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Application of a comfort index for evaluating tactile and thermo-physiological comfort properties of surgical gowns

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The primary objective of this study is to develop a mathematical tool to calculate a global desirability index value (comfort index) for disposable surgical gowns which will enhance the market value for the product. The mathematical tool is based on the desirability function approach, by using its different modules such as maximization, minimization, and target as per the objectives chosen. Three different disposable nonwoven surgical gowns, such as Fabrics *C* (44.35 g/m^2, 0.32 mm thickness & 11 micron pore size), *A* (46.31 g/m^2, 0.29 mm thickness & 10 micron pore size) & *S* (44.71 g/m^2, 0.36 mm thickness & 8.9 micron pore size), intended for hospital application have been used. The developed model focuses on predicting tactile and thermophysiological comfort, by considering the importance of certain physical properties, leading to the comfort of the wearer. Results reveal that out of the three gowns, Fabric *C* gown fetches the best comfort index value of 0.5689 followed by the Fabric *S* and *A* gowns with the values of 0.3009 and 0.1969 respectively.

Keywords: Comfort index, Consumer requirements, Desirability function, Disposable surgical gown, Global desirability value, Individual desirability, Tactile comfort, Thermo-physiological comfort

1 Introduction

A comfort index is a tool developed to simulate the degree of consumer satisfaction. In consequences, to satisfy a health care professional, it is indispensable to go with a quality that communicates to his / her expectations[1]. The term “Quality” is subjective and depends on the choice of each individual, on the circumstances of use and the level of importance he/she assigns; along with his / her extent of requirement[2].

Owing to the specific performance level of the tactile and thermophysiological properties, the desirability function gives the transformation of d_i (individual desirability) values which represents the identical and comparable level of satisfaction as per one’s expectations. In addition to that, for those properties whose importance is ensured with the customer-satisfied level of quality, an appropriate relative weightage was assigned towards highlighting the property’s importance[3].

Comfort index incorporates a set of properties affecting tactile comfort like bending, compression, heat flux, friction and roughness, which contribute to the primary sensory indices like smoothness, softness and warmness; thermophysiological comfort indices like air permeability, thermal and moisture transport properties like water vapour transmission rate, water vapour resistance and thermal resistance. Moreover, this index emphasizes on consumer requirements. Hence, the overall comfort value is inferred by the dynamics of these properties.

With the increase of global desirability value (comfort index value), the interaction between the properties affecting the quality will be better; it becomes the best when the value reaches one. However, with the individual desirability values approaching zero, the outcome will be with a value outside of tolerance, which would impact the global desirability, whereby the interaction between those properties is rejected.

Surgical gowns for medical personnel come under the classification of healthcare products. The primary objective of the surgical gown is to safeguard both the surgical crew and patients against cross-infection, the spread of hazardous micro-organisms, body fluids and blood-borne pathogens. Apart from the protective performance of surgical gowns in four distinct levels as per AAMI PB 70 standard, the comfort properties of the surgical gowns need to possess excellent wear

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comfortness; considering the duration the gowns are intended to be worn, when they are used during work, which requires both physical and mental efforts[4]. Thermal comfort and tactile comfort play a vital role with the health care workers and surgical personnel inside the operation theatre. The surgical gowns are constructed in many different combinations to the availability of materials, such as single-use (nonwoven fabric), reusable (woven or knitted fabric), with reinforcements (films, coating, plastics and lamination) of nonwoven, woven and knitted fabrics in critical portions[5]. The indoor environmental conditions like temperature and humidity prevailing at the operation theatre, contribute to the comfort of healthcare professionals involved in certain activities.

