the standard of BFP. Therefore the new index, IOI is accurate and reliable in the estimate of the prevalence in statistical sample population.

However, among the IOI defined obese population there are 483 people whose BMI are within normal range, and 42 people out 483 are diabetic. The diabetes prevalence of this group is8.7%, consistent to the incidence of diabetes in obese population, which is significantly higher than that in non-obese population.The above analysis so in the special individual the new index will compensate for the lack of common obesity standard in some extent, namely there are advantages for new index in individual applications.

To further analyze the advantages of the new index in the individual applications, in this paper we select two representative groups of individuals from the database for detailed analysis (Table 5 and Table 6):

Table 5：Part of the sampling data 1

	height（cm）	weight（kg）	BMI	waist（cm）	hip（cm）	WHR	BFP（%）	IOI（δ）
Individual 1	166	67	24.3	77	99	0.778	26.8	12.4
Individual 2	175	75	24.5	81	104	0.779	23.4	12.5
Individual 3	165	66	24.3	75	94	0.799	22.3	12.6
Individual 4	162	63	24.1	74	91	0.813	25.6	12.6
Individual 5	164	65	24.2	80	99	0.808	20.5	12.6
Individual 6	170	70	24.2	80	98	0.816	22	12.7
Individual 7	158	61	24.4	78	97	0.804	17.8	12.7
Individual 8	161	63	24.1	80	96	0.833	22.3	12.8
Individual 9	173	72	24.1	85	102	0.833	23.2	12.8
Individual 10	164	67	24.8	78	98	0.796	21.6	12.8
Individual 11	170	70	24.2	72	86	0.837	15.3	12.8
Individual 12	166	67	24.4	89	107	0.832	24.3	12.9
Individual 13	174	74	24.6	83	101	0.822	25.0	12.9
Individual 14	161	62	24.1	82	96	0.854	24.2	12.9
Individual 15	170	70	24.2	78	92	0.848	27.0	12.9
Individual 16	174	73	24.1	83	97	0.856	19.9	12.9
Individual 17	174	75	24.8	83	102	0.814	27.1	13.0
Individual 18	172	74	24.9	84	104	0.808	19.5	13.0

The examples are IOI-defined normal Asian BMI-defined overweight, among whom there is only one diabetic patient, and the group incidence is about 5.5%, consistent to prevalence among normal people. Further analysis finds that examples above are individuals with comparatively smaller WHR and BFP value. One educated guess is that due to frequent exercise or congenital factors, their body contain more muscle than most people. Clinically, with the application of IOI,the examples above should be analyzed individually instead of being suggested to be on diet or lose weight arbitrarily, which reflects the advantage of IOI in the diagnosis of obesity for individual applications in one aspect.

Similarly, we also have selected some examples from the obese population based on IOI (Table 6):

Table 6：Part of the sampling data 2

	height（cm）	weight（kg）	BMI	waist（cm）	hip（cm）	WHR	BFP（%）	IOI（δ）
Individual 19	148	50	22.7	76	94	0.809	30.6	11.8
Individual 20	152	52	22.4	84	90	0.934	34.4	12.6
Individual 21	164	63	23.3	89	96	0.927	28.4	13.1
Individual 22	156	55	22.8	82	93	0.881	31	12.4
Individual 23	163	62	23.1	80	95	0.842	29.7	12.3
Individual 24	162	60	23	79	89	0.888	31.3	12.6
Individual 25	149	52	23.2	82	95	0.863	33.4	12.5
Individual 26	159	59	23.3	73	89	0.820	33.2	12.2
Individual 27	159	59	23.3	75	90	0.833	33.6	12.3
Individual 28	163	62	23.3	76	91	0.835	30.7	12.3
Individual 29	164	63	23.3	89	96	0.927	28.4	13.1

The above examples are IOI-defined obese and BMI-defined normal diabetic patients.A thorough analysis of their physical index finds that the relatively small body sizes of the examples directly results in the small value of their BMI, despite the fact that their BFP, waist and hip value are significantly higher than normal people, which all correspond to their IOI value. An intersecting fact is that their IOI values are even greater than those of the previous table. Therefore, the application of IOI will also benefit obese people with small body sizewhich reflects the advantage of IOI in the diagnosis of obesity for individual applications in another aspect.

