Improving the tribological efficacy of viscosupplementation in the knee joint by the synergetic behavior of albumin

D.Prekasan, K.K.Saju, Shybu Varghese

Abstract - The effectiveness of viscosupplementation in the knee joint is not consistent and this cannot stop the wear rate of cartilage. The study carried out by the author revealed the effectiveness of viscosupplementation. This work is focused on the improvement of the efficacy of tribological behavior in viscosupplementation and reduces the wear rate of cartilage by adding albumin in hyaluronic acid (HA). The methodology is unique by using a bovine plug as the pin and the synovial fluid is prepared by ultrasonically mixed with HA and Albumin. The albumin injection and HA injection fluids added in different ratios like maximum, minimum and an average. HA and 20% albumin injection mixed by ultrasonic mixing in 1:3.5, 2.5:0.2, 4:0.35 by ml. Bovine femur plug specimen specially prepared for wear test on a pin on disc apparatus is used for the study. Rheological tests are carried out for the specific mixtures in the Anton Par tribometer. It is observed that the addition of a particular amount of albumin can reduce the wear rate and increase the viscosity of the HA.

Keywords- albumin, hyaluronic acid, pin on disc, rheology, surface-active phospholipids, tribology, viscosupplement.

1 Introduction

THOUGH the easiest and low-cost remedy for osteoarthritis is viscosupplementation, the majority of the Doctors do not prefer this method [1]. American society of orthopedic surgeons (AAOS) stating that HA injection is inconclusive and they strongly oppose it [2]. This is because of the lack of strong and scientific support of viscosupplementation. But the Journal of International organization of Arthroscopy and also the Knee Surgery and Orthopaedic Sports Medicine are promoting the viscosupplementation [3]. The consistency of the viscosupplementation is in a cross argument. The author presented the tribological behavior of synovial fluid that exists in human joints [4] After analysing the vibroarthrography, Dawid Baczkowicz et al stated that viscosupplementation may improve the function of the synovial joint [5]. Injecting the hyaluronic acid, one of the major component of synovial fluid, is termed as Viscosupplementation. Balazs introduced the viscosupplementation as a new concept for the treatment of osteoarthritis in 1993 [6]. But till now this method is not widely used in the treatment of osteoarthritis. A lot of studies ensured the effectiveness of viscosupplementation [7],[8],[9],[10]. Rebenda et al noticed the synergetic effect of hyaluronic acid with albumin [11]. Cross-linked viscosupplement is more effective than non-cross-linked [12]. The author was proved the tribological effectiveness of hyaluronic acid injection [13].

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2 Synovial fluid –A novel biofluid

Synovial fluid possesses salient ingredients of glycoprotein and phospholipids. Albumin spreads over globulin by hydrophobic bonding after the creation of globulin coating on hydrophilic cartilage surface and phosphatidylcholine spreads over a hydrophilic surface of albumin by the formation of phospholipids by layer[14]. Easy articulation of joints is achieved by synovial fluid. The synovial membrane produces synovial fluid. The synovial fluid contained molecules that decreased friction and wear properties of the articulating cartilage. The synovial fluid performs lubrication by providing proteoglycan 4 (PRG4), hyaluronic acid, and surface-active phospholipids (SAPL)[15]. Synovial joints have a little coefficient of friction [16]. This fluid acts as a lubricant in every joint. But the quantity that exists in the joint is as low as 1 to 2 ml [17]. SF is a highly viscous fluid with a low strain rate and it shows a high elastic property at high strain rates [18]. The value of viscosity ranges from 1 to 83 Pa S at zero shear rate [19],[20],[21],[22]. SF is a low coefficient of friction fluid which protects the cartilage from distracting force [23],[24]. In normal SF the pH value ranges from 7.3 to 7.43 [25]. SF is a non- Newtonian fluid and its viscosity depends on the shear rate [26]. Rheological properties of cartilage and SF are the major reason for effective lubrication in the Knee joint [18]. Several lubricating models prescribed for knee lubrication such as hydrodynamic lubrication, boundary lubrication, osmotic lubrication, mixed lubrication, elastohydrodynamic lubrication, weeping lubrication, boosted lubrication and squeeze-film lubrication [27], [28],[29]. In this, the most accepted models are mixed lubrication and squeeze- film lubrication [30].