In this study, a mathematical function-based desirability function approach has been used for judging the subjective tactile and thermophysiological clothing comfort, from the objective measurement of physical properties of surgical gowns. This comfort index value would enhance the marketing value of the product at the competitive global market level. The chosen approach for optimizing several responses called the “Desirability” function, arises when all multicriteria phenomena, which need a synchronized fulfilment of several measures are considered in a simple computable way, without compromising their quality. This is called the desirability function approach[6], and it consists of following three stages:

(i) collecting the various parameters affecting the comfort perception with their objective values,

(ii) converting the obtained objective values into individual desirability value (d_i) based on the objective fixed and along with their specific performance limits such as minimum value, maximum value and target values; and

(iii) computing a global desirability function by using the geometric mean of obtained individual desirability values.

2 Materials and Methods

2.1 Materials

Three different disposable nonwoven surgical gowns, such as C, A & S, intended for hospital use were sourced from commercially successful manufacturers. Their weight per unit area and thickness ranged between 44 - 46 g/m^2 and 0.29 - 0.36 mm respectively. The specifications of the sourced sample are given in Table 1.

Table 1 – Specification of surgical gown

Surgical gown sample variety	Weight per unit area, g/m^2	Thickness mm	Pore size, microns
Fabric – 1 (A)	46.31	0.29	10
Fabric – 2 (S)	44.71	0.36	8.9
Fabric – 3 (C)	44.35	0.32	11

2.2 Deriving Desirability Index

A usual complication in product development involves the choice of a set of conditions, such as the X’s, which will end up in a product with a preferable combination of properties; and the Y’s. The instantaneous optimization of Y’s or response variables always become difficult, which depends upon a set of conditions/variables X1, X2…..Xp (ref. 7).

To overcome this issue, the desirability function approach was chosen which optimizes several independent variables towards arriving at the global desirability function, with interactions between those selected independent variables/parameters, towards assessing “comfort”.

The desirability function approach provides a value, which enumerates how the arrived value satisfies the combined goals for all the selected variables. It ranges between zeros and one; where one represents the best level of satisfaction and zero represents an unsatisfactory condition on each of the chosen variables.

2.2.1 Computing Individual and Global Desirability Values

The global desirability function to optimize the individual response is done with the following formula with the geometric mean of all those[7]:

$$D = (d_1 \times d_2 \times d_3 \ldots d_m) \wedge {}^{1/m}$$

where D is the global desirability function to optimize, d_1, the individual desirability function of the property “Yi”, affecting the comfort perception; and m, the number of properties.

This “D” value shows a clear picture of how it has satisfied the goal with all the input parameters. Whenever there exists a ranking or grading among the properties/parameters chosen, towards the comfort perceptions; then there comes the term “relative importance” or “weightage”.

Thus, to contribute a quality that merges with the customer expectations, the taste/weightage/ importance/relative weightage of every individual plays an important role for that particular product condition of use and degree of requirement.

Individual differences exist between customers in terms of their preference. Each customer has his/her taste concerning the end- use of the product. A property that seems to be important to one need not be at the same level for others.

The formula to compute the global desirability index was as per the equation given below[8] of which helps in highlighting the relative importance of each property:

$$d_i = (d_1^{W_1} \times d_2^{W2} \times d_3^{W3} \ldots d_m^{Wm}) \wedge 1/W$$

where d_i is the individual desirability function of the Y_i property affecting the comfort perception; W_1, the weightage of the property "Yi"; and W, the sum of the individual properties weightage from 1 to m.

2.2.2 Evaluation of Satisfaction Degree by using a Mathematical Function

Desirability functions are grouped as follows;

(a) Desirability function to maximize,
(b) Desirability function to minimize,
(c) Desirability functions to reach a property target value.

Concerning comfort perception properties subjected to objective evaluation, in this study, two modules from the group of three desirability functions have been chosen as shown below:

(i) Desirability function to maximize has been used for moisture vapour transmission rate, air permeability, liquid moisture management properties, and tactile property

(ii) Desirability function to minimize has been used for water vapour resistance and thermal resistance.