In the database, the application of IOI on 29 individuals out of 2202 fully demonstrates the absolute advantage for the primary obesity assessment of individuals; In other words, one out of every 40 borderline cases (individuals who are BMI-defined obese and WHR-defined normal or vice versa) will directly benefit from the application and promotion of IOI. The above analysis shows that the values of IOI are of science and accuracy for individual with significant advantage over the use of BMI or WHR alone. The application and promotion of IOI among people who are borderline cases or with special body type will compensate for the deficiencies of currently used common obesity standard to some extent.

3.4 Misjudgment Probability and Correction Analysis

In the previous analysis the paper demonstrates that the accuracy of IOI is similar to BMI in the application among sample population, which indicates that the two are equally feasible and worthy of promotion for demographic or epidemiological use. The following analysis of misjudgment probability and correction of IOI and other obesity index will demonstrate the new index's superiority over the existing ones.

Analysis and comparison of the misjudgment probability of obesity indexes:

We use BFP define absolute obesity and calculate the following probabilities:

A= {BFP-defined obese individuals}; B= {obese individuals defined by other indexes}

P_1 can be considered as the probability of underlying obese individuals, and P_2 van be considered as normal people misjudged as obese by either IOI, BMI, or WHR, namely P_1 is negatively correlated to the enlargement of obese population, and P_2 is positively correlated to the enlargement of the obese population. The main purpose of proposing IOI is to raise the public attention towards obesity and possibly reduce the incidence of diabetes and metabolic syndromes caused by underlying obesity, we design IOI with a smallest possible P_1 value and a comparatively small P_2 value.

Use Matlab to calculate P_1 and P_2 for BMI:

Male: $P_1 = 0.8806$, $P_2 = 0.0758$

Female: $P_1 = 0.8944$, $P_2 = 0.0460$

Thus, there will be 90% obese patients remainundetected under the application of BMI.

Similarly, use Matlab to calculate P_1 and P_2 for IOI:

Male: $P_1 = 0.1466$, $P_2 = 0.2063$

Female: $P_1 = 0.0929$, $P_2 = 0.1262$

We notice that P_2 elevates slightly while P_1 declines significantly. Thus, 90% obese patient CAN be found by IOI while the total number of defined obese population remains the same with BMI. Hereby, IOI demonstrates its superiority over BMI with significantly smaller misjudgment probability.

As previously mentioned, because all obesity standards were initially introduced for female, male demonstrates both a low fitting of the linear regression and extreme tendencies in data analysis. To improve the accuracy of IOI's application in male, the paper proposes a possible methodby utilizing the same practice of calculating the misjudgment possibility to optimize the cut-off points for male population. The application of this method may be limited and needs further analysis due to its large dependence on the demographic data of sample population.

Since the linear regression between IOI and BFP with a comparatively low accuracy has already be obtained and thoroughly analyzed, the improving process is mainly based on the cut-off points derived from the linear regression as stated before (namely IOI>=12.96 represents obesity in male). Hence, we calculate the values of P1 and P2 in the region of [12, 14] at 0.01 intervals. Accomplishing the process by inputting data into Matlab program, wefind a pair of value for P1 and P2 within which the possibility of misjudgment are comparable to that in female, labeling the corresponding IOI value as the more accurate, improved cut-off point.

We get from Matlab as follow:

when IOI=12.44, P1 in male is most close to P1 in female;

when IOI=13.38, P2 in male is most close to P2 in female.

Thus, we could conclude that the accurate boundary in male should be in the range of [12.44, 13.38] based on different need for significance in P1 and P2. In this paper, we consider the misjudgment of IOI in male to be less as the boundary approaches 12.44 due to the purpose of including as much obese individual in the IOI-based obese group as possible, namely P1 overweigh P2.

In a larger range of samples, the new index presents even more significant performance in accuracy and constancy way ahead common obesity indexes. At the same time the new index plays an efficient and high-accuracy role when correcting the erroneous judgments made from common obesity index, which is incapable for such evaluation. Therefore, the following section would filter out several groups of data for analysis and comparison:

1）With individual's BMI<30 and BFP>=30%（for male BFP>=25%), this group stays out of exact evaluation of the degree of obesity by BMI. In the database, 148 female individuals are consistent with this standard, 99 of those are in the catalog of IOI>=11.64, which reaches the limits of obese for women. The percentage for female individual who can be successfully identified by IOI among them who fail to be accurately evaluate by BMI is 99/148≈66.89%; On the other hand, 48 male individuals are in the range of inconsistency between the standard of BMI and BFP, 7 of them whose IOI>=12.976, reach the IOI male limit of obese. The adjusted accuracy of new index from BMI is 14.58%. Though seemingly not as significant, as we mentioned previously, males are not suitable for the majority of obesity standards. A relatively diminutive percentage for male is also constant for the previous magnitude of p≈ 20.

