Acta vet. scand. 1976, *17*, 169—177.

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VISCOSITY OF EQUINE SYNOVIAL FLUID*

By

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REJNÖ, S.: *Viscosity of equine synovial fluid.* Acta vet. scand. 1976, *17*, 169—177. — Synovial fluid samples from 51 light horses were examined with respect to their rheologic properties. The analyses were made with a Rotovisco RV3 rotational viscosimeter. Samples from carpal, stifle and hock joints and from healthy joints, joints with synovitis and joints with infectious arthritis were studied. The analyses showed that synovial fluids from both healthy and diseased joints have complex rheologic properties. In most samples the viscosity varied with the shear rates, the main exceptions being synovial fluids from joints with infectious arthritis. Flow curves (flow behaviour), rather than single observations on viscosity, were considered to be representative for the synovial fluids examined.

viscosity; rheology; horse; synovial fluid; joint disease.

In the 17th century Newton proposed "that the resistance which arises from the lack of slipperyness of the parts of the liquid, other things being equal, is proportional to the velocity with which the parts of the liquid are separated from one another". Many liquids, such as water, alcohol, and all but the heaviest oils obey Newton's law and are thus called Newtonian. However, nowadays we know that many elastic materials show a more complex relation between stress and strain. In ordinary

* This investigation was supported by grants from professor Gerhard Forssell's stipendiefond, H. C. Lagers stipendiefond, Sveriges Veterinärförbunds forskningsfond, Virginska fonden, Jordbrukets försäkringsbolag. and Anslaget för främjande av ograduerade forskares vetenskapliga verksamhet.

parlance the words stress and strain are synonymous. The rheologist, however, uses the former term to refer to a force and the latter to mean changes of shape and/or volume. Viscosity is defined as the stress divided by the rate of change of strain-rate of shear. Many suspensions and emulsions show a fall in viscosity as the stress is increased, some show a rise. In some cases the fall in viscosity is slowly recovered on standing — thixotropism. When the structure, broken down by shearing, is recovered so fast that all that is observed is a fall in viscosity with increasing rate of shear, the original value being re-established when the shear rate is lowered, the material is said to show shear thinning. The reverse effect, i.e. an increase in viscosity with increasing shear rate, is called shear thickening.

Several investigations on synovial fluid viscosity have been presented in the literature. *Sundblad* (1953) calculated the intrinsic viscosity of synovial fluid using an Ostwald viscosimeter and Huggin's formula. *Persson* (1971) and *Persson & Nilsson* (1971) used the same methods to determine viscosity of normal equine synovial fluids. Similarly, *Nilsson & Persson* (1973) examined fluids from diseased equine joints. Several investigators on equine synovial fluid reported thixotropic or similar rheologic properties on gross examination (*van Pelt* 1962, *Gängel* 1970, *Persson* 1972). It has been claimed that capillary viscosimeters — as for example an Ostwald viscosimeter — are of limited value for measurements of fluids which are not Newtonian.

Recently, rheogoniometers or similar sophisticated instruments have been used in studies to characterize synovial fluids. It has been shown that synovial fluids are non-Newtonian, showing shear thinning in both normal and pathological conditions (*Scott Blair* 1974). At high shear rates they show Newtonian behavior. Among others *Hertel* (1974) has been able to demonstrate different rheologic properties of the synovial fluids of different joint diseases in man.

This study reports results obtained with a rotational viscosimeter in synovial fluids from healthy and diseased equine joints.

MATERIAL & METHODS

Samples of synovial fluid from 20 radio-carpal and intercarpal joints (17 horses) were analyzed. Four samples were from healthy joints, two from joints with infectious arthritis and 14 from joints with serous arthritis (synovitis). The criterion for the diagnosis of infectious arthritis was the isolation of pathogenic bacteria in the synovial fluid. The criteria for healthy joints and for the diagnosis of serous arthritis were the same as described by *Rejnö* (1976). Samples of synovial fluid from 33 tibiotarsal joints (25 horses) were analyzed. Eight samples were from healthy joints, four from joints with infectious arthritis and 21 from joints with synovitis. Samples of synovial fluid from 12 stifle joints (nine horses) with synovitis were analyzed. The horses in this investigation were thoroughbred, standardbred and half bred Swedish horses between six months and 12 years of age. All samples were stored frozen before the measurements. Measuring was performed at a constant temperature of 37°C with a Rotovisco RV3* (Gebrüder Haake, Karlsruhe, Western Germany). Flow curves were recorded on a Philips PM 8120 XY-recorder.