When the objective is to maximize the property such as the ones stated above, the desirability function is used, as shown below[7] :

$$d_i = \{(Y_i - Y_{minimum}) / (Y_{target} - Y_{minimum})\}^S$$

where d_i is the individual desirability function of the particular property; Y_i, the obtained value from testing (objective characterization); $Y_{minimum}$, the specific acceptance level called minimum value set for this property; Y_{target}, the specific acceptance level called target value set for this property, and S, the customer requirement represented as a numerical value in terms of 0.5, 1 and 2 to differentiate the level of requirement; here "S" value will be "2" when the requirement is high, "0.5" when it is low and "1" when the requirement is moderate.

Moreover, with the d_i formula shared above, following two conditions exist:

(i) $d_i = 0$, if Y_i is less than or equal to $Y_{minimum}$

That is, individual desirability for that particular property will become zero when the obtained (tested) value is less than or equal to the minimum value prescribed.

(ii) $d_i = 1$, if Y_i is greater than or equal to Y_{target}

That is, individual desirability for that particular property will become one when the obtained (tested) value is greater than or equal to the target value prescribed.

Thus, when the objective is to minimize the properties like water vapor resistance and thermal resistance, the desirability function to minimize the type is used, as shown below[7]:

$$d_i = \{(Y_i - Y_{maximum}) / (Y_{target} - Y_{maximum})\}^T$$

where $Y_{maximum,}$ the specific acceptance level called maximum value set for this property; T, the customer requirement represented as a numerical value in terms of 0.5, 1 and 2 to differentiate the level of requirement; here "T" value will be "2" when the requirement is high, "0.5" when it is low and "1" when the requirement is moderate.

Moreover with the d_i formula shared above, following two conditions exist:

(i) $d_i = 1$, if Y_i is less than or equal to Y_{target}

That is, individual desirability for that particular property will become one when the obtained (tested) value is less than or equal to the target value prescribed.

(ii) $d_i = 0$, if Y_i is greater than or equal to $Y_{maximum}$

That is, individual desirability for that particular property will become zero when the obtained (tested) value is greater than or equal to the maximum value prescribed.

2.3 Objective Evaluation Methods

2.3.1 Tactile Property Measurement

The drapability of a surgical gown should be higher. Without any rubbing or chafing, they should move freely, with a soft and smooth feel. A rigid material will prevent the usage of the gown due to its uncomfortable touch. The perspiration and mobility will be affected by stiff material. The fabric touch tester (FTT) (SDL Atlas, Model 293 & Hong Kong) was used to measure the total hand value of surgical gowns. Evaluating fabric quality and its performance with 13 indices towards total hand value was carried out through the measurement of the properties, such as fabric thickness, fabric compression, fabric bending, fabric surface roughness, fabric surface friction and fabric thermal properties[9].

2.3.2 Measurement of Thermophysiological Property

The balance between the heat generated and the heat lost leads to thermal comfort. Concerning the surrounding temperature and atmospheric conditions, the kind of satisfaction is perceived as comfort; which depends on both the inside and outside temperature level. The atmospheric condition of the surgical environment, duration of the operation procedure and the level of exposure constitute the thermal and moisture comfort of the surgical gowns. It was found that temperature and relative humidity ranged between 15˚C & 25˚C and 30% & 60%, respectively. Moreover, the temperature of the surgical theatre was also increased due to the radiant heat emitted from the overhead light. The release of body heat will be high due to the high-stress environment and with the release of radiant heat from the light source. Their performance will get deteriorated if the generated heat is not properly dissipated outside[10]. Owing to this, the following thermophysiological properties for the surgical gowns were evaluated.

2.3.2.1 Air Permeability

Quantification of air through the fabric is measured as air permeability. How well the fabric allows the air to pass through it, that helps in the dissipation of the body's metabolic heat. With the level of air permeability as higher for the fabric, the water permeability regarding liquid and moisture will be generally higher. Owing to this, air permeability is always related to moisture vapour permeability and liquid moisture transmission. Moreover, the level of still air associated with the fabric represents the thermal resistance of a fabric; which, in turn, is strongly influenced by the structure of the fabric. Textest FX 3300 instrument was used to measure the air permeability of the samples according to the standard ASTM D737-18[10]. The air pressure maintained was 125 Pa, with a test area of 38 cm^2. The volume of air passing through the fabric per unit area per unit time was measured by this instrument.