Similarly, to individuals with BMI>=30 and BFP<30%（for male BFP<25%), the new index is also affective. The size of male sample corresponding to the above standard is not abundant enough from being negligible, it would not be discussed since the space of this paper is limited.

2）With individual's WHR<0.85 and BFP>=30%（for male WHR<0.9 and BFP>=25%), this group stays out of exact evaluation of the degree of obesity by WHR. The percentage for female individual who can be successfully identified by IOI among them who fail to be accurately evaluate by WHR is 69/144≈47.92%. Similarly, the statistics for male is 16.67% in this case, also relatively bantam.

Likewise, in 40 female individual whose WHR>0.85 and BFP<30%, 22 are with a IOI<=11.64, giving a correction rate of 55%; in 21 male individuals whose WHR>0.9 and BFP<25%, 20 are with a IOI<=12.976, giving a correction rate of 95.24%.

The conclusion establishes as following:

First, for relatively lower content of fat in male, the IOI correction percentage results extreme statistics. The trend could be an inspiration for the future application of IOI: even if the waist-hip ratio of male (most males are middle-aged and abdominal obesity) is mildly higher, they do not belong to obese population in some extent, and the new index would be an effective way for their verification of their body status.

Secondly, the individuals selected are mostly with abdominal obesity in paragraph (1), among which vast majority of female individual can be corrected by IOI-BMI misjudgment correction, and a relative limit for correction of male not only shows IOI's value for abdominal obesity, but also proves the abdominal trend in obesity of male would not change the degree of obesity in some extent.

At last, the individuals selected in paragraph (2) are mostly not abdominal obese. According to statistics, the new index also holds a significant accuracy for determination of non-abdominal obesity.

Chapter 4CONCLUSION AND OUTLOOK

This paper proposesan **Integrated Obesity Index** (IOI) based on height, weight, waist and hip circumference, physical indicators that can be accessed through regular physical examinations, on top of the common obesity standards, including Body Mass Index (BMI), Waist-Hip Ratio (WHR), and Body Fat Percentage (BFP). IOI is aimed to be feasible and convenient under application, as well as comprehensive, compensating for the limitations of common obesity standards to some extent. Based on this idea, this paper proposes the application formula of the IOI($IOI = BMI \times \left[\frac{5}{39(WHR^2 + WHR)} + \frac{1}{3}\right]$) by establishing geometric model of human body and elaborates the deduction process. Then, this paper uses the latest epidemiological survey data of Jiangsu Province and introduces physical indexes, such as gender, BFP and other variables into the model for data analysis makes linear regressions on the images. Based on the intersection of the fitting curve of body fat percentage and the linear regressions, the standard cut-off points of Integrated Obesity Index (IOI) has been obtained: If male≥12.98 and female≥11.64 they are obese.

By applying the standard to sample population for the analysis and comparison of prevalence, this paper shows that the accuracy of IOI is similar to BMI in the application amongsample population, which indicates that the two are equally feasible and worthy of promotion for demographic or epidemiological use. Although statistically IOI does not show significant superiority over BMI on group population, it displays remarkable advantages for the primary obesity assessment of individuals in following aspects: Firstly，the method of IOI measurement is simple, which does not require blood tests or underwater weighing. Secondly, he value of IOI index demonstrates a closer correlation with BFP compared to BMI and WHR, which indicates that IOI can make more representative prognosis on the prevalence of diabetes and metabolic syndromes. Thirdly, by comparing the misjudgmentprobability and correction significance of IOI with common obesity index, we demonstrates the advantages thoroughly, and propose a possible solution for the low fitting regression on male population. Thus, this paper concludes that the future application and promotion of IOI will compensate for the deficiencies of currently used common obesity standard to some extent.

On the basis of this paper, future studies may bring other potentially relevant variables, including age, race, familial inheritance, the content of visceral fat and living habit into the model for more detailed analysis.In addition,a correction factor may be considered to add to the formula to improve the accuracy of both common obesity standards and IOI in the application of male population.