RESULTS

The synovial fluids from the clinically healthy carpal joints showed a marked pseudoplastic appearance. At higher shear rates the fluid became more Newtonian — shear thinning. Three out of four samples from healthy joints also yielded distinct rheopectic flow curves (Figs. 1 and 2). The viscosity at shear rate 958 s^{-1} varied between 7.2 and 15.2 cP (centipoise), namely 7.2, 7.2, 8.6 and 15.2 cP. In the cases of synovitis there were more flattened flow curves and consequently lower viscosity values. Also in these samples there was predominantly shear thinning and rheopexy, but in contrast to controls there were also samples with thixotropic flow behavior (Fig. 3). Both samples from infected joints had low viscosity (3.6 and 4.2 cP respectively) and no detectable flow anomaly; they showed Newtonian flow behavior (Fig. 4).

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* Measuring head 50, viscosity sensor system SV 1, factor A = 11.5, factor M = 3.83, factor G = 300. Rotor ∅ = 20.15 mm, length = 61.20 mm, cup ∅ 20.70 mm, length = 68.20 mm, acceleration and retardation = 100 rounds/min^2. Maximum rotational speed = 250 r.p.m.

In general the synovial fluid samples from the stifle and tibiotarsal joints had the same flow curve appearances as those from the carpal joints. There were flow anomalies such as shear thinning, rheopexy and thixotropism. The general tendency towards more flattened flow curves, lower viscosity values and more Newtonian behavior with increasing degree of inflammation was again noticed, although the results were not as consistent as those obtained with synovial fluid from the carpal joints. The results are summarized in Table 1.

Acceleration and retardation of the rotating cylinder in the rotational viscosimeter were linear, 100 rounds per min.^{2} from 0 to 250 rounds per min. and reverse. Shear rate (D) at each point of the flow curves may be calculated with the formula $D = M \cdot n$ ($n =$ rounds/min.) and is obtained in sec.$^{-1}$. Shear stress (τ) may also be calculated in each point of the flow curves by the formula $\tau = A \cdot s$ (dyn/cm^2) ($s =$ number of divisions on the graph). Viscosity may be calculated in each point of the flow curves by the formula $\eta = \frac{G \cdot s}{n}$ (cP). The factors G, M and A are given in the text under material and methods. In the figures arrows show which part of the curve is obtained at acceleration and retardation respectively.

Figure 1. Rheopexy. The synovial fluid examined was taken from a clinically healthy joint. The flow curve is slightly bent and becomes more flattened at higher rotational speed both at acceleration and retardation. The curve of retardation exceeds the acceleration curve at every point of the diagram. The viscosity value (in cP) of some coordinates were calculated from the diagram, and high differences were obtained within this fluid and even between two measurements within the same shear rate.

Figure 2. Rheopexy. The synovial fluid examined was taken from a clinically healthy joint. The same general qualities as in Fig. 1 are shown. However, there is a lower viscosity.