2.3.2.2 Water Vapour Transmission Rate

It was found that the rate of contamination in the surgical field would be higher when the rate of sweating from the surgeon was greater. The capability of medical personnel to handle the tolerable levels of heat and cold was found to vary. Owing to the higher temperature and humidity, the personnel to get exhausted prevails at a quicker rate. Hence, most of the hospital operation theatre is equipped with airconditioning system to control temperature between 20˚C and 25˚C. However, Surgical gown without barrier layer, personnel may feel quite comfortable, but the level of barrier performance will be poor. With a coated or laminated one, the barrier performance will be good, but the level of comfort is questionable[11].

The water vapour transmission rate of the samples was measured on a sweating-guarded hotplate tester (M259B of SDL Atlas, Hong Kong); according to ASTM E96-2010 standard, with option B test method[10]. The air speed was maintained at 1 m/s ± 0.05, with a temperature of 23°C and 50% RH. The instrument measures the breathability of textile clothing material by the evaporation of moisture through the clothing layer.

2.3.2.3 Water Vapour Resistance

The ability of the fabric to allow water vapor to get evaporated is quantified as water vapor resistance. Similar to the presence of still air thickness, which has the same amount of resistance to water vapor diffusion, the resistance to water vapor migration is measured here. Owing to the increase in water vapor resistance, the capability of sweat getting evaporated from the body to the external atmosphere gets reduced[12]. The water vapour resistance rate of the samples was measured on a sweating-guarded hotplate tester (M259B of SDL, Atlas Hong Kong), according to the ISO 11092:1993 standard[10]. This instrument calculates the water vapour resistance, with the amount of power needed to ensure a constant vapor pressure between the top and the bottom layers of the fabric sample specimen. It records the mean power required to place the measuring unit at its predetermined temperature. The air velocity was 1 m/s ± 0.05, with a test area of 30 cm^2, temperature and relative humidity were 35° C and 40%.

2.3.2.4 Thermal Resistance

Thermal resistance is considered the most influential parameter with thermophysiological comfort. It is the measure of fabric resistance against heat flow. It implies the insulation value of the fabric, representing the number of heat differences existing between the two sides of the fabric with respect to the heat flow. An increase in thermal resistance values implies that the temperature of the human body increases[13]. A sweating-guarded hotplate was used to measure the thermal resistance of the surgical gown fabrics as per the standard ISO 11092:1993[14]. This apparatus measures the resistance to the heat flow, placing the sample over the calibrated test plate at a temperature of 35° C, with an air temperature of 20°C, velocity of 1 m/s ± 0.05 and relative humidity of 65%[5].

3 Results and Discussion

For these base parameters of the sourced disposable surgical gown fabrics, the tactile and thermophysiological comfort properties of different fabric have been computed (Table 2). The table represents the specific performance level for each property, which is the acceptance interval, such as minimum value, target value and maximum value. However, to define the desirability function there is a need to fix the objective of all the properties getting evaluated towards the comfort perception (Table 3).

By using the individual desirability function approach, the individual desirability (d_i) for the selected properties affecting comfort for the three disposable surgical gown fabrics are calculated for three different types of desirability function approaches (Table 4).

With the availability of individual desirability values, the global desirability function was calculated to select the best fabric from each group, based on the computed index value. The calculated index value for each group is given in Table 5. To simulate the level of requirement from low, moderate and high three values for 'S' & 'T' requirements are used to show the significance of it. This can be used as an indication of customer satisfaction. Here, 'S' & 'T' represent the requirement values used with the formula of different desirability function approach.

