On Factors Influencing the Absorption Capacity of Surgical Sponges

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Abstract

Background Cotton balls and surgical gauzes (CSG) have been routinely used for mopping fluids and blood in surgeries. Polyurethane sheets (PUS) are increasingly used instead of CSG. The factors influencing the absorption of fluids by CSG and PUS have not been studied in detail. There are a variety of factors that could be modified by the manufacturer while a limited number of them could be manipulated by the operator.

Materials and Methods Mathematical models and equations have been employed in this study. The impact of absorbency was performed by modulating various factors.

Results and Discussion A variety of factors such as thickness, density of the web, radius of fiber, temperature, surface tension and viscosity of fluid, all influenced the absorption rate and capacity to varying degrees. The optimal variation by which the PUS can be effectively used is discussed. The suggested mathematical model will help the operator to choose the appropriate type of PUS based on the individual's needs.

Conclusion In an area of rapidly developing technology and change in biomaterials, where the choice of such materials are overwhelming, hopefully this basic knowledge will help the clinician to make a more educated and rational decision.

Keywords Absorption · Surgical sponge · Surgical gauzes

Introduction

Cotton balls and cotton surgical gauze (CSG) (as sponges or wadding) are used in minor surgical procedures for the absorption of fluids including blood and identification of bleeding points. Often in dental surgery, significant amounts of CSG are used because once a CSG piece gets soaked in oral fluids, they do not regain their original shade and absorption capacity. The oral cavity has a continuous flow of fluids like saliva and gingival crevicular fluid, as well as water (used as a coolant for rotary instruments) along with blood. The fluid flow increases during surgery for many reasons. Hence, consumption of CSG may increase enormously, particularly during surgeries that involve bone with intractable bleeding. Use of high power suction may not be practicable in certain situations and mopping with the CSG would be the better choice.

Polyurethane sheet (PUS) has a microstructure of sponge with excellent mechanical properties for medical use. It is a non-woven fiber arranged in a sponge-like structure, white in colour, soft and flexible. It is also stable against acidic or alkaline fluids and its intra-operative use is considered safe. As the absorption ratio of PUS has been proven better than CSG, it has been reported to be a better alternative to CSG. However, its potential for reuse has to be studied in depth. PUS is reported to have good biological compatibility, to be lint free and can alleviate pain and promote wound healing without damaging or leaving fibers in the wound [1]. Polyurethane is available in several forms such as sheets, sponges and foams, which are highly absorbent, with the absorbency being manufacturer

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controlled by properties such as texture, thickness and pore size [2]. Their properties are believed to aid in the healing process [3]. PUS can be either hydrophilic or hydrophobic. PUS are available commercially for use in dentistry, such as Dry Tips® (Mölnlycke Health Care, UK) and Invacare Polyurethane Foam®.

Mathematical models are a proven way to study the changes in a contained biological or chemical or a physical system. They employ a derived equation that relates all possible factors that relate to the event in question. As factors can be made uniform in the case of PUS as they can be controlled by the manufacturer. Certain factors such as thickness of web, viscosity of liquid, and contact angle can be manipulated to an extent by the operator. Previously it has been proved that such models can be used to accurately predict performance which is similar to that seen under real experimental situation [4]. This study was performed to identify the effect of operator-controlled and manufacturer controlled factors that could influence the absorption rate and capacity of fluids for the purpose of absorption of oral fluids by PSU using mathematical models.

Materials and Methods

For this study, it was assumed that all fibers in the PUS are uniformly hydrophobic, have isotropic mean capillary diameter, fiber diameter, thickness of web and area of the web. This study utilized the absorption capacity and absorption rates of PUS. Earlier published models that had been built to characterize the absorbent capacity (C) and absorbent rate (Q) were considered for this study [4]. Absorbent Capacity—C (in cc/g fluid/g) is depicted by the volume per mass of fluid absorbed at equilibrium divided by the dry mass of the specimen. The model to calculate C is based on the published formula [4] using the total interstitial space available for holding fluid per unit dry mass of fiber. The dominant factor that controls the C is the web thickness per unit mass on dry basis.

$$\text{Absorbent Capacity } C = A + \frac{T}{Wf} - \frac{1}{Pf} + (1 - \alpha) \frac{Vd}{Wf}$$

where, A is the area of the web (in cm²), T is the thickness of the web (in cm), Wf is the mass of the dry web (in gm), Pf is the density of the dry fiber (in gm/cm³), Vd is the amount of fluid diffused into the structure of the fibers (in cc), α is the ratio of increase in volume of a fiber upon wetting to the volume of fluid diffused into the fiber [4].

