CHAPTER 4

EFFECT OF CORE STRUCTURE AND PLY NUMBER ON MECHANICAL AND HANDLING PROPERTIES OF DEVELOPED SILK BRAIDED SUTURES

4.1 INTRODUCTION

Silk from silkworm (*Bombyx mori*) has been an open choice of suture material for many years (Panilaitis et al. 2003). Silk fibre has flattened sides with an isosceles triangle cross-section resulting in a secure knot (Gurumoorthy et al. 2013). In general, natural silk fibres are considered to be biocompatible as human tissue culture cells can grow and get attached to them. This indicates that silk does not create any threat to the patient and does not behave as a possible foreign antigen (Baier 2006). Silk sutures are found to have low tensile properties and prone to microbial infections. Few studies were made on the effect of braiding parameters on suture properties. However, there is no published information available, which elucidates the influence of core structure and ply number on resultant properties of suture. This chapter focuses on the construction of different suture materials and to evaluate the influence of core structure and ply number on mechanical and handling properties of braided silk suture.

4.2 MATERIALS AND METHODS

Preliminary process of preparing the silk yarn from *Bombyx mori* silk filament was described in Chapter 3. Twelve different suture structures were constructed by introducing core to the suture and by changing the ply number of the sheath 12 and 16 filaments. Table 4.1 details about the construction of twelve different suture structures.
Table 4.1 Construction details of braided silk sutures

<table>
<thead>
<tr>
<th>Ply</th>
<th>3 ply</th>
<th></th>
<th>4 ply</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of filament</td>
<td>12</td>
<td>16</td>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>Structure</td>
<td>without core</td>
<td>with 3 ply core</td>
<td>with cable yarn core</td>
<td>without core</td>
</tr>
<tr>
<td>Sample code</td>
<td>S1</td>
<td>S2</td>
<td>S3</td>
<td>S4</td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>0.48</td>
<td>0.5</td>
<td>0.56</td>
<td>0.52</td>
</tr>
<tr>
<td>Denier</td>
<td>841</td>
<td>874</td>
<td>1009</td>
<td>1240</td>
</tr>
</tbody>
</table>
4.3 EFFECT OF CORE STRUCTURE AND PLY NUMBER ON TENACITY AND ELONGATION OF SILK SUTURE

The tenacity of a suture is very important for a surgeon in making a knot as it can easily break if tenacity is lesser than the knotting force (Kem et al. 2013). Tensile properties of braided silk sutures are shown in Figure 4.1. The results revealed that, the tenacity of sutures was in the range of 30 cN/tex to 40 cN/tex and increased with an increase in diameter of the braided structure. This result confirms with the previous study, that the yarn structural parameter (USP size/diameter) plays an important role in determining the strength of suture material (Gurumoorthy et al. 2013). Diameter varied according to the presence and absence of the core and the type of core. It is also clear from Figure 4.1, that for the same diameter of 0.5 mm, S2 showed higher tenacity of 33.17 cN/tex than S7 with 32.34 cN/tex and for the same diameter of 0.56 mm S3 showed higher tenacity of 34.45 cN/tex than S5 with 34.24 cN/tex. It proves that the suture with core possessed more tenacity than coreless suture and the suture with cable core possessed tenacity more than the suture with 3 ply core. This may be due to higher load bearing capacity of the cable core yarn. Cable core gives a balanced structure and remains straight and does not have a tendency to twist upon itself like 3 ply core or protrude through the sheath (core popping) (Zusammenfassung 1995). In contrast to the studies made by Husain & Pal (1997) in cored and coreless cordages, in which coreless cordages found to have good breaking strength compared to cored cordages stating that a uniform distribution of load on sheath yarns was achieved which resulted in the better translation of yarn strength to the coreless cordage.
It is worth mentioning that cored suture generally assumes a round cylindrical shape which is not generally assumed by a coreless suture. When the suture has to pass through the tissues, round shape is important for easy stitching and removal of stitches.

Figure 4.1 also shows that the tenacity of the sutures with 4 ply yarn (S9) is more than the sutures constructed with 3 ply yarn (S6) for the same diameter of 0.6 mm. The reason was well explained by Sengupta et al. (2000) in their research work, that the increase in the ply number improves the regularity and inter yarn radial force which results in an effective contribution of fibre length towards tenacity and better packing of the structure. The sutures S3 and S1 showed highest and lowest elongation values and no correlation existed between the tensile strength of a suture and its elongation (Gurumoorthy et al. 2013; Rajendran & Anand 2002).
4.4 EFFECT OF CORE STRUCTURE AND PLY NUMBER ON KNOT STRENGTH AND ELONGATION OF SILK SUTURE

It is important for a suture material to support the wound healing by providing proper tissue unification without slippage, breakage and untying. From Figure 4.2 it is observed that, in all the samples knot strength and elongation were decreased due to internal fibre fracture. Knotting always induces decrease in mechanical properties (Shanmugasundaram et al. 2011).

![Figure 4.2 Knot properties of suture samples](image)

These results are consistent with previous findings (Gurumoorthy et al. 2013) that knot being the weakest part of any suture and failure of suture occurs only at the knot signifying that knot itself causes an area of high stress concentration. There are several factors contributing to the suture breakage at the knot. First, due to orientation of force at the knot point at an acute angle to the thread axis. Second, due to the weakening of suture yarn at the knot area during knot construction and loading. Third, the failure of knot caused by the tightening and friction between the yarns (Abdessalem 2009). Present study correlates with the third factor of suture breakage. Suture with cable yarn core
resists the frictional force while knotting, due to its balanced flexible structure. Whereas the 3 ply core gets twisted inside the sheath and increases the friction. Knot strength of the ply yarn followed the similar trend of tenacity.

