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Circumcenter of centroid of fuzzy number for identifying risk factors of obesity: a qualitative evaluation

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Abstract Obesity and its associated health problems have been considered as a burden to health care providers where treatment may incur tremendous loss of public fund. Recent studies reveal that authentic factors contributed to obesity are very much inconclusive. Magnitude of risks for each factor remains unknown. This paper aims to propose risk values for the selected risk factors contributed to the development of obesity using an approach of ranking fuzzy number. The method of ranking fuzzy numbers based on circumcenter of centroid is proposed. The proposed model, which takes into account spread, area, and distance of trapezoidal fuzzy numbers was implemented to the case of obesity. Three experts were invited to provide qualitative linguistic evaluation over the importance of risk factors toward development of obesity. The risk values obtained from the proposed method unveiled that the factor of family history is the highest risk factor followed by sedentary life style. The results also indicate that gender is lowest risk factor. An implication for the general public is that the importance of knowing the status of family history and also the awareness in practising healthy life style.

Keywords Obesity · Trapezoidal fuzzy numbers · Risk factor · Qualitative linguistic evaluation

1 Introduction

Obesity is a common public health problem that normally associated with a number of health related complications. Diabetes, hypertension, cardiovascular diseases are among the common complications of obesity (WHO 1998). It has been known as global epidemic

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(WHO 2000) where these problems are common especially among developed and higher income countries. The prevalence of obesity continues to remain low in many lower income countries (Kelishadi 2007). Obesity and its associated diseases signify great burden for policy-makers and healthcare providers. It would incur enormous cost in managing high-incidence of obesity-related health complications. In other words, management of the obesity epidemic is not only escalating in terms of money spending but also brings serious problems to society at large. It has been discussed in many literature that several tangible and intangible key factors may contribute to the development of obesity. One of the commonly discussed factors is people lifestyle. Development in technology and economics that have been thriving nowadays gives a profound impact on a country's population life style. Despite of providing amenities to people, the development also has a negative impact due to improper practice. Today's lifestyle which depends too much on technological facilities drives a significant impact on human health, physically and mentally. This is especially true among developed and developing societies where daily activities are no longer rely on physical endeavor to earn living (Abdullah and Azman 2011). Advances in telecommunication and transportation have minimize the needs for physical activity. Due to physically inactive lifestyle, modern life has becoming increasingly sedentary and has been associated with an increased risk of obesity. This statement is supported by a long time research conducted by Martínez-González et al. (1999) where obesity and higher body weight were strongly associated with a sedentary lifestyle and lack of physical activity in a case of adult population. Thibault et al. (2010) pointed out that physical activity is determined from the number of weekly hours the adolescents are reported doing exercises or sports. Lack in physical activities will likely to burn fewer calories from what we eat each day, thus increasing the risk of becoming obese.

Other than physical activity and sedentary lifestyle, psychological factors may also contribute to obesity diseases. Psychology can influence eating habits because many people eat excessively in response to emotions such as boredom, sadness, stress or anger. Zellner et al. (2006) reported that negative emotions not only increases consumption of food but also shifts consumption toward high caloric foods that are normally avoided. Gender may play an important role in the development of obesity based on psychological and physical differences between male and female (Sweeting 2008). According to WHO (2012), women's obesity is significantly higher than men's obesity. Thus, women are more likely to be obese as compared to men. This statement has been supported by a study in Saudi Arabia where the risk of obesity is especially alarming among Saudi women (Alsaif et al. 2002). Moreover, a study by Puoane et al. (2002) also shows that in South Africa, urban African females have the highest prevalence of obesity. Del et al. (2002) stated that females have a higher prevalence of obesity compared to males is related to gender differences in the brain's response to hunger and satiety. Furthermore, body composition factors such as hormone changes during puberty have shown to influence the risk of obesity in females. Family history or genetic is another biggest factors that can significantly influence obesity. A person is more likely to develop obesity if one or both parents are obese. Garn and Clark (1976) found that the offspring of two obese parents had an 80 per cent chance of becoming obese compared with a less than 10 per cent chance for the offspring of two lean parents. By using Body Mass Index (BMI) as a fatness measure, Guillaume et al. (1995) also showed strong correlations in body fatness between children and both parents as well as grandparents in their study of Belgian-Luxemborg Child Study. Bella and Lucchini (2014) also conducted an obesity study in Italy and the result clearly confirm the importance of genetic factors in explaining inter-individual differences in BMI. Certain physical and mental illnesses and the pharmaceutical substances that are used for treatment can increase the risk of obesity. Some medical problems can lead to decrease in activity, which may result in weight gain. For example, several rare genetic syndromes and night eating syndrome may increase obesity risk. The factor of medication that may cause weight gain was supported by research conducted by Haslam and James (2005). They asserted that weight gain is caused by changes in body composition which include insulin, steroids and some forms of hormonal contraception.