For absorbent rate, Q, the modified Washburn's equation was employed from published reference [4]. The higher the absorption rate of the material (PSU), faster will be the absorption of fluids. By altering the values, the effect of each factor can be studied.

$$\text{Absorbent rate } Q = \frac{\pi r \gamma \cos \theta}{2\eta} \cdot \left(\frac{T}{Wf} - \frac{1}{APf} \right)$$

where, r is the mean pore radius of the capillary, γ is the surface tension of the fluid, θ is the contact angle of the fiber, η is the viscosity of the fluid, T is the thickness of the web, Wf is the mass of the dry web, A is the area of the web, Pf is the density of the dry fiber. It is expressed as cc/g.sec. For this equation, the only variable is the angle of the contact that can be handled by the operator. The other factors can only be manipulated by the manufacturer.

Both the described formulae were entered into separate Microsoft Excel 2007 chart. For practical purposes, to calculate C, all the values were arbitrarily assumed to be: one for area; 2 for thickness of web, Wf and Pf as 0.001, alpha set at 5 and Vd at 0.1. To identify the effect of each of the parameters, they were altered and the effect of the change on C was recorded. The changes were expressed as percentage of difference.

To identify the changes in the Absorbent rate, Q, arbitrarily the mean pore radius of the capillary was taken as 0.001, γ the surface tension of the fluid as 1, 90° contact angle of the fiber, viscosity of the fluid as 1, the thickness of the web as 0.001, 0.001 is the mass of the dry web, 0.001 is the area of the web, 0.001 as the density of the dry fiber. To identify the effect of angle, it was altered to identify the effect of the change. The changes were expressed as percentage of difference.

Results

Table 1 depicts the changes of the absorbent capacity C with changes in the factors as described below.

Influence of area and web thickness It was identified that when the area was reduced by 50 %, C was reduced by 167 %, when area was decreased by 25 %, C was decreased by 83 %. On increasing the area by 25 %, C increased by 83 %. On doubling the area, C increased by more than three fold. A similar trend was observed with web thickness (Fig. 1).

Influence of the mass of dry web Reduction of the mass, increased the C. The relationship was inverse. A reduction in 25 % of the mass increased C by 89 % while an increase in mass by 25 % decreased C by 89 % (Fig. 1).

Influence of the density C showed a proportional direct relationship with the density of the material. Reduction of density by 25 %, reduced C by 56 % whereas an increase by 25 % showed an increase of 33 % (Fig. 1).

Influence of alpha (ratio of increase in volume of a fiber upon wetting to the volume of fluid diffused into the fiber): A reduction of 25 % of alpha, increased C by 21 % while an increase of 25 % decreased C by 21 % (Fig. 1).

Table 1 Changes with absorption capacity with operator and manufacturer controlled factors

Changes	Change of absorption capacity with					
	Area (%)	Web thickness (%)	Mass of dry web (%)	Density of fibre (%)	Alpha (%)	Vd (%)
Reduced by (%)						
50	−167	−167	267	−167	42	33.30
25	−83	−83	89	−56	21	16.67
Increased by (%)						
25	83	83	−53	33	−21	−16.67
50	167	167	−144	56	−42	−33.33
75	250	250	−162	71	−62.50	−50
100	333	333	−175	83	−83.30	−66.67

Fig. 1 Change in absorbent capacity with factors. Results of model based calculation for changes in absorbent capacity of surgical sponges varying the various factors including area, web thickness, mass of dry web, density of fiber expressed as percentage

Influence of amount of fluid diffused into the structure of the fibers A reduction of 25 % of this factor, increased C by 16.67 % while an increase of 25 % decreased C by 16.67 % (Fig. 1).