4.5 EFFECT OF CORE STRUCTURE AND PLY NUMBER ON BREAKING STRENGTH OF SILK SUTURE

The breaking strength of a suture is the limit of tensile strength at which suture failure occurs. Suture is considered to be failed, when tearing occurs in the skin or the suture itself. It is seen from the Figure 4.3 that the breaking strength of all samples has same trend as tensile strength (Lai 2010).

![Figure 4.3 Breaking strength of suture samples](image)

4.6 EFFECT OF NORMAL LOAD ON FRICTION

Type of suture material, its construction and tension applied on the suture material are the variables which determine the coefficient of friction. A constant sliding speed of 50 mm/min was used to study the friction by varying the load (Gupta et al. 1985). It is observed from the Figure 4.4 that as the load
increases from 20 g to 100 g there is a decrease in coefficient of friction in all silk suture samples. This result matched with the studies made in several research works (Gowda & Mohanraj 2008; Das et al. 2005) and can be well explained by adhesion theory of friction, which states the decrease in true area of contact with increase in normal pressure. Coefficient of friction gets decreased with increased normal load due to the nonlinear relationship between the change in normal load to the change in real area of contact (Das et al. 2005).

![Figure 4.4](image_url)  
**Figure 4.4 Effect of normal load on co-efficient of friction of sutures**

### 4.7 EFFECT OF SLIDING SPEED ON FRICTION

The effect of various sliding speed on coefficient of friction of braided silk sutures is given in the Figure 4.5. A normal load of 50 g was taken to study the coefficient of friction at varied sliding speeds. A decrease in the coefficient of friction can be observed as the sliding speed increases from 20 mm/min to 100 mm/min.
This behavior was explained by Das et al. (2005) in their research work that, as the sliding speed increases, time of contact between the sliding members decreases which results in the reduction of actual number of contact points. So the bonds are broken easily at the junction points resulting in reduced frictional coefficient. In contradiction, Gowda & Mohanraj (2008) reported that there was no change in co-efficient of friction.

4.8 EFFECT OF CORE STRUCTURE AND PLY NUMBER ON COEFFICIENT OF FRICTION OF SILK SUTURE

It was observed from the Figure 4.4 and 4.5 that the suture with core gave high packing of yarns and less friction (Ramasamy et al. 2014). No specific difference was found in the co-efficient of friction for sutures with 3 ply core and cable yarn core.
At the same time suture with 3 ply sheath showed more friction than 4 ply sheath because the thread with flattened width are highly compressible and can easily rearrange themselves into the restricted spaces and are subjected to less friction (Rengasamy & Samuel 2011).

4.9 EFFECT OF CORE STRUCTURE AND PLY NUMBER ON BENDING PROPERTIES OF SILK SUTURE

Coarser yarns have high bending rigidity than finer yarns since, as size increases the stiffness increases significantly. Due to decreased flexibility of coarser yarns, tightening of the knot becomes difficult affecting the knot stability. So the suture yarn of smaller diameter would allow tighter knot and larger diameter would allow looser knots (Gurumoorthy et al. 2013). But to contradiction, Figure 4.6 represents that the sutures with cable core provided less bending rigidity than suture with 3 ply core and coreless suture. For same diameter S3 had lower bending rigidity value than S5. This indicates that S3, S6, S9 & S12 suture samples with cable yarn core contained good flexibility inspite of their increased diameter. Cable yarns appear to allow the most flexible mechanical outcomes with highly organized geometry (Horan et al. 2006). Bending deformation is a very low load phenomenon where the role of radial forces is insignificant. Relative fibre mobility within and between the component yarn was higher with an increase in the ply number of ply which reflected in lower bending rigidity (Sengupta et al. 2000). Same trend can be seen in the Figure 4.6, which shows less bending rigidity value of 0.00014 N/m³ for suture constructed with 4 ply yarn (S9) than 3 ply yarn (S6) with a value of 0.00013 N/m³ for same diameter.
4.10 CONCLUSIONS

- Twelve different silk braided sutures were produced using a circular braiding machine with 12 and 16 carrier arrangement. All the twelve structures were evaluated for the mechanical and handling properties.

- The diameter of the sutures ranged between 0.48 mm to 0.7 mm. As the diameter of the suture increased strength of the suture also increased. Effect of core and ply number on mechanical properties of suture were studied. Four conclusions were arrived from the suture tensile data analysis. Firstly, cored suture exhibited higher tenacity, knot strength and breaking strength than core less suture of same diameter. Secondly, suture with cable core possessed more strength values than 3 ply core for same diameter. Thirdly, for the same diameter suture constructed with 4 ply sheath exhibited higher strength values and lower bending rigidity than suture constructed with 3 ply sheath. Fourthly, it was observed that there was no correlation
between tenacity and elongation % of the suture. S3 and S1 showed highest and lowest and lowest elongation values of 21.63% and 20.03% respectively.

- Frictional properties of the suture structures were studied by increasing the normal load from 20 g to 100 g with constant sliding speed and by increasing the sliding speed from 20 mm/min to 100 mm/min with constant load. For all the structures, it was observed that there was a decrease in the coefficient of friction with increase in normal load and sliding speed. It was also observed that co-efficient of friction values were less for sutures constructed with core and 4 ply sheath yarn.

- Sutures with cable core showed less bending rigidity inspite of increased diameter. It was seen that for the same diameter, suture with 4 ply sheath exhibited lower bending rigidity than suture with 3 ply sheath.

- Based on the above study, sutures constructed with cable core (S3, S6, S9 and S12) met the required tensile and bending properties. All these four sutures have their own properties based on diameter and construction. Considering further processes, treatments and property requirement for wound healing studies aimed in this research, suture sample S3 was taken for further study.