Many studies has been conducted worldwide to investigate various risk factors that related to development of obesity. Several approaches have been employed to search for conclusive risk factors of obesity and also association of obesity and risk factors. Zou et al. (2005), for example, investigated the incidence of overweight and obesity and probing the affecting factors of overweight in Liuzhou city, China. They employed logistic stepwise regression analysis using data of the diabetic incidence rate from 1994 to 1999 to identify risk factors of obesity. They singled out that BMI was the risk factor of the incidence of overweight and obesity. However, this study does not provide magnitude or quantitative value of BMI. De Fonseca et al. (1998) assessed the obesity prevalence and associated factors in middle class adolescents of a school in the city of Niteroi, Rio de Janeiro, Brazil. They applied simple descriptive statistics of frequencies and percentages to identify eating habits, parents anthropometric characteristics, physical activity and other factors associated with obesity. The result show that BMI appear to be a good indicator of obesity among adolescents. In another study, Peltzer and Pengpid (2011) employed unconditional logistic regression analyses to assess the relationship between dietary behavior, substance use, physical activity, psychosocial factors and overweight or obesity. In a study at Czech Republic, Kunesova et al. (2007) analyzed the changes in overweight and obesity prevalence and the influence of socioeconomic status and parental obesity on overweight and obesity of children and adolescents using Pearson's Chi square test and by linear regression analysis with backward factor reduction. Harijono et al. (2013) employed multivariate regression analysis to determine the prevalence of overweight and obesity in adolescents and to identify the risk factors in Indonesia. These reviews show that most of the research are depended on quantitative statistical analysis in identifying the risk factors of obesity. Although extensive researches have been conducted by numerous researchers over the risk factors that lead to obesity, little attention has been given to investigate which factor is important than the others. In other words, the degree of importance or value of the risk factors contribute to development of obesity is rarely measured.

In contrast to the quantitative statistical analyses, this paper employs a qualitative new center- based method of ranking fuzzy numbers is proposed and tested on a case of measuring risk factors of obesity. Ranking fuzzy numbers play an important role in many applications including decision making, optimization, fuzzy control and statistics with imprecise probabilities (Klir and Yuan 1995). Abdullah and Ahmad (2011), for example, applied a method of ranking fuzzy numbers to ranking four chocolate cakes according to five attributes. Very recently, Duzce (2015) proposed a new method for ranking trapezoidal fuzzy numbers and applied it to fuzzy risk analysis problem. In application of decision making, Zhang et al. (2014), proposed new method for comparing fuzzy numbers based on a fuzzy probabilistic preference relation. Chen and Hwang (1992) made a comprehensive description of ranking fuzzy numbers and its application in decision making. Akyar et al. (2013) presented a new method for ranking generalized trapezoidal fuzzy numbers based on the incenter and inradius of a triangle and applied it to risk analysis. Differently from these previous studies, this paper aims to propose a circumcenter of centroid method in ranking fuzzy numbers. Risk factors of obesity is subsequently measured using the proposed method. The paper is organised as follows. Section 2 elucidates the basic concepts of fuzzy numbers. A new circumcenter of centroid for fuzzy numbers is proposed in Sect. 3. The implementation of the new circumcenter of centroid for fuzzy numbers to the case of risk factors of obesity is presented in Sect. 4. Section 5 concludes.

2 Preliminaries

The concept of fuzzy numbers were first investigated by Chang and Zadeh (1972). Such concepts are prominent in characterizing fuzzy variables. Fuzzy numbers can be viewed as a subset from the real numbers set and represent uncertain values. Fuzzy numbers are also known as fuzzy sets on the set $\Re$ of real numbers which the membership functions of A is written as $A : \Re \to [0, 1]$. Fuzzy numbers and types of fuzzy numbers are defined in the following definitions.

Definition 1 *Fuzzy Numbers* (Chu and Tsao 2002a, b) A fuzzy number $\tilde{A}$ is described as any fuzzy subset of the real line $\Re$ with membership function $f_{\tilde{A}}$ which processes the following properties:

(i) $f_{\tilde{A}}$ is a continuous mapping from $\Re$ to the closed interval $[0, w]$, $0 \le w \le 1$.
(ii) $f_{\tilde{A}}(x) = 0$, for all $x \in (-\infty, a]$.
(iii) $f_{\tilde{A}}$ is strictly increasing on $[a, b]$.
(iv) $f_{\tilde{A}}(x) = w$, for all $x \in [b, c]$, where w is constant and $w \in (0, 1]$.
(v) $f_{\tilde{A}}$ is strictly decreasing on $[c, d]$.
(vi) $f_{\tilde{A}}(x) = 0$, for all $x \in [d, \infty)$, where a, b, c, d are real numbers.