Figure 2 indicates the change of the absorbent capacity with the change in each angle of contact. It was observed that maximum absorption occurred with 15°. The radius of capillary is the single most important factor influencing the absorption rate.

Figure 3 studies the influence of the viscosity of the oral fluids on the absorption rate while Fig. 4 shows the effect of surface tension on the absorption rate.

Discussion

The documented use of gauze or surgical sponge or wads in surgeries dates back to nineteenth century [5]. They along with sponges have been extensively used in the minor surgical and dental procedures for hemostasis, retraction,

isolation, protection, dissection and bleeding management. The oxygen atom in water attracts electrons, giving it a negative charge while both the hydrogen atoms have a slightly positive charge. This causes the water ends to behave in a magnet-like fashion, with water molecules readily bonding easily with molecules with an opposite charge. The polymers (either cellulose of cotton or polyurethane) contain hydroxyl ions or other groups on the outer perimeter of sponges, which are negatively charged and which attract water and aid water absorption.

Surgical sponges or gauze dressings are manufactured using woven and nonwoven fibres of cotton, synthetic material or combination of both. There is still wide spread, continued use of traditional gauze dressings even with the introduction of more modern superior products. The absorptive capacity of PUS for fluids has not been studied in detail till previously. The only available related cited reference in the literature is of a study that compared the absorption rate of saline by several PU foam products in comparison to gauze [6]. They reported a marked variance

Fig. 2 Change in absorbent rate with radius of capillary and angle of contact. Results of model based calculation for changes in absorbent rate of surgical sponges varying with mean capillary radius and angle of contact expressed as percentage

Fig. 3 Changes in absorption rate with changes in viscosity of fluid

Fig. 4 Changes in absorption rate with surface tension of fluids

in absorption rate and amount of saline absorbed. PU based products such as PolymemTM, CuraformTM and HydrasorbTM absorbed saline within seconds, LyofoamTM and AllevynTM took 1.5–2 min and TielleTM more than 5 min. The weight of saline absorbed varied from only 7.8 g/in³ with LyofoamTM to 39 g/in³ with TielleTM. In their study the authors classified PU dressings into two different types. There are the true foams (that siphon fluid into their holes like a sea sponge through capillary mechanism) and hydroactive dressings (which absorb fluid into their structure and lock it away). It is widely believed that the hydroactive

dressings adsorb fluids more rapidly and in greater amounts than the true foams. Also, as an added advantage, the hydroactive dressing retains the fluids even when pressure is applied to it [6]. The greatest disadvantage is that hydroactive dressings do not absorb or retain cellular material as well as other fluids [6]. Thus, in the presence of blood in large quantities, their performance may be compromised. They agreed that the hydroactive dressings did retain the blood more effectively within the dressing than the foam dressings. However the true foams in their test performed poorly on the squeeze test and hence were not recommended for areas subjected to pressure. However their efficacy in absorption of fluids, blood and retaining was unmatched [6]. Based on their findings it could be assumed that PU is an ideal potential substitute for CSG.

In an ideal dry state, the PU fiber chains have random spaghetti-like structures that impede the passage of moisture. As the structures get wet, these chains form coil like structure that facilitate fluid transportation [7]. On application of pressure, they tend to regain the original state. It is this property of PU that makes it an effective substitute for CSG. Pressure has been identified as an important factor influencing absorbency rate. It has been documented in literature that an increase in pressure would decrease the interstitial space between fibers which will reduce the size of capillary space between them along with distortion of the spaces. This will lead to decrease in the Q and C [4]. However, if the fibers are compressed and left to rebound, the increasing dimension, will aid to increase the absorption rate and capacity of the material. Fluffing of fibers will help to increase the radius and thereby help to absorb more oral fluids.

