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REVIEW OF THE TRIBOLOGICAL CHARACTERISTICS OF SYNOVIAL FLUID

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Abstract

Movement of the knee joint requires an effective lubrication mechanism. Synovial fluid is reported to serve this function. Synovial fluid is an extra cellular biofluid present in the synovial joint of living beings. Numerous studies have been conducted on the characteristics of synovial fluid. Total Knee Replacement is seen as a permanent cure to acute arthritic condition. Synovial fluid supplementation is seen to enhance the life of Total Knee Replacement Joints. Development of an effective synovial fluid for this purpose is being researched worldwide. This paper reviews the properties of synovial fluid as reported under various studies and can form the basis for development of a good artificial synovial fluid.

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Nomenclature

SF	synovial fluid
HA	hyaluronic acid
OA	Osteoarthritis
ECF	Extra cellular fluid
SAPL	Surface active phospholipids
PRG 4	Proteoglycan 4

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1.0 Introduction

Arthritis is seen as a major health problem of the world. According to “Center for Disease Control and Prevention” arthritic patients will increase to 67 million by 2030 in the US [1]. It is understood that Arthritis affects 15% people i.e. over 180 million people in India [2]. This prevalence is higher than many well known diseases like diabetes, AIDS and cancer [3]. This alarming situation indicates more intensive study in this regard and the need for precise diagnostics and more effective treatment for the patients. More than 100 forms of arthritis have been reported [4]. Among these, two major types of arthritis are found to be very common. They are osteoarthritis and rheumatoid arthritis. In Osteoarthritis the cartilage loses its elasticity. If the cartilage is stiff it has more chance to get damaged easily. The cartilage, which acts as a shock absorber, will gradually wear away in some areas. When the cartilage becomes damaged, tendons and ligaments become stretched, resulting in pain. Eventually the bones may rub against each other causing very severe pain. This generally affects elderly patients. Rheumatoid arthritis is an inflammatory form of arthritis. The synovial membrane (synovium) is attacked, resulting in swelling and pain [5]. If this is not treated, the arthritis can lead to deformity. It is found that this arthritis is significantly more common in women, than men and generally strikes when the patient is aged between 40 and 60 [5]. However, children and much older people may also be affected by this disease. Though it can happen in childhood itself, the chances are more over 65 years of age. Studies show that 24.3% women and 18.7% men are affected by this disease [1]. Main cause of this joint pain is seen to be the absence of sufficient synovial fluid which leads to the failure of boundary lubrication and thereby a direct bone to bone contact takes place leading to bone wear as well as pain [6]. It is seen that this situation can be corrected by total knee replacement and using synthetic synovial fluid for improved lubrication [6].

2.0 Synovial fluid- A Gifted Biofluid for Joint Movement

There are two different kinds of biofluids such as intracellular and extracellular fluids (ECF). ECF has fluid outside the cell and it includes interstitial fluids, lymph and blood. Intra cellular fluids are the liquids found inside the cell. Intracellular fluids contain 62.5% of body fluids and the remaining 37.5% is the extra cellular fluids [6]. Any change in intracellular fluid will lead to health problem [7]. Synovial fluid is reported as a thick, stringy fluid found in the cavities of synovial joints. With its egg-like consistency ("synovial" partially derives from *ovum*, Latin for egg), synovial fluid reduces friction between the articular cartilage and other tissues in joints to lubricate and cushion them during movement. A synovial membrane which is the inner liner of articular cartilage produces synovial fluid. The micro folds of this membrane are in response to joint movement and manage the intra articular pressure [8,9]. The presence of the synovial fluid was first cited in “Of the Places of Man” - a Greek Hippocratic text [10]. Another earlier reference was from “Galen”- a Roman physician in his text “On the Functions of Parts of the Human Body” [10]. The quantity of synovial fluid in knee joint has been reported to vary from 0.5 to 2 ml [11]. The volume can be as little as 0.2 ml [12]. The large number of studies published in world scientific literatures in recent years points to the importance of the subject. A review published in French compiled the International literature from 1972 to 1975. It categorizes physico- chemical properties and the composition of the synovial fluid [13].

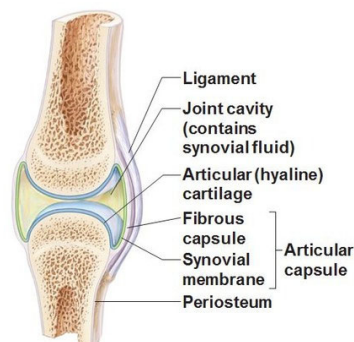


Fig.1. Schematic view of synovial joint [adapted from studyblue.com/notes/lecture 5 joints and articulations]

3.0 Composition of Synovial Fluid

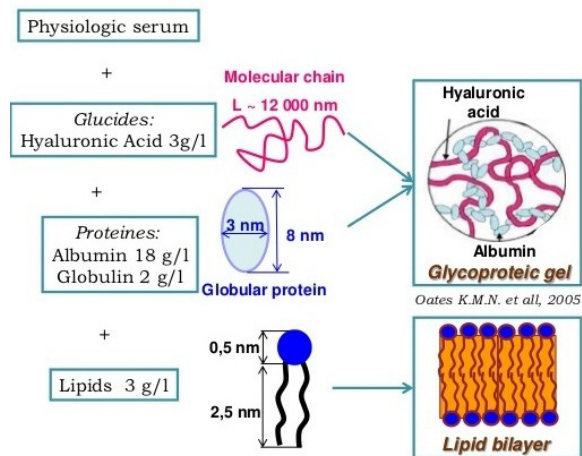


Fig-2 Composition of Synovial fluid [adapted from slideshare.net]