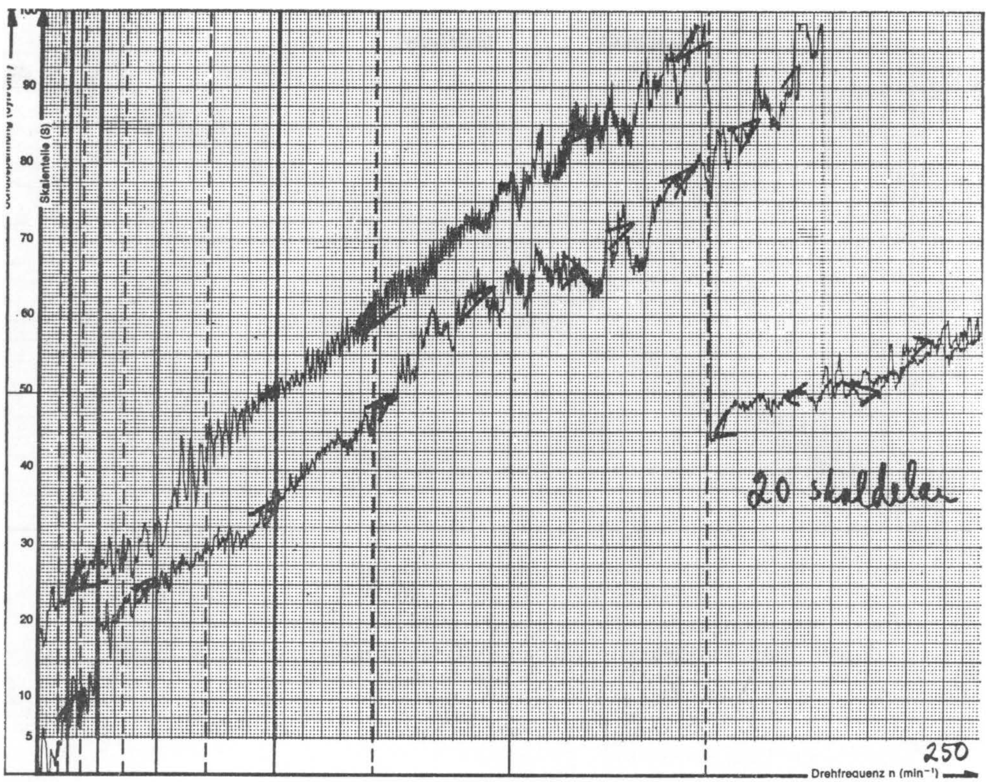


Figure 1.