It is assumed that $\tilde{A}$ is convex and bounded for such $-\infty < a, d < \infty$. If $w = 1$, in (iv), $\tilde{A}$ is a normal fuzzy number, and if $0 < w < 1$, in (d), $\tilde{A}$ is a non-normal fuzzy number. The fuzzy numbers can be denoted by $\tilde{A} = (a, b, c, d; w)$ while the image of that fuzzy numbers can be given by $-\tilde{A} = (-d, -c, -b, -a; w)$. The membership function of $f_{\tilde{A}}$ can be expressed as

$$f_{\tilde{A}}(x) = \begin{cases} f^l_{\tilde{A}}(x), & a \le x \le b \\ w, & b \le x \le c \\ f^r_{\tilde{A}}(x), & c \le x \le d \\ 0, & \text{otherwise} \end{cases} \tag{1}$$

where $f^l_{\tilde{A}} : [a, b] \to [0, w]$ and $f^r_{\tilde{A}} : [c, d] \to [0, w]$. Since $f^l_{\tilde{A}}$ and $f^r_{\tilde{A}}$ are continuous and strictly increasing and decreasing respectively, then inverse function of $f^l_{\tilde{A}}$ and $f^r_{\tilde{A}}$ can be denoted by $g^l_{\tilde{A}}$ and $g^r_{\tilde{A}}$ respectively. Since $g^l_{\tilde{A}}$ and $g^r_{\tilde{A}}$ are continuous on $[0, w]$ so they are integrable on $[0, w]$. That is, both $\int_0^w g^l_{\tilde{A}} dy$ and $\int_0^w g^r_{\tilde{A}} dy$ exist (Dubois and Prade 1983).

A fuzzy number $\tilde{A}$ is convex if

$$\mu_A(\lambda x_1 + (1 - \lambda)x_2) \ge \min\{\mu_A(x_1), \mu_A(x_2)\}, \quad x_1, x_2 \in X, \lambda \in [0, 1]$$

Convexity of fuzzy number is defined with reference to the membership function (Zimmermann 2001). A trapezoidal fuzzy number is represented by using four real numbers $a < b < c < d$ (Duraisamy and Usha 2010). The base of the trapezoid is the interval $[a, d]$ along with the vertices at $x = b$ and $x = c$.

Definition 2 *Generalized Trapezoidal Fuzzy Number* (Chen 1985) Let $\tilde{A}$ be a generalized trapezoidal fuzzy number, $\tilde{A} = \left(a, b, c, d; w_{\tilde{A}}\right)$ as shown in Fig. 1, where a, b, c, d are real values, $w_{\tilde{A}}$ denotes the height of the generalized trapezoidal fuzzy number $\tilde{A}$, and $w_{\tilde{A}} \in [0, 1]$. If $0 \le a \le b \le c \le d \le 1$, then $\tilde{A}$ is called a standardized generalized fuzzy number.

The membership function of trapezoidal fuzzy number is defined as follow:

$$f_{\tilde{A}}(x) = \begin{cases} 0, & x < a \\ \dfrac{x-a}{b-a}, & a \le x \le b \\ 1, & b \le x \le c \\ \dfrac{d-x}{d-c}, & c \le x \le d \\ 0, & x > d \end{cases} \tag{2}$$

Assume that $\tilde{A}$ and $\tilde{B}$ are two generalized trapezoidal fuzzy numbers, where $\tilde{A} = \left(a_1, b_1, c_1, d_1; w_{\tilde{A}}\right)$ and $\tilde{B} = (a_2, b_2, c_2, d_2; w_{\tilde{B}})$. $a_1, b_1, c_1, d_1, a_2, b_2, c_2, d_2$ are real values and the interval of vertices are $0 \le w_{\tilde{A}} \le 1$ and $0 \le w_{\tilde{B}} \le 1$.

Definition 3 *Triangular Fuzzy Number* (Ban 2011) A fuzzy set $\tilde{A}$ on the universe of discourse U is described by a mapping $\tilde{A} : U \to [0, 1]$, where $\tilde{A}(x)$ is the membership degree of x. A triangular fuzzy number is a fuzzy set on the real line $\Re$ with the membership function given by

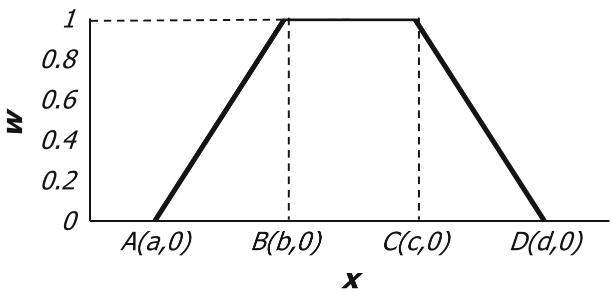
$$f_{\tilde{A}}(x) = \begin{cases} 0, & x < a \\ \dfrac{x-a}{b-a}, & a \le x \le b \\ \dfrac{c-x}{c-b}, & b \le x \le c \\ 0 & x > c \end{cases} \tag{3}$$

where $a, b, c \in \Re$, $a < b < c$ as shown in Fig. 2 and can be denoted as a triplet. The parameter b gives the most possible value of the evaluated data and a, c are the lower and upper bounds of the available area for the evaluated data.