The standard tests used for absorbency are the absorbency test (before and after immersion), degree of expansion, squeeze test, absorbency rate, lateral wicking and sheet integrity test. In lab studies PU were able to absorb more saline than the fiber based materials. Fluids that need to be absorbed in dental settings are often water and diluted body fluids, making this an ideal material [6]. However while dealing with pure blood, fiber dressings performed better than the PU based components [6].

Key factors of C and Q are controlled by manufacturer. Only minor variations could be manipulated by the operator. Compression will reduce the thickness of the web. An increase of thickness by about 5 % would bring about 16.6 % increase in efficacy of the absorption capacity. Similarly wetting the material and squeezing it will probably increase the mass of the web owing to presence of moisture. Moreover, presence of moisture will ideally cause faster absorption rate and decrease the absorption capacity. However this needs to be verified in clinical settings.

Compressed packs could increase thickness and hence absorb increased amount of fluids [4]. The operator can add to this by compressing the wet material as much as possible to increase the absorption capacity as well as increase the rate before employing. Similarly, the angle of contact of the fiber system can be effectively altered to fit in the system. The conventional wisdom of squeezing CSG after dipping with saline and employing to absorb more oral fluids is also explained by the phenomenon of the increase in capillary radius as well as interacting with swelling capacity of the cotton fiber.

By decreasing the viscosity of the oral fluids through addition of water, the absorption rate can be increased and by decreasing the surface tension, optimum absorption of fluids may be achieved as seen in Figs. 3 and 4. Surface tension could be altered by using warm water or jets with high speed, as increase in these results in decrease of the surface tension [8].

Hydrophobic nonwoven sponges have better absorption capacity than the woven cotton sponges [9, 10]. In reality, absorbent PUS sponges are a mix of hydrophobic and hydrophilic fibers in different ratios with presence of super absorbent polymers besides other additives. Also the curing time, structure of cell determines the affinity of the product to absorb fluids [10, 11].

As various products have their advantages and disadvantages, a dentist needs to identify and choose the sponge he or she needs. In a situation in which there is more water to be removed or a strict “no moisture” situation is required in the operating area, PU sponge is the ideal candidate. When the field demands removal of blood with adequate strength, interlocking and resistance to pressure, PUS is also the ideal candidate. When only blood removal is warranted fiber products are better. However the choice is also dictated by several other factors such operator’s choice, training, economic reasons, local regulations concerning waste disposal, etc.

In a situation where hemostasis needs to be achieved and the sponge needs to be placed for time greater than 30 min such as extraction sockets, surgical areas, PU based product has been demonstrated to be the most efficient [6]. Another added advantage of PU is that they can be radio-tagged

easily to prevent gossypiboma or textiloma or guazoma or cottonoids caused by leaving behind these materials in the surgical site [9]. The model discussed in this paper is the same as in clinical practice—lateral wicking (or lateral spreading) only. The drawback of this study model is that in a clinical situation, the mean pore size, shape of capillary and axial path of the capillaries will not be equal. Moreover, the model has not considered the swelling of fibers and assumes that there is no interaction between the absorbent and absorbate. The values assumed in the study are arbitrary though nearer to the actual situation as marked in data-sheets. As the result is expressed in percentages, the assumption assumes minor significance only. In addition, the ratio of super absorbent polymers added to increase the absorbency in PU, retards the absorbency capacity by swelling and physically reducing the absorption by blocking the capillary channels. However published experiments, in spite of all the drawbacks, have demonstrated that the employed mathematical models have been able to predict the trend of change with highest degree of accuracy [4]. Hence the results of the study could be safely extrapolated.

Conclusion

Clear, dry oral field contributes to the efficiency of the dental surgeon. A good absorbent needs to absorb faster and hold more fluid. Through the mathematical models, PU has been demonstrated to be an excellent material to retain and absorb oral fluids faster than conventional gauzes and cotton. In minor oral surgery, this will be an added advantage. Dentist need to be aware of the mechanism and efficiency of the various sponging products available. Selection and manipulation of sponging material based on the surgical field requirement would aid the surgeon to get a clear and dry field for comfortable surgery.

We hope that the basic knowledge presented in this paper will help the clinician to make a more educated and rational decision.

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