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Appendix

Calculation code of Matlab

a). Linear Regression

```
% Linear regression between BFP and δ：

F=xlsread('work\female')；
M=xlsread('work\male')；

% Making a linear regression between IOI and BFP in women：
x1=F(:,231)；% IOI
y1=F(:,201)；%BFP
[B,BINI,R,RINI,STATS]=regress(y1,[ones(length(x1),1),x1])；

% Making the image of linear regression and the scatter of data：
x=0:25；
y=B(1)+B(2)*x；
figure
plot(x,y)；
hold on；
scatter(x1,y1)；
% Making the image of boundary line：
plot([0,25],[30,30]);
% Making the intersection of the boundary line and the regression line：
aa=solve('y=30','y=B(1)+B(2)*x');
[aa.x,aa.y];

% Making a linear regression between IOI and BFP in men：
x2=M(:,231);
y2=M(:,201);
[B,BINI,R,RINI,STATS]=regress(y2,[ones(length(x2),1),x2]);
% Making the image of linear regression and the scatter of data：
x=0:25;
y=B(1)+B(2)*x;
plot(x,y);
hold on;
scatter(x2,y2);
% Making the image of boundary line：
plot([0,25],[25,25]);
```

```
% Making the intersection of the boundary line and the regression line：
aa=solve('y=25','y=-B(1)+B(2) *x');
[aa.x,aa.y];



% Linear regression between BFP and BMI：
F=xlsread('work\female');
M=xlsread('work\male');


x1=F(:,187); %BMI
y1=F(:,201);%BFP
[B,BINI,R,RINI,STATS]=regress(y1,[ones(length(x1),1),x1]);

x=0:50;
y= B(1)+B(2)*x;
plot(x,y);
hold on;
scatter(x1,y1);
plot([0,25],[30,30]);
aa=solve('y=30','y=B(1)+B(2)*x');
[aa.x,aa.y];


x2=M(:,187);
y2=M(:,201);
[B,BINI,R,RINI,STATS]=regress(y2,[ones(length(x2),1),x2]);
x=0:50;
y=B(1)+B(2)*x;
plot(x,y);
hold on;
scatter(x2,y2);
plot([0,25],[25,25]);
aa=solve('y=25','y=B(1)+B(2) *x');
[aa.x,aa.y];
```

b). Calculation of Probability

```
%Probability of BMI on male
function y=myfun(beta)
M=xlsread('work\male');
a=find(M(:,5)>=beta);
b=find(M(:,13)>=25);
```

```
p1=length(setdiff(b,a))/length(b);
p2=length(setdiff(a,b))/length(a);
y=[p1,p2];

y=myfun(30)

y =

    0.8806    0.0758



%Probability of IOI on male
function y=myfun(beta)
M=xlsread('work\male');
a=find(M(:,12)>=beta);
b=find(M(:,13)>=25);
p1=length(setdiff(b,a))/length(b);
p2=length(setdiff(a,b))/length(a);
y=[p1,p2];

y=myfun(12.97)

y =

    0.1644    0.2063



%Probability of BMI on female
function y=myfun(beta)
F=xlsread('work\female');
a=find(F(:,5)>=beta);
b=find(F(:,13)>=25);
p1=length(setdiff(b,a))/length(b);
p2=length(setdiff(a,b))/length(a);
y=[p1,p2];

y=myfun(30)

y =

    0.8944    0.0460
```

```
%Probability of IOI on female
function y=myfun(beta)
F=xlsread('work\female');
a=find(F(:,12)>=beta);
b=find(F(:,13)>=25);
p1=length(setdiff(b,a))/length(b);
p2=length(setdiff(a,b))/length(a);
y=[p1,p2];

y=myfun(11.64)

y =

    0.0929    0.1262
```

```
%IOIoptimizing on male
%myfun program
function y=myfun(m,beta)

a=find(m(1,:)>=beta);
b=find(m(2,:)>=25);
p1=length(setdiff(b,a))/length(b);
p2=length(setdiff(a,b))/length(a);
y=[p1,p2];

%count for varying values
count=0;
p=[];
M=xlsread('male');
m=[M(:,12)    M(:,13)]';
for beta=12:0.01:14
    count=count+1;
    p(count,:)=myfun(m,beta);
end
```