Assume $\tilde{A}$ and $\tilde{B}$ are two triangular fuzzy numbers parameterized by the triplets $\tilde{A} = (a_1, b_1, c_1)$ and $\tilde{B} = (a_2, b_2, c_2)$ respectively.

The definitions of fuzzy numbers are predominantly used in the proposed method.

Fig. 1 A generalized trapezoidal fuzzy number $\tilde{A}$



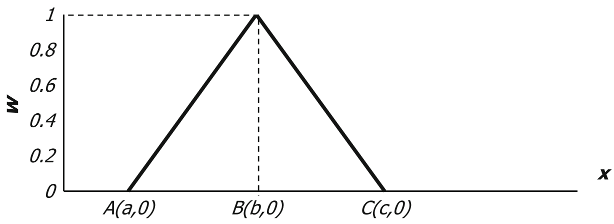


Fig. 2 A triangular fuzzy number $\tilde{A}$

3 Proposed computational method

In a trapezoid, centroid is considered as an equilibrium point that give a balancing to the trapezoid. The new method to derive a circumcenter of centroid is based on the illustration of trapezoidal fuzzy numbers. Figure 3 shows a trapezoid KNRS which are split into three parts of triangle. The centroid for each part of triangle is calculated and the combination of the centroid will generate a triangle. The circumcenter of centroid is derived from the new triangle's point using the computer algebra software, *Mathematica*. The new centroid for circumcenter $C = (x, y)$ is obtained as follows.

Since point P is located in between of point L and M, thus P is defined to be the midpoint of line LM with the point given is $((b + c)/2, 0)$. Based on Fig. 3, the centroids for each part of the trapezoid are denoted as:

$$T_1 = \left(\frac{2a + 3b + c}{6}, \frac{w}{3}\right) \tag{4}$$

$$T_2 = \left(\frac{b + c}{2}, \frac{2w}{3}\right) \tag{5}$$

$$T_3 = \left(\frac{b + 3c + 2d}{6}, \frac{w}{3}\right) \tag{6}$$

From the centroid of each triangle parts as above, the circumcenter of centroid for trapezoidal fuzzy numbers is defined as:

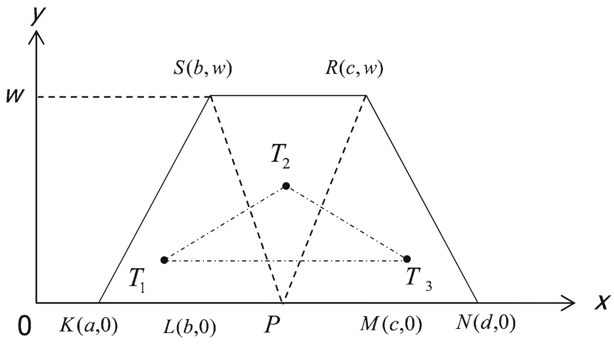


Fig. 3 A trapezoid of fuzzy numbers

$$C(x,y) = \left(\frac{a+2b+2c+d}{6}, \frac{a(d-b)+bc-cd+3w^2}{6w}\right) \tag{7}$$

As for the special case of triangular fuzzy numbers, where $c = b$, the circumcenter of centroid is given by

$$C(x,y) = \left(\frac{a+4b+d}{6}, \frac{a(d-b)+b^2-bd+3w^2}{6w}\right) \tag{8}$$

Based on the circumcenter of centroid obtained as above, the new proposed algorithm for ranking fuzzy numbers is executed according to the following steps:

Considers a trapezoidal fuzzy number $\tilde{A} = (a,b,c,d;w)$ where a, b, c and d are real numbers and w denotes the maximum membership value of the trapezoidal fuzzy number $\tilde{A}$ with $0 < w \leq 1$. The ranking fuzzy numbers can be done according to the following steps.

Step 1: Find w which indicates the minimum value in the given fuzzy numbers.

$$w = \min(w) \tag{9}$$

Step 2: Calculate circumcenter of centroid $C = \left(x_{\tilde{A}}, y_{\tilde{A}}\right)$ for each of trapezoidal fuzzy numbers by using Eq. (7).

Step 3: Calculate the distance which is the Euclidean distance between the circumcenter point and the original point using the equation as follow:

$$d_{\tilde{A}} = \sqrt{\left(x_{\tilde{A}}\right)^2 + \left(y_{\tilde{A}}\right)^2} \tag{10}$$

Step 4: Calculate the spread of the trapezoidal fuzzy numbers as below:

$$r_{\tilde{A}} = (d-a) \tag{11}$$

Step 5: Calculate the area of the trapezoidal fuzzy numbers by using the equation as given:

$$A_{\tilde{A}} = \frac{|(a+b-c-d)w|}{18} \tag{12}$$

Step 6: Calculate the ranking value $R_{\tilde{A}}$ of trapezoidal fuzzy numbers by the given equation as follow:

$$R_{\tilde{A}} = \frac{1}{3}\left[\left(2 \times d_{\tilde{A}} + r_{\tilde{A}}\right) \times w_{\tilde{A}} + A_{\tilde{A}}\right] \tag{13}$$

Information in Step 3, Step 4 and Step 5 is used to find ranking value in Step 6. It is an arithmetic mean of distance, spread and area. Each ranking value represents a specific trapezoidal fuzzy number.