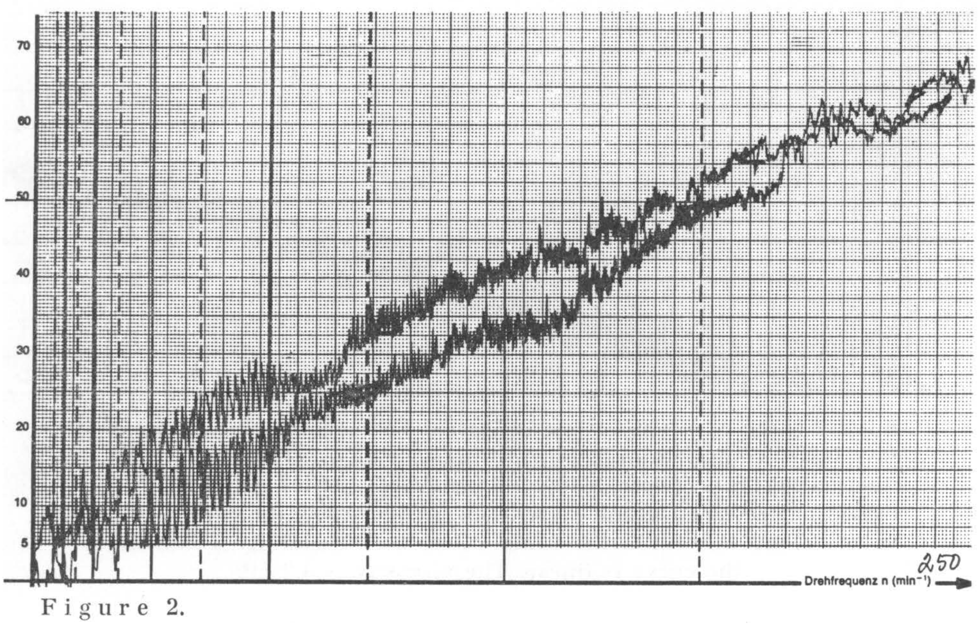
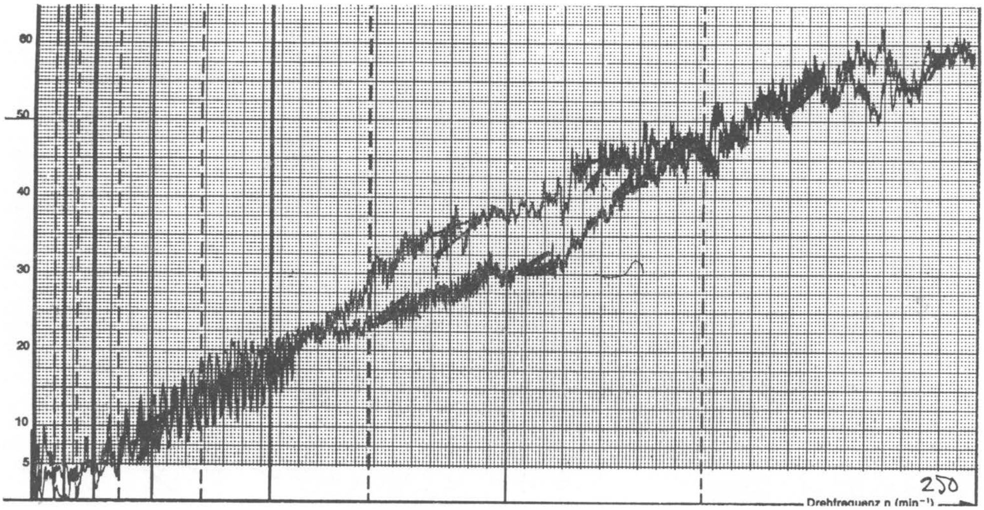
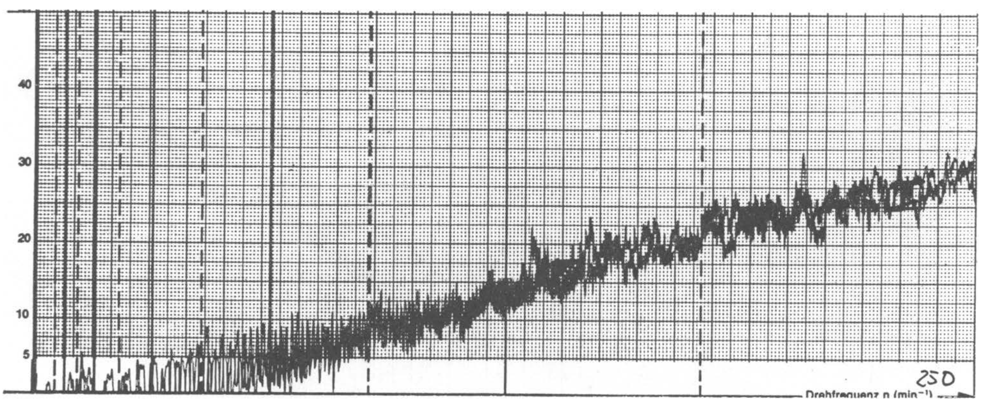


Figure 2.



F i g u r e 3. Thixotropism. The synovial fluid examined was taken from a joint with serous arthritis. The curve of acceleration exceeds the retardation curve. The viscosity values calculated are somewhat lower than in the synovial fluids from clinically healthy joints.



F i g u r e 4. Newtonian flow behavior. The synovial fluid examined was taken from a joint with infectious arthritis. The flow curve is linear and level. There is no distinguisable difference between the curves of acceleration and retardation. When calculating the viscosity values along the curve the same value was constantly obtained, as the curve is linear. The viscosity is 4.2 cP.