%Matlab feedback of optimizing IOI cut-off points on male：

P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
0.0626	0.2872	0.0920	0.2528	0.1487	0.2120	0.2192	0.1739	0.2818	0.1344
0.0646	0.2866	0.0939	0.2520	0.1487	0.2120	0.2192	0.1705	0.2857	0.1351
0.0665	0.2849	0.0939	0.2520	0.1487	0.2120	0.2231	0.1712	0.2857	0.1351
0.0665	0.2838	0.0939	0.2508	0.1487	0.2105	0.2231	0.1677	0.2896	0.1337
0.0705	0.2814	0.0939	0.2484	0.1487	0.2091	0.2250	0.1663	0.2896	0.1337
0.0705	0.2814	0.0939	0.2472	0.1507	0.2080	0.2270	0.1667	0.2896	0.1337
0.0705	0.2792	0.0998	0.2484	0.1507	0.2080	0.2309	0.1656	0.2896	0.1337
0.0763	0.2794	0.1057	0.2484	0.1585	0.2096	0.2309	0.1638	0.2896	0.1337
0.0763	0.2772	0.1076	0.2475	0.1605	0.2085	0.2348	0.1645	0.2896	0.1316
0.0763	0.2772	0.1076	0.2475	0.1624	0.2089	0.2387	0.1652	0.2896	0.1295
0.0763	0.2761	0.1076	0.2475	0.1624	0.2074	0.2387	0.1616	0.2975	0.1244
0.0763	0.2738	0.1076	0.2450	0.1644	0.2063	0.2407	0.1602	0.2994	0.1247
0.0783	0.2731	0.1135	0.2463	0.1663	0.2037	0.2427	0.1587	0.3014	0.1229
0.0783	0.2720	0.1135	0.2463	0.1761	0.1981	0.2446	0.1590	0.3053	0.1213
0.0783	0.2720	0.1174	0.2458	0.1761	0.1981	0.2446	0.1572	0.3053	0.1169
0.0783	0.2709	0.1174	0.2395	0.1761	0.1981	0.2485	0.1579	0.3053	0.1147
0.0783	0.2709	0.1174	0.2382	0.1781	0.1969	0.2485	0.1579	0.3112	0.1156
0.0783	0.2698	0.1174	0.2382	0.1820	0.1977	0.2485	0.1579	0.3151	0.1162
0.0802	0.2691	0.1174	0.2382	0.1820	0.1977	0.2485	0.1579	0.3151	0.1162
0.0802	0.2691	0.1174	0.2382	0.1840	0.1919	0.2485	0.1542	0.3190	0.1168
0.0802	0.2656	0.1213	0.2377	0.1840	0.1903	0.2485	0.1504	0.3190	0.1168
0.0802	0.2656	0.1213	0.2364	0.1898	0.1898	0.2505	0.1470	0.3190	0.1145
0.0802	0.2656	0.1233	0.2355	0.1898	0.1882	0.2505	0.1470	0.3190	0.1145
0.0802	0.2645	0.1233	0.2329	0.1898	0.1882	0.2524	0.1473	0.3229	0.1151
0.0802	0.2645	0.1233	0.2329	0.1937	0.1874	0.2544	0.1438	0.3249	0.1154
0.0802	0.2645	0.1252	0.2320	0.1937	0.1874	0.2564	0.1422	0.3288	0.1091
0.0802	0.2645	0.1272	0.2310	0.1937	0.1874	0.2564	0.1422	0.3346	0.1099
0.0802	0.2633	0.1272	0.2310	0.2016	0.1889	0.2603	0.1429	0.3366	0.1102
0.0802	0.2610	0.1272	0.2297	0.2016	0.1889	0.2603	0.1429	0.3425	0.1111
0.0802	0.2610	0.1272	0.2297	0.2035	0.1876	0.2661	0.1438		
0.0802	0.2598	0.1292	0.2288	0.2035	0.1860	0.2701	0.1445		
0.0802	0.2598	0.1311	0.2251	0.2035	0.1844	0.2701	0.1445		
0.0802	0.2598	0.1311	0.2251	0.2035	0.1844	0.2701	0.1425		
0.0802	0.2587	0.1311	0.2251	0.2055	0.1831	0.2701	0.1425		
0.0802	0.2587	0.1370	0.2250	0.2074	0.1802	0.2720	0.1409		
0.0802	0.2587	0.1370	0.2236	0.2133	0.1813	0.2740	0.1412		
0.0802	0.2563	0.1389	0.2199	0.2133	0.1813	0.2779	0.1419		
0.0802	0.2563	0.1389	0.2199	0.2133	0.1813	0.2779	0.1419		
0.0802	0.2540	0.1389	0.2185	0.2133	0.1796	0.2798	0.1422		
0.0802	0.2540	0.1448	0.2168	0.2133	0.1779	0.2798	0.1422		
0.0822	0.2544	0.1448	0.2168	0.2133	0.1762	0.2798	0.1402		

0.0881	0.2520	0.1448	0.2168	0.2192	0.1739	0.2818	0.1385
0.0900	0.2524	0.1487	0.2134	0.2192	0.1739	0.2818	0.1365