However, ranking of any two fuzzy numbers is adhered to the following axioms.

Let $\tilde{A}_i$ and $\tilde{A}_j$ be two fuzzy numbers, then

(i) if $R(\tilde{A}_i) > R(\tilde{A}_j)$, then $\tilde{A}_i \prec \tilde{A}_j$,
(ii) if $R(\tilde{A}_i) < R(\tilde{A}_j)$, then $\tilde{A}_i \prec \tilde{A}_j$,
(iii) if $R(\tilde{A}_i) = R(\tilde{A}_j)$ then in this case, the discrimination of fuzzy numbers is not possible.

3.1 Illustrative example

In order to clarify the steps of the proposed method, a computation of the proposed algorithms is shown to rank fuzzy numbers. A numerical example from Chen and Chen (2009) is retrieved and applied in the new proposed method.

Assume that there are three trapezoidals of fuzzy numbers such that $\tilde{A} = (0, 0.4, 0.6, 0.8; 1.0)$, $\tilde{B} = (0.2, 0.5, 0.5, 0.9; 1.0)$ and $\tilde{C} = (0.1, 0.6, 0.7, 0.8; 1.0)$. The given fuzzy numbers is illustrated in Fig. 4.

Based on Fig. 4, the computations for circumcenter of centroid in ranking fuzzy numbers $\tilde{A}$, $\tilde{B}$ and $\tilde{C}$ are shown as follows.

Step 1: The heights for each of the given fuzzy numbers are similar which is $w = 1.0$. Thus the value for $w_{\tilde{A}} = w_{\tilde{B}} = w_{\tilde{C}} = 1.0$.

Step 2: By using the Eq. (7), the results for circumcenter of centroids are obtained as below:

$$C(x_{\tilde{A}}, y_{\tilde{A}}) = (0.4667, 0.46)$$

$$C(x_{\tilde{B}}, y_{\tilde{B}}) = (0.5167, 0.48)$$

$$C\left(x_{\tilde{C}}, y_{\tilde{C}}\right) = (0.5833, 0.48)$$

Step 3: The calculation for the Euclidean distance between the circumcenter point and the original point based on Eq. (10) shows the results as follows:

$$d_{\tilde{A}} = 0.6553$$

$$d_{\tilde{B}} = 0.7052$$

$$d_{\tilde{C}} = 0.7554$$

Step 4: Below are the results for the spread of trapezoidal fuzzy numbers using Eq. (11):

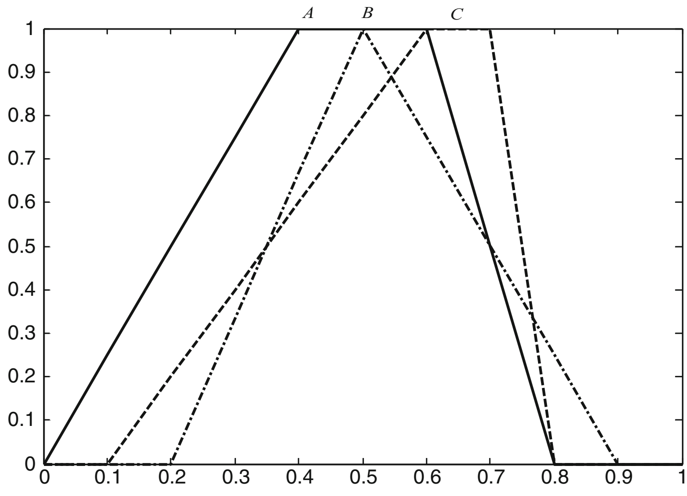


Fig. 4 Trapezoidal Fuzzy Numbers (Chen and Chen 2009)

$$r_{\tilde{A}} = 0.8$$

$$r_{\tilde{B}} = 0.7$$

$$r_{\tilde{C}} = 0.7$$

Step 5: Based on Eq. (12), the area for each fuzzy numbers acquired as follows:

$$A_{\tilde{A}} = 0.0556$$

$$A_{\tilde{B}} = 0.0389$$

$$A_{\tilde{C}} = 0.0444$$

Step 6: The ranking value of the trapezoidal fuzzy numbers for $\tilde{A}$, $\tilde{B}$ and $\tilde{C}$ are calculated using Eq. (13). Therefore, the following results are obtained:

$$R_{\tilde{A}} = 0.7220$$

$$R_{\tilde{B}} = 0.7164$$

$$R_{\tilde{C}} = 0.7518$$

It is clear that the results from the ranking value in Step 6 indicate that the ranking value for fuzzy number $\tilde{C}$ is greater than fuzzy number $\tilde{A}$ and $\tilde{B}$. Therefore, the ranking order for trapezoidal fuzzy numbers using the circumcenter of centroid is $\tilde{C} \succ \tilde{A} \succ \tilde{B}$.