It is noticeable that the customer level of satisfaction becomes more difficult to achieve when the level of requirement becomes high (S = T = 2), and the global desirability values become weak; however, the same becomes easily achievable when the requirement becomes low (S = T = 0.5). That's why, the customer requirement values for 'S' and 'T' are taken as "1", as a moderate value. Moreover, in all

Table 2 – Tactile and thermo-physiological comfort properties of different surgical gown fabrics [Mean and Standard deviation values]

Comfort type	Properties	Fabric – 1 (A)	Fabric – 2 (S)	Fabric – 3 (C)
Tactile	Total hand value– Fabric touch tester	0.49±0.01	0.48±0.02	0.59±0.16
Thermo-physiological	Moisture vapour transmission loss g/m^2/24 h – Sweating guarded hotplate	1717.80± 111.69	2121.85± 180.18	1826.77± 178.86
	Air permeability, c.c/cm^2/s – Textest FX 3300 air permeability tester	26.12± 1.956641	19.53± 0.651579	32.57± 2.770098
	Water vapour resistance, m^2.Pa/W – Sweating guarded hotplate	3.1616± 0.08	3.5965± 0.08	2.9536± 0.18
	Thermal resistance, °C.m^2/W – Sweating guarded hotplate	0.0107± 0.0022	0.0321± 0.0026	0.0223± 0.0020

Table 3 – Target values and limits of studied comfort properties for surgical gown

Comfort type	Property	Reference test method	Objective	Minimum value	Target value	Maximum value
Tactile	Total hand value	SDL Atlas Method	Maximize	0.45	0.65	NA
Thermo-physiological	Moisture vapour transmission loss g/m^2/24 h	ASTM E-96:95	Maximize	1715	2310	NA
	Air permeability c.c/cm^2/s	ASTM D 737:18	Maximize	16	35	NA
	Water vapour resistance, m^2.Pa/W	ISO 11092:2014	Minimize	NA	2	4
	Thermal resistance °C.m^2/W	ISO 11092:2014	Minimize	NA	0.0100	0.05

NA – Not applicable.

Table 4 – Individual desirability values (d_i) for the properties affecting comfort
[With the customer's requirement as moderate with the values of S & T =1]

Comfort type	Property	Objective	Individual desirability value (d_i)		
			Fabric – 1 (A)	Fabric – 2 (S)	Fabric – 3 (C)
Tactile	Total hand value	Maximize	0.20	0.15	0.70
Thermo-physiological	Moisture vapour transmission loss g/m^2/24 h	Maximize	0.007	0.980	0.269
	Air permeability c.c/cm^2/s	Maximize	0.533	0.190	0.870
	Water vapour resistance, m^2.Pa/W	Minimize	0.419	0.202	0.523
	Thermal resistance °C.m^2/W	Minimize	0.98	0.45	0.69

Table 5 – Global desirability function (D) for the properties affecting comfort of disposable surgical gown fabric
[With the customer's requirement as low, moderate and high; values of S & T =0.5, 1 & 2]

Global desirability function (D) / comfort index value	Fabric – 1 (A)	Fabric – 2 (S)	Fabric – 3 (C)
S = T = 0.5	0.4437	0.5485	0.7542
S = T = 1	0.1969	0.3009	0.5689
S = T = 2	0.0388	0.0905	0.3236

the cases for calculating the global desirability value or comfort index, the relative importance for each property is assigned with equal weightage, i.e. W_i = 1. That is, for all the properties equal importance is given. The results obtained by assigning various customer requirement values are given in Table 5.

Owing to the different end uses and various performance requirements, the textile fabrics are manufactured and served at the global level. The performance level and suitability for a particular end product will be contributed by the physical and chemical composition of the textile materials.

The structural features affect textile properties, which, in turn, predict end-use performance. The raw materials and their weave structures, along with the type and level of finishes applied to the fabric, determine its performance while being used by the customer. The role of all these features will contribute in a complex fashion towards the end-use performance.

The importance of textile material properties prediction goes with a better understanding for the engineers involved in designing a new product, towards benefiting the clients and enhancing their business with merchandisers and solving the customer problems with the end product. These are considered as the foundation of quality, wherein a product that meets the expectations of the customers will be considered as a quality product. As the product's level of performance is found to be acceptable, it will be perceived that the quality is maintained and the level of satisfaction increases with the end product.