3 HYALURONIC ACID AND VISCOSUPPLEMENTATION

HA is the major constituent of SF. It contains 1-4 mg/ml of SF[31],[32]. HA has a molecular weight range of 4-7 MDa[32],[33]. HA is a linear glycosaminoglycan consisting of D-glucuronic acid and N-acetyl-D-glucosamine linked alternately [34]. HA concentration is abundant in rooster comb and in human umbilical cords. HA has been produced in industrial scale from these sources until the growing concern about the animal-derived products for biomedical. Therefore microbial fermentation was evolved in 1989. Injecting HA in arthritis joint is termed as viscosupplementation and this treatment is effective for initial stages as mentioned early. But the result is not consistent and some scientific research evidences questioned the effectiveness of this treatment. This research backups the viscosupplementation with tribological and rheological evidence.

4 METHODOLOGY

'Pin on disk apparatus' is used for wear testing. Test results obtained from the prepared composition of viscosupplement is compared with that of presently using hyaluronic acid. In order to experiment the same, the Bovine femur plug is used as the pin in the 'Pin on Disk apparatus' which is lubricated with viscosupplement.

TABLE 1

PROPORTIONS OF VISCOSUPPLEMENT AND ALBUMIN

SF constituents	Low Compound	Medium Compound	High Compound
Viscosupplement (HA)	1ml	2.5ml	4ml
Human albumin 20% Concentrated	0.35ml	0.2ml	0.05ml
Total quantity	1.35ml	2.7ml	4.05ml

This further envisages whether synovial fluid can be substituted with the viscosupplement. Hyaluronic acid and human albumin are to be used in different ratios for manufacturing the viscosupplement as in Table 1. Albumin used is 20% concentration which is widely used as injections. The first ratio is prepared by adding a maximum value of hyaluronic acid in SF and the minimum value of Albumin present in SF. The second ratio is prepared by taking the average values of hyaluronic acid and Albumin. The third composition prepared by mixing the minimum value of hyaluronic acid and the maximum value of Albumin. Tested the prepared compounds in pin on disc for 60 sec and weighed the pin after the abrasion. Three runs are carried out and the mean value is taken for weight loss for each composition. The composition is tested in the rheometer for rheological properties. Tribological and rheological properties are plotted and then compared with properties of HA.

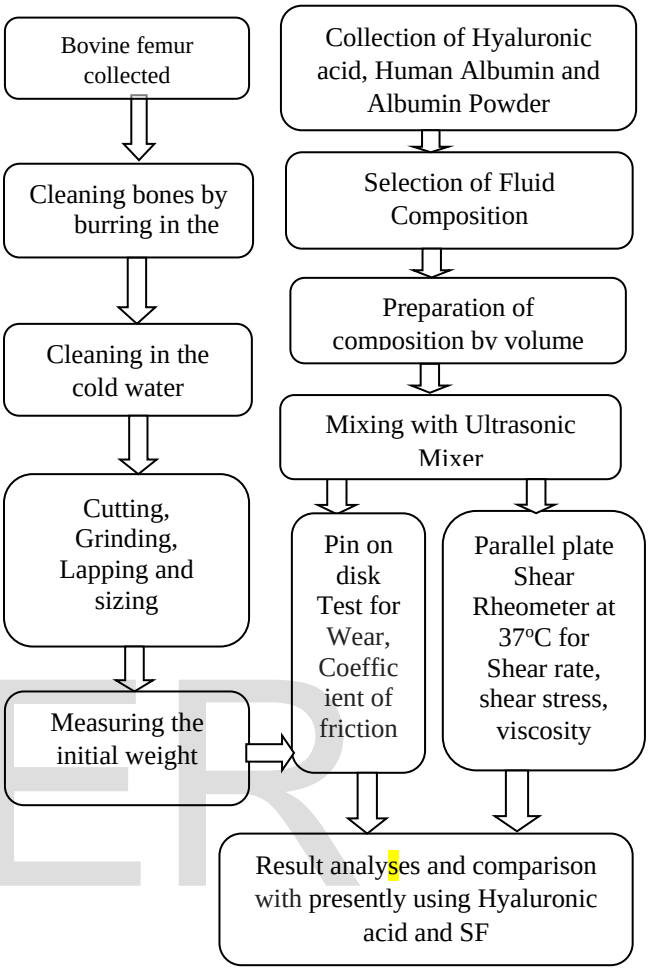

Fig. 1. The flow chart representation of the methodology

4.1 Experimentation procedure

A femur bone is procured from the local butcher shop and prepared after removing the flush. The bone is cleaned with a potassium permanganate solution and cut to the required length. The plugs are sized 50mm length and 5x5 mm cross-sectional area. The plug end is ground and lapped for surface smoothness. Hylasto-one HA injection is used for this experiment. Hylasto-one is mixed with 20% concentrated albumin injection in different ratios by ultrasonic mixer as per Table 2. Since the minimum quantity required for the pin on disc as well as a rheometer is 3ml, the total volume of mixer samples limited to 3 ml. Three samples prepared and it is used as the lubricant in pin on disc wear test by the femur plug. Each sample tested three times with the same controlled parameters and the mean value is taken for weight change. Velocity is kept as 5m/s and 10 N load is given to keep the plug press firmly on the disc. The high-velocity test reveals the maximum wear behavior of the plug. Each test lasts for 60 seconds.

Pin on disc test focused on the wear rate of the bovine plug, therefore the selected speed was high and also selected maximum load. Each plug weighed in an electronic weighing machine, prior to abrasion and after abrasion. The prepared samples of lubricants continuously fed to the abrasion tip of the plug by a specially prepared system while the disc is running with plug. Data are collected and analysed by the LabVIEW software.

TABLE-2
SAMPLES PREPARED WITH PRESCRIBED RATIOS

Sl.No.	Fluid Composition in ml	Instrument used	Sample No.
1	HA & Albumin 6:2.100	Pin on disc	S1
2	HA & Albumin 6:0.480	Pin on disc	S2
3	HA & Albumin 6:0.075	Pin on disc	S3
4	HA & Albumin 6:2.100	Rheometer	S1
5	HA & Albumin 6:0.480	Rheometer	S2
6	HA & Albumin 6:0.075	Rheometer	S3

The same samples are tested in the Anton Par rheometer to analyse the rheological properties. In both tests, the samples were kept at a temperature of 37oC. Graphs are plotted with the data and evaluated the performance.

5 RESULTS AND DISCUSSIONS

Fig.2 shows the wear rate is less in a particular composition of HA and Albumin instead of HA alone. When the presence of Albumin is more and the HA is low, the wear is less. When the Albumin concentration is low, the wear rate increases. This wear rate is more than the wear rate of HA alone. This composition is nearly a healthy synovial fluid composition.

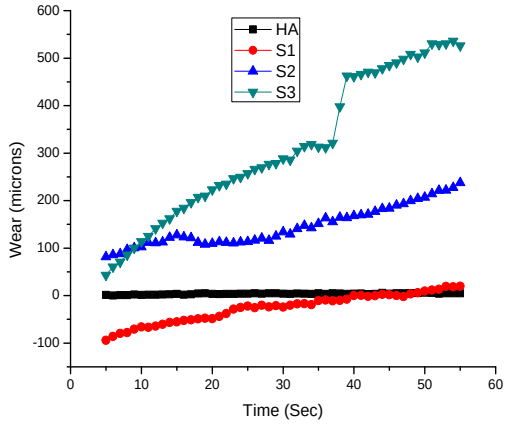

Fig 2 Wear comparison of HA and samples

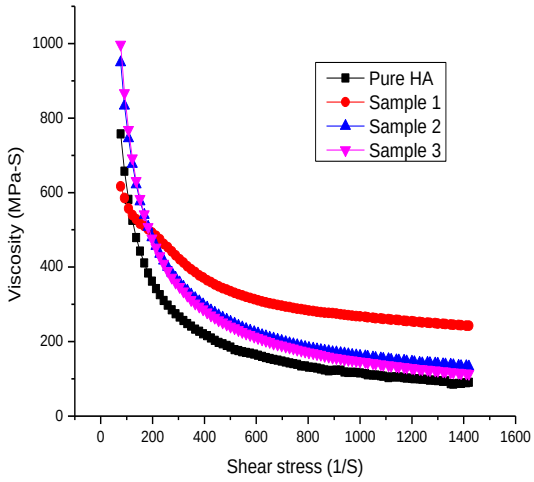

Fig.3 Viscosity comparison

Viscosity is plotted in Fig.3 and it is very clear that the viscosity can be improved by adding albumin. The S1 is the more realistic sample with the healthy synovial fluid and it gives the maximum viscosity. High viscous fluids prevent surface to surface contact and reduce wear.

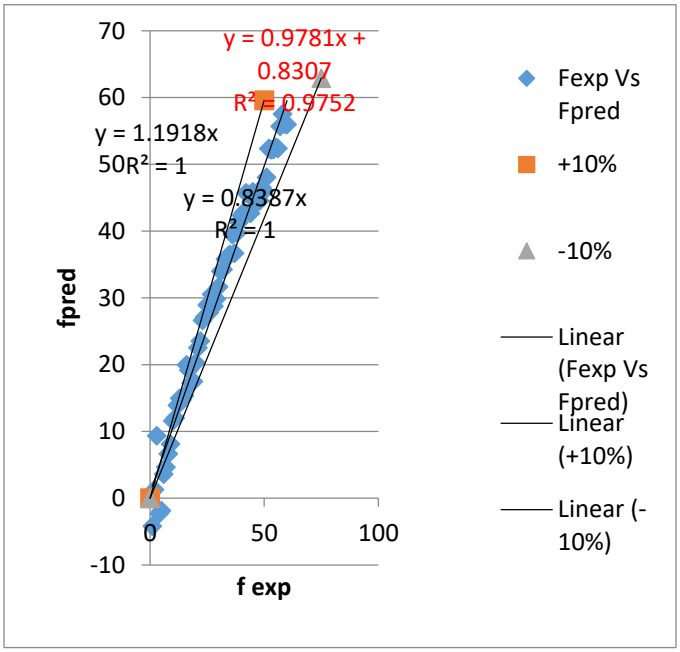

Fig.4 Comparison of predated results with experimental data

The predictions based on the models developed in the study were compared with the corresponding experimental results and are given in Fig. 4. The data points were found to be lying within the boundaries indicating ± 10% variation. This indicated that the predictions based on the models were in good agreement with the experimental data. Normalized value of wear and viscosity is correlated and the Pearson correlation gave -0161 and P-value 0.218. The data does not show any correlation with wear and viscosity for the sample1.

6 Conclusion

Viscosupplementation can reduce cartilage wear and the efficacy can be improved by adding albumin which is the constituents of healthy synovial fluid. To find out the correct combination researcher prepared maximum, minimum and average combinations of HA and albumin injections. Injections preferred because of the protocol limitation. The result shows effective wear reduction by using the realistic ratio of HA and Albumin combination in SF. The viscosity of HA can be considerably increased by adding albumin. But the correlation between wear and viscosity is not proven after normalizing the data statistically. The quantity of fluid is very limited between the cartilage surface in the knee joint and the viscosity property alone cannot prevent the wear. The result focused on the synergetic behavior of the albumin to this wear reduction.

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