3.2 Comparative analysis

In order to test the consistency of the proposed circumcenter of centroid, the method is now compared with the methods of other researchers. A comparison on ranking order between the proposed circumcenter of centroid and other researchers' methods is shown using numerical examples adopted from Rezvani (2012). Three sets of generalized trapezoidal fuzzy numbers are used to compare the proposed circumcenter of centroid with Cheng's (1998) method, Chu and Tsao (2002a, b) method, Abbasbandy and Hajjari's (2009) method, Rao and Shankar (2011) method, Shankar et al.'s (2012) method, Thorani et al.'s (2012) method and Rezvani's (2012) method. The three sets of trapezoidal fuzzy numbers are,

Set 1: $\tilde{A} = (0.2, 0.4, 0.6, 0.8; 0.35)$, $\tilde{B} = (0.1, 0.2, 0.3, 0.4; 0.7)$
Set 2: $\tilde{A} = (0.1, 0.2, 0.4, 0.5; 1.0)$, $\tilde{B} = (0.1, 0.3, 0.3, 0.5; 1.0)$
Set 3: $\tilde{A} = (0.1, 0.2, 0.4, 0.5; 1.0)$, $\tilde{B} = (1.0, 1.0, 1.0, 1.0; 1.0)$

Results from the calculation using the proposed method are presented in Table 1.

A comparative results between the proposed method and other researchers' methods are illustrated in Table 2.

The comparative results show that ranking of Set 1 from the proposed method is consistent with Rao and Shankar (2011), Shankar et al.(2012), and Thorani et al.(2012). The error results in Set 1, Set 3 and Set 6 respectively by Cheng (1998), Chu and Tsao (2002a, b) and Abbasbandy and Hajjari (2009) occurs when their methods failed to calculate the ranking value. Hence, the results are not comparable between fuzzy numbers. This result is possibly due to the introduction of height, distance, spread or area of fuzzy numbers to the proposed method.

Table 1 Ranking of three sets of trapezoidal fuzzy numbers using circumcenter of centroid

Set	Fuzzy numbers	Circumcenter		Distance (d_{FN})	Spread (r_{FN})	Area (A_{FN})	Ranking (R_{FN})
		x	y				
Set 1	A	0.5	0.0988	0.5097	0.6	0.0156	0.1941
	B	0.25	0.1560	0.2947	0.3	0.0078	0.1063
Set 2	A	0.3	0.4850	0.5703	0.4	0.0333	0.5246
	B	0.3	0.4933	0.5774	0.4	0.0222	0.5257
Set 3	A	0.3	0.4850	0.5703	0.4	0.0333	0.5246
	B	1.0	0.5000	1.1180	0.0	0.0000	0.7454

Table 2 Comparative results between the proposed method and other researchers' methods

Methods	Set 1	Set 2	Set 3
Cheng (1998)	$\tilde{A} < \tilde{B}$	$\tilde{A} \approx \tilde{B}$	Error
Chu and Tsao (2002a, b)	$\tilde{A} < \tilde{B}$	$\tilde{A} < \tilde{B}$	Error
Abbasbandy and Hajjari (2009)	Error	$\tilde{A} \approx \tilde{B}$	$\tilde{A} < \tilde{B}$
Rao and Shankar (2011)	$\tilde{A} > \tilde{B}$	$\tilde{A} < \tilde{B}$	$\tilde{A} < \tilde{B}$
Rezvani (2012)	$\tilde{A} < \tilde{B}$	$\tilde{A} > \tilde{B}$	$\tilde{A} > \tilde{B}$
Shankar et al. (2012)	$\tilde{A} > \tilde{B}$	$\tilde{A} > \tilde{B}$	$\tilde{A} < \tilde{B}$
Thorani et al. (2012)	$\tilde{A} > \tilde{B}$	$\tilde{A} > \tilde{B}$	$\tilde{A} < \tilde{B}$
Proposed method (Circumcenter)	$\tilde{A} > \tilde{B}$	$\tilde{A} < \tilde{B}$	$\tilde{A} < \tilde{B}$

To present the rationality and necessity, the proposed method is applied to the risk factors of obesity.

4 A case of risk factors of obesity

A committee of three experts has been identified and was invited to provide qualitative evaluation using linguistic variables pertaining obesity. The experts were interviewed in three different sessions in order to tap their evaluation regarding the factors that lead to obesity. The three experts were a medical officer of Klinik Balqis in Kuala Terengganu (D_1), a medical officer of Klinik Hafizah in Kuala Terengganu (D_2), and Medical officer of Klinik 1 Malaysia in Kuala Terengganu (D_3). Table 3 shows the personal profile of all the three experts. The experts are chosen based on their experience in the medical fields and obesity cases.

A case study of risk analysis in obesity using the proposed ranking trapezoidal fuzzy numbers based on centroid methods is performed. The task is to rank the factors with the

Table 3 Personal profiles of experts

No.	Position	Sector	Experience	Qualification	Length of service
1	Doctor	Private	5–9 years	MD	5–9 years
2	Doctor	Private	15 years and above	MD	15 years and above
3	Doctor	Government	5–9 years	MBBS	5–9 years

highest risk that lead to obesity. The selection of ten risk factors in this experiment is based on literature given in Sect. 1. Implementation in establishing the risk values of obesity risk factors is presented into two phases. The purpose of computation in Phase I is to obtain trapezoidal fuzzy numbers for each risk factor. Ranking values of risk factors are obtained through the computation is Phase II.

4.1 Phase I

Step 1: Construct a decision matrix

The decision-maker uses the nine linguistic scale developed by Patra and Mondal (2012). The linguistic terms data provided by the experts are shown in Table 4.

Step 2: Convert linguistic terms into trapezoidal fuzzy numbers

The data from Table 2 is converted into linguistic form where the linguistic terms are written as a trapezoidal fuzzy number. The representation of linguistic term is shown in Table 5.

By using the average formula in Eq. (14), a trapezoidal fuzzy number for each factor is calculated.

Table 4 Linguistic of decision matrix

Factors of obesity	D_1	D_2	D_3
Gender (A_1)	VL	H	L
BMI (A_2)	L	VH	H
Family history (A_3)	VH	VH	FL
Sedentary lifestyle (A_4)	AH	VH	M
Physical activity (A_5)	M	H	FL
Energy intake (A_6)	AH	VH	L
Psychological (A_7)	H	H	VL
Behavioral factor (A_8)	VH	H	FL
Medical illness (A_9)	FL	H	FH
Social determinants (A_{10})	FL	H	VL

Table 5 Representation of linguistic term

Linguistic term	Linguistic values trapezoidal fuzzy numbers
Absolutely low (AL)	(0,0,0,0;1.0)
Very low (VL)	(0.42,0.47,0.52,0.58;1.0)
Low (L)	(0.36,0.4,0.6,0.64;1.0)
Fairly low (FL)	(0.3,0.35,0.65,0.7;1.0)
Medium (M)	(0.24,0.29,0.71,0.76;1.0)
Fairly high (FH)	(0.18,0.23,0.78,0.82;1.0)
High (H)	(0.12,0.16,0.84,0.88;1.0)
Very high (VH)	(0.06,0.09,0.91,0.94;1.0)
Absolutely high (AH)	(0,0,1.0,1.0;1.0)

$$TFN_{D_{\tilde{A}n}} = \frac{D_1 + D_2 + D_3}{3}; \quad (14)$$

where $D_{\tilde{A}n}$ is the fuzzy numbers for each decision maker or expert.

The mean trapezoidal fuzzy numbers for every risk factor are listed in Table 6.

4.2 Phase II

The main computational steps leading to the risk values and ranking are given as follows.

Step 1: Calculate the height, *w*

Since the value of w for every trapezoidal fuzzy numbers are 1.0, therefore based on Eq. (9), the height for each factors are determined as $w_{\tilde{A}} = 1.0$.

Step 2: Calculate the center-based point

By using the centroids Eq. (7), the results for center-based methods are obtained. Table 7 presents the circumcenter for every risk factor.

Table 6 Trapezoidal fuzzy numbers for factors of obesity

Factors	Trapezoidal Fuzzy numbers
A_1	(0.3,0.3433,0.6533,0.7;1.0)
A_2	(0.18,0.2167,0.7833,0.82;1.0)
A_3	(0.08,0.1133,0.8867,0.92;1.0)
A_4	(0.10,0.1267,0.8733,0.9;1.0)
A_5	(0.22,0.2667,0.7333,0.78;1.0)
A_6	(0.14,0.1633,0.8367,0.86;1.0)
A_7	(0.22,0.2633,0.7333,0.78;1.0)
A_8	(0.16,0.2,0.8,0.84;1.0)
A_9	(0.2,0.2467,0.7567,0.8;1.0)
A_{10}	(0.28,0.3267,0.67,0.72;1.0)

Table 7 Center-based points for ranking factors of obesity

Factors	Circumcenter	
	x	y
A_1	0.4989	0.4790
A_2	0.5	0.4393
A_3	0.5	0.3915
A_4	0.5	0.4003
A_5	0.5	0.4561
A_6	0.5	0.4191
A_7	0.4989	0.4558
A_8	0.5	0.4317
A_9	0.5011	0.4487
A_{10}	0.4989	0.4744

Step 3: Calculate the distance

The calculation for the Euclidean distance between the center-based points and the original point using on Eq. (10). The results are shown in Table 8.