It's not practically easy to come up with a term enumerating the value for "Performance Durability", it may be presumed as how well the fabric performs up to the last level of usage. The most difficult part is, defining the requirements or specific performance levels for each fabric property intended for evaluation. Factors in establishing the best performance level lie with the knowledge gained by the manufacturer and shared by the consumer and supplier. The usage of standard and specific performance levels is discretionary. Many manufacture seem to have established their own specific performance requirements. The different target values and limit values specified in Table 2 can be changed accordingly as per the base parameters in use and the specific end use of the proposed product.

The method used in this study is to generate a database for characterizing the fabric properties of disposable surgical gown fabrics. The input variables are primarily construction parameters like weight per unit area, thickness and pore size.

From the results obtained with the characterized three disposable surgical gown products, as given in Table 3, Fabric 3 (C) has the best comfort index. The reason behind the "C" fabric possessing the best comfort index lies with the results of individual properties where it has the highest total hand value, highest air permeability and lowest water vapour resistance. The highest total hand value is probably due to the coating which is applied for the barrier protective performance. This makes the fabric appear to be smooth and soft without any imperfections, and also shows the capability of allowing the heat and vapours to pass through, due to its pore size. The increase in air permeability and low water vapour resistance goes hand in hand with the low weight per unit area of the fabric. The results obtained in the study are in sync with previous similar studies[7].

However, Fabric 2 (S) has the highest moisture vapour transmission rate. This is because of the bulkier fabric structure and the air retained inside its bulkier structure. The thermal resistance property is found to be the best in Fabric 1 (A), with its lowest resistance to heat owing to the thickness value and the pore size of the fabric.

As a result, with the three different varieties of disposable surgical gown nonwoven fabrics characterized, the comfort index based on the tactile and thermophysiological property can be estimated, according to the requirements of the customers and the relative importance associated with every selected fabric property. Thus, the calculated desirability value is based on the objective (that is to maximize or minimize) assigned with every property. The specific performance levels, such as minimum value, maximum value and target value i.e. the acceptance interval levels which makes the product as useful in the market to its level of activity and at least with the required level of customers towards every property are associated with the comfort perception.

Thus, the derived global desirability index value can be used as a comfort index of consumer comfort perception for disposable nonwoven surgical gowns. By using this discussed mathematical part, based on the desirability function approach towards arriving, the comfort index can also be used for different kinds of fabrics to foresee their clothing comfort index according to their end-use applications.

4 Conclusion

A mathematical tool has been developed towards arriving at a comfort index value, comprising objectives, specific performance intervals, requirements and importance of the properties affecting the comfort, as represented by the customer. Owing to the particular end use of a specific product, with its associated comfort properties, manufacturers can target his group of customers to reach a high margin of profit.

With only one function called global desirability, the satisfaction degree is highlighted by considering different parameters of manufacturers with the requirements such as low, moderate and high. This obtained degree of satisfaction can also be perceived as an indication of quality that enables us to get a clear picture of, whether the desired level of quality is achieved or not.

This study serves as a useful mathematical tool to rate the level of comfort. With this index, manufacturers will have a mechanism that enables them to cover their intended customers, to sell their product with the best comfort. It will also aid the customers to select a product based on the tag, representing the tactile and thermophysiological properties of the fabric.

As a future scope of work, in continuation of mathematical derivation, a subjective analysis will be conducted in a hospital with surgical crews, wherein three types of surgical gown fabrics will be shared with them towards evaluating the best comfort. Moreover, the customer requirement degree and weightage will be calculated based on the values recorded from the customers of 30 in numbers (minimum), based on the number of times, occurrence of a particular value. A concordance value of ‘W’ will be arrived towards predicting the level of agreement between the surgical personnel, where “W” value closer to one will shows that the agreement is high.

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