Synovial fluid is blood plasma dialysate composed of hyaluronic acid [14, 15]. The protein content is about 2% and is identical with the blood plasma [16, 17, 18]. A synovial joint is shown in Fig 1. Lubrication in the natural synovial joint is executed by the utilization of synovial fluid. Synovial fluids contain proteoglycan 4 (PRG4), hyaluronic acid (HA), and surface active phospholipids (SAPL) [19]. These lubricants are secreted by chondrocytes in articular cartilage and synoviocytes in synovium, and concentrated in the synovial space by the semi-permeable synovial lining. A deficiency in this lubricating system may contribute to the erosion of articulating cartilage surfaces in conditions of arthritis [7]. The molecules of Synovial fluids have been detailed in Table. 1[20-24].

Table 1. Constituents of synovial fluids

Molecules	Notation	Concentration
proteoglycan 4	PRG 4	0.05-0.35 mg/ml
hyaluronic acid	HA	1-4 mg/ml
surface active phosphor lipids	SAPL	0.1 mg/ml

4.0 Tribological Properties of synovial Fluid

Tribology deals with the study of interacting surfaces in relative motion. Movement causes friction between mating parts generating wear which is reduced by a lubricant which brings down friction and provides a separation between the two surfaces in contact.. Main function of synovial fluid is to act as a lubricant. The proteins and hyaluronic acid present in the synovial fluid performs the same role as additives in standard lubricants by enhancing the lubricating efficiency [25-28]. Lubricating ability of synovial fluid is linked with its rheological property. Rheology refers to the study of deformation and flow of fluids under pressure. Viscosity is considered as the standard property which needs to be determined initially [29]. Viscosity of synovial fluid is seen to vary with the shear rate. Synovial fluid can be collected from the joint by means of aspiration through a syringe. Viscosity is seen to be reduced if the joint is inflamed. Primary viscosity reduction of synovial fluid can be identified by dropping it from the aspirated syringe.

Sufficient viscosity is indicated if it forms a string about 4-6 cm long while dropping. A free flow from the syringe indicates a reduction of viscosity and a diseased joint [30]. The collection of normal synovial fluid is very difficult since its quantity is very less in the joint. Therefore most of the analysis is taken from the post-mortem collection. However the specimen taken post-mortem may be diluted after death [29, 30]. Normal synovial fluid has a clear pale yellow colour. A difference in colour is seen to indicate a diseased joint. Values of viscosity reported under studies by various researchers are tabulated in table 2

Table-2. Viscosity values from different studies

Viscosity at zero shear rate, η_0 (Pa s)	Collection Method	References
>20	Normal aspiration	Cooke et al [31]
10-34	Normal aspiration	Safari et al [32]
1-40	Post-mortem	Schurz , Ribitsch [33]
6-12	Post-mortem	Schurz [34]
29	Normal	Mazzucco et al [23]
83	Normal	Petcharatana B [35]

Elastic modulus (storage modulus) by G' and Viscous modulus (loss modulus) G'' have been reported by various researchers and are tabulated in table 3

Table-3. Storage and loss moduli for synovial fluid in different study in 0.1 Pa
Data are presented as mean \pm standard deviation

G' (Pa)	G'' (Pa)	Reference Study
18.9 \pm 3.3	10.1 \pm 1.2	Balazs [36]
1.9 \pm 0.5	1.4 \pm 0.3	Muzzucco et al [23]
3.55 \pm 0.56	2.51 \pm 0.26	Petcharatana B[35]

6.0 Scope and future work

After reviewing thirteen papers published from 2003 to 2013 it is found that four major biological components of synovial fluid named albumin, globulin, hyaluronic acid and lubricin have an influence on film thickness, friction coefficient and wear rate [36-40]. An appropriate synovial fluid component has to be developed in the place of bodyfluid. Future work can be focused on the effectiveness of visco supplements in osteo arthritis patients and categorically establish the functional as well as characteristic similarity of these fluids. The presence of synovial fluid in joint cavities provides a lubricating effect for the joint [41-43]. These biological phenomena can be simulated and analysed using force analysis software and modeling. The consistent rheological property values can be obtained by limiting the controlling features.

6.0 Conclusion

The importance of an effective Synovial fluid is essential for the smooth functioning of the knee joint. Viscosity and colour of the synovial joint are main parameters that have been reported to be associated with healthy knee joints. There is a wide range of viscosity values and it could be the post-mortem condition and the patient's characteristics. More close values may get if we limit the controlling parameters and by using more precise instruments. Total knee replacement is seen to be an effective cure to acute arthritic problems. In this case the joint life is seen to be increased when supplemented with synthetic synovial fluid. There exists a scope for producing artificial synovial fluids for this requirement. The properties reported through various studies can be used as a base for development of an effective artificial synovial fluid which can enhance Total knee replacement joint efficiency.

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