Step 4: Calculate the spread

Table 9 shows the results for the spread of trapezoidal fuzzy numbers using Eq. (11):

Step 5: Calculate the area

By using the Eq. (12), area for each fuzzy numbers obtained. It is presented in Table 10.

Step 6: Calculate the risk value

The risk value of the trapezoidal fuzzy numbers is calculated using Eq. (13). The results are presented in Table 11.

The risk value depicts the strength of the risk factors and its association with development of obesity.

The results of the risk value of obesity using the new proposed circumcenter of centroid method can be visualized Fig. 5.

Table 8 Euclidean distances for ranking factors of obesity

Factors	Distance (d_C)
A_1	0.6916
A_2	0.6656
A_3	0.6351
A_4	0.6405
A_5	0.6768
A_6	0.6524
A_7	0.6757
A_8	0.6606
A_9	0.6726
A_{10}	0.6885

Table 9 Spreads for ranking factors of obesity

Factors	Spread (r_C)
A_1	0.4
A_2	0.64
A_3	0.84
A_4	0.8
A_5	0.56
A_6	0.72
A_7	0.56
A_8	0.68
A_9	0.6
A_{10}	0.44

Table 10 Areas for ranking factors of obesity

Factors	Area (A_C)
A_1	0.0394
A_2	0.0670
A_3	0.0896
A_4	0.0859
A_5	0.0570
A_6	0.0774
A_7	0.0572
A_8	0.0711
A_9	0.0617
A_{10}	0.0435

Table 11 Risk value for factors of obesity

Factors	Risk value (R_C)
A_1	0.6075
A_2	0.6794
A_3	0.7333
A_4	0.7223
A_5	0.6569
A_6	0.7007
A_7	0.6562
A_8	0.6908
A_9	0.6690
A_{10}	0.6202

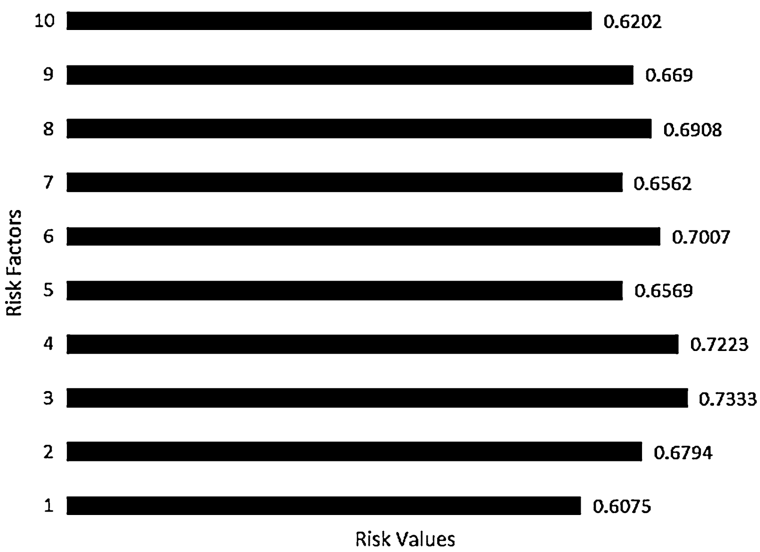


Fig. 5 Summary of risk values and risk factors

Based on these results, the experts agree that family history (risk factor 3) is a major factor contributed to the development of obesity, followed by sedentary lifestyle, energy intake, behavioral factor, body measurement index, medical illness, physical activity, psychology, and social determinants. The experts chose gender as the least important risk factor that leads to obesity since obesity can happen to anyone regardless of gender.

5 Conclusions

As described in literatures, the current trend of modern life style may lead to the development of obesity, which leaves several challenges, including the identification of conclusive risk factors of obesity. With the importance of identifying the risk factors, this paper has been utterly dedicated to the discovery of values of the risk factors. The uncertainty of the risk factors motivates a new research in ranking fuzzy numbers by introducing circumcenter of centroid thanks to the uncertain characteristics of fuzzy set theory. This paper has proposed the a new circumcenter of centroids in which these contriods were eventually used in ranking fuzzy numbers. The proposed method was tested in a case of establishing the ranking of risk factors contributed to obesity. The three experienced experts were invited to provide linguistic evaluation over the degree of contribution of risk factors to obesity. The proposed two-phase computational procedure has successfully identified the risk factor of family history as the highest risk value in explaining factors contributing to obesity. In addition, the use of circumcenter of centroid in ranking fuzzy numbers identified sedentary life style as the second highest risk value. This finding is consistent with a report of WHO (2009) in which sixty percent of world's population gets insufficient exercise. The factor of gender is recorded as the lowest risk contributed to the development of obesity. Future research may be undertaken to include more risk factors and embark with other intelligent based methodology research as to validate and compare the experiment results.

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