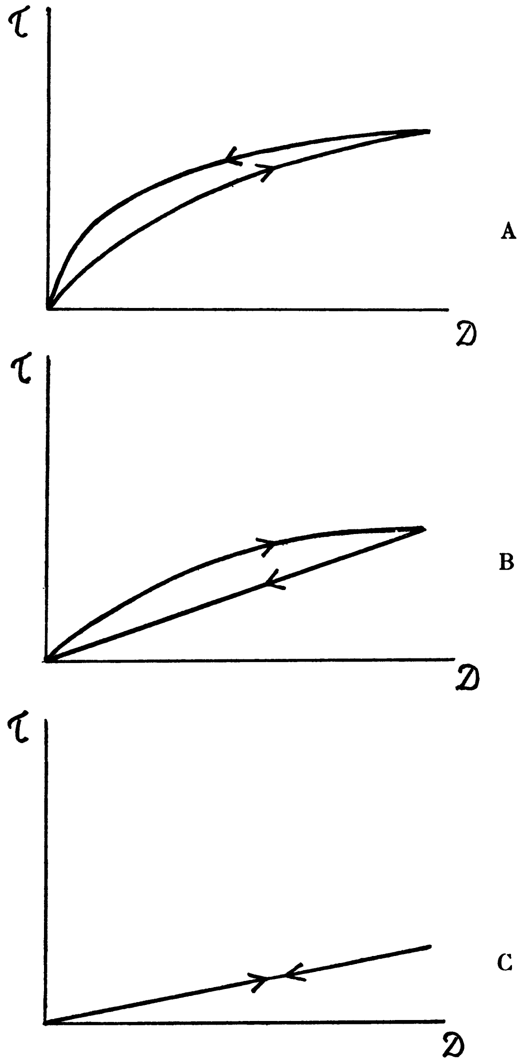


Figure 5. Schematic drawings of three different flow curves. A is a typical rheopectic flow curve, often found in synovial fluids from healthy joints. B is a typical thixotropic flow curve, often found in synovial fluids from joints with synovitis. C is a flow curve of a Newtonian substance, independent of shear rate. This type of flow curve was often found in synovial fluids from joints with infectious arthritis. τ = shear stress. D = shear rate. (Viscosity $\eta = \frac{\tau}{D}$).

Table 1. Flow behaviour of the synovial fluids from the different joints is summarized (n = numbers of analyses).

Fluids	Flow behaviour			
	Newtonian	thixotropic	pseudoplastic	rheopectic
Carpal joints				
healthy (n = 4)	0	0	1	3
synovitis (n = 14)	1	2	7	4
inf. arthritis (n=2)	2	0	0	0
Stifle joints				
synovitis (n = 12)	0	6	5	1
Tibiotarsal joints				
healthy (n = 8)	0	2	5	1
synovitis (n = 21)	6	9	2	4
inf. arthritis (n = 4)	4	0	0	0

DISCUSSION

Hertel (1974) stated that storage in room temperature for less than 1 hr. results in changes in the viscosity of synovial fluid, while storage in a freezer for some days does not influence the viscosity. The present material was frozen for several weeks and had been thawed once in the meantime before analyzing it. Therefore the viscosity values obtained may not be directly comparable to values reported by other investigators. However, all samples in the present investigation were treated in the same way. Therefore comparisons may be made between the results obtained from the different synovial fluid samples within the present material. The results are in general agreement with those reported by workers on synovial fluids from humans (*Scott Blair* 1974, *Hertel*). It was shown that synovial fluid from both clinically healthy and diseased equine joints have complex rheologic properties. Synovial fluids from healthy joints were pseudoplastic. Furthermore many of them were characterized by rheopectic flow curves, i.e. the viscosity values recorded at increasing shear rates were exceeded by those obtained when the shear rates were decreased (Fig. 2). In cases of mild inflammation, serous arthritis, the pseudoplasticity of the synovial fluid flow curves was less pronounced and lower viscosity values were obtained. In some cases the original viscosity values were not reestablished when the shear rate was lowered, which constituted thixotropism (Fig. 3). In cases of more intensive inflammation, infectious arthritis, no flow anomalies were recorded. Low viscosity values were obtained and the fluid was Newtonian (Fig. 4).

In the present investigation it was found that changes in flow anomalies rather than single observations on viscosity values may be representative for different joint diseases (Fig. 5). It is thought that the structural state of the hyaluronic acid molecules is important for the rheologic characteristics of the synovial fluid. Destruction, