Tribological effectiveness of viscosupplements for osteoarthritis in knee joint

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Abstract

Most common treatments for knee pain due to osteoarthritis are viscosupplementation and total knee replacement. Injecting hyaluronic acid in the knee can increase the viscosity of the synovial fluid (SF) considerably. Thereby, the lubrication properties of synovial fluid can improve and reduce the wear in cartilage. But certain studies reject the role of hyaluronic acid (HA) in alleviating knee pain. This experiment revealed the effectiveness of viscosupplementation. Wear test is carried out in a pin on disc apparatus, and the wear rate is calculated. Viscosupplement (VS) is added at different proportions in inflamed synovial fluid collected from osteoarthritis patients. Bovine femur plugs are used for wear test in 1/4th, 1/2nd, 3/4th concentrations of viscosupplement and in inflamed SF. Test is also carried out in pure HA. Tribological properties are tested in pin on disc wear testing machine. The rheological properties are also examined in these concentrations. The result shows that viscosity can be increased by adding viscosupplement. Shear stress is also increasing with the addition of viscosupplementation. VS can reduce the wear and the effect of viscosupplementation can be increased by aspirating the inflamed synovial fluid completely from the patient and injecting the viscosupplement in the knee.

Keywords Synovial fluid · Hyaluronic acid · Viscosupplement · Tribology

1 Introduction

As per the Arthritis Foundation, osteoarthritis is one of the major forms of arthritis among more than 100 types [1]. It is estimated that 52.5 million adults were affected from OA in 2010–2012 and it is projecting to affect 78.4 million by 2040 [2]. The report reveals that severe joint pain prevails in 45–64 and women are mostly affected [3]. Cartilage degradation is the major cause for osteoarthritis [4]. Synovial fluid (SF) existing in the joints acts as the lubricant in the moving joints and prevents wear [5]. When the synovial fluids get inflamed, it loses its tribological properties [6]. Most common treatments in knee pain are viscosupplement injection and joint replacement. Joint replacement requires an open surgery, and the lifetime of joint is estimated

as 25–30 years. In the other case, the viscosupplement treatment in osteoarthritis is not consistent in result. The effectiveness of viscosupplement is not confirmed. Some injections last for 2 weeks, but some may take as long as 6 months. The cost per injection ranges from 5000 to 15000 Indian rupees. Most of the studies agreed that the synovial fluid in the joint acts as a lubricant and prevents cartilage wear [7–10]. But some studies point out that hyaluronic acid which is a major constituent of synovial fluid has no role on the knee wear. In the journal of American family physician, it is stated that the result of hyaluronic acid injection having mixed result [11]. American Society of Orthopaedic Surgeons are strongly against the HA injections [12]. In the recent guideline of National Institute for health and Care Excellence of UK, the HA injection is prevented for the OA treatment

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[13]. But HA injection is promoted in the journal of International Society of Arthroscopy, Knee Surgery and Orthopaedic Sports Medicine [14]. So, there is no common opinion regarding this procedure. The characterization of synovial fluid is yet to be exposed [15]. So, this experiment focused on the role of viscosupplementation in knee lubrication and wear. The study also aims to improve the effectiveness of viscosupplementation.

1.1 Tribological properties of synovial fluid

Synovial fluid has two functions, such as to lubricate the joints and to aid in nutrition of the cartilage [16]. The quantity of synovial fluid in the knee joint is very small, and it could be 0.5–2 ml [5, 17–19]. The major composition of synovial fluid is shown in Table 1 [9].

Viscosity is the major tribological property of the SF. The string test can evaluate the condition of SF. It forms a string about 4–6 cm long while dropping from an aspirated syringe and has a low coefficient of friction [25]. Normal synovial fluid has a clear pale yellow colour. It is very difficult to collect normal SF from human beings since the quantity is very limited. So, the test result mostly depends on the postmortem body. But the SF collected from the body may dilute after death [26]. The inflamed SF has a very low viscosity [27]. SF shows a wide range of viscosity in different collection (Table 2).

A number of lubrication mechanisms are suggested for knee joint. It includes hydrodynamic, fluid film, weeping lubrication, elastohydrodynamics, squeeze film, boundary lubrication, boosted and multi-mode lubrication [33–43].

Table 1 Composition of synovial fluid [20–24]

Molecules	Notation	Quantity (mg/ml)
Hyaluronic acid	HA	1–4
Proteoglycan 4	PRG4	0.05–0.35
Surface active phospholipids	SAPL	0.1

Table 2 Viscosity values from different references [8]

Viscosity at zero shear rate, η_0 (Pa s)	Collection method	References
> 20	Normal aspiration	Cooke et al. [28]
10–34	Normal aspiration	Safari et al. [29]
1–40	Postmortem	Schurz and Ribitsch [30]
6–12	Postmortem	Schurz [31]
29	Normal	Mazzucco et al. [23]
83	Normal	Petcharatana [32]

1.2 Viscosupplements

Hyaluronic acid (HA) is the major constituent of synthetic synovial fluid or viscosupplement (VS). HA is a carbohydrate particularly a mucopolysaccharide. It is a linear polyanion, and its function is to maintain elastoviscosity of the fluid [44]. The concentration of HA in rooster comb and human umbilical cords is very high. Now, HA is produced commercially from microbial fermentation [45]. Many pharmaceutical manufacturers produce HA commercially. Only 57% positive response is claimed by Bowman et al. [46] in their article named “Hyaluronic acid injections for osteoarthritis of the knee: predictors of successful treatment”. The effectiveness of this injection is not consistent according to the Doctors report. Injecting VS is costly, and the patient may need more than one injection. Synvisc, Hylan, Hylasto-one, Orthovisc, Euflexxa, Gel-One, Supartz are some of the VS available in market. This test is focused to confirm and improve the efficacy of VS injection in knee joint.

2 Materials and methods

For the above purpose, a VS is purchased from the market. Two types of tests were carried out: One test for finding out the rheological properties of the compound, and the other was the wear test on pin on disc. Inflamed synovial fluid is collected from osteoarthritis patients with their consent. The collected specimen fluid was stored in a cold storage. When sufficient quantity of fluid is received, the specimen is transferred from the hospital to the laboratory in a cold pack. The specimen then was exposed in the atmosphere to reach the atmospheric temperature. The aim was to keep the fluid within body temperature. The viscosupplement is brought from Cipla pharma. The rheological properties such as shear rate and viscosity of the viscosupplement are tested. 2 ml mixture of viscosupplement and inflamed synovial fluid was prepared as Nill, 1/4, 1/2 and 3/4% of concentrations. These mixtures are also tested in an Anton Paar rheometer. The rheometer was allowed to stabilize its temperature and the temperature set for 36 °C as human body temperature. Shear rate versus viscosity and shear stress are plotted for all the concentrations, and test result was compared.

The bone plug is prepared from bovine tibia. The knee joint was buried for 9 weeks to remove the flesh from the bone. The bone is cleaned with potassium permanganate liquid solution. Sized the bone and polished the end. Produced 5 mm square plugs with 30 mm length.

The end of the plug lapped and polished again with emery cloth. These pins are used for wear test in pin on disc apparatus. The initial weight of the pin is weighed in the digital weighing machine after ensuring the zero load. The bone pin plugged into the jaw of the disc and allowed to spin on the disc with a velocity of 5 m/s. The speed of the disc is changed according to the track selection. One minute duration is set for disc rotation with a load of 150 N. The compound of fluid supplied continuously between the pin and disc ensuring film lubrication. The weight is measured after the rotation, and the weight difference is calculated. All the four compounds are tested in a similar manner, and the wear rate is assessed. Wear versus coefficient of friction graph is plotted, and the result is analysed.

3 Results and discussions

The test is carried out at a constant temperature of 36 °C. Time taken for the pin on disc test was 1 min, and the load given was 150 N. Velocity is fixed as 5 m/s, and the tracks selected are 30, 40, 50 and 60 with rpm 638, 478, 382 and 320, respectively. LabVIEW is the software for pin on disc apparatus.

Wear is less when the VS concentration is increased as 0.75% concentration (Table 3). But wear slowly increased when the concentration reduced as 0.25% and 0.50%. Wear rate is reduced in higher concentration of fluids. In 0.75% concentration, the maximum value of weight difference is 0.0034 mg. This is the lowest weight loss ever measured in various concentrations. But in 0.25% concentration and 0.5% concentrations, the weight loss increased as 0.0069 mg and 0.006 mg, respectively. The maximum wear rate is obtained in the 0.5% concentration. The value is 228.0425405 micron. In 0.75% concentration of VS, the maximum value is reduced as 183.7927977 micron. But it is not less than the maximum value of 0.25% VS concentration. The maximum value in 0.25% VS concentration is 110.4808132 micron. This result shows the improvement of tribological properties of synovial fluid by adding viscosupplement. But the increased wear rate of 0.5% VS concentration needs an intensive study (Figs. 1, 2, 3, 4).

In the rheology meter, rheological properties are tested. Graph was plotted with viscosity in abscissa and shear rate

in mantissa. 0.25% and 0.5% concentration gives a non-steady nature of graph because of the inconsistency in tribological property, whereas the concentration increases, the result is more consistent and supports the efficacy of viscosupplementation in its rheological behaviour. Anyhow, there is no experimental evidence to connect the rheological properties.

Fig. 1 Wear characteristics of inflamed SF

Fig. 2 Wear characteristics of SF with 0.25% VS

Table 3 Weight measurement

Concentration	Initial weight (g)	Final weight (g)	Weight difference
Inflamed SF 0% VS	1.6533	1.6496	0.0037
0.75% VS	1.6496	1.6462	0.0034
0.5% VS	1.6462	1.6402	0.006
0.25% VS	1.6402	1.6343	0.0069

Fig. 3 Wear characteristics of SF with 0.5% VS

Fig. 5 Viscosity VS Shear rate

Fig. 4 Wear characteristics of SF with 0.75% VS

Fig. 6 Shear stress VS shear rate

The graph is plotted for inflamed SF alone and the different percentage of VS added solution namely 0.25%, 0.5% and 0.75% VS. In Fig. 5, shear rate is taken as constant and the variable is viscosity. By the analysis of graph, it is clear that the viscosity is increased by increasing the concentration of VS. Figure 6 shows the maximum shear stress is of 0.75% VS added SF. The maximum viscosity can be obtained for 75% viscosupplement concentration (Fig. 7). So, from the tribological point of view, injecting viscosupplement can reduce friction by lubrication (Fig. 8).

4 Conclusion

It is evidently proven that the synovial fluid has tribological properties and that prevent the knee joint from wear. The effectiveness of the viscosupplement is established

by adding viscosupplement at various percentages in inflamed synovial fluid which is collected from the patients. The role of viscosupplement in cartilage wear is not established completely. Even though the viscosity improved by adding 3/4th HA in inflamed SF, the wear rate shows higher. But by adding 1/4th HA, the wear rate can be controlled as in the case of inflamed SF. The concentration of HA in SF does not reduce the wear rate always. So, a further study is required to establish the role of VS in wear prevention. Anyway, the presence of viscosupplement increases the viscosity of SF significantly. High concentration of viscosupplement gives more effectiveness. It is always recommended to

Fig. 7 Wear of bovine pin in various concentrations

Fig. 8 Tribological characteristics of HA

aspirate the inflamed SF and inject HA fully. Complete injection is effective rather than partial injection of HA.

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Compliance with ethical standards

Conflict of interest The author(s) declare that they have no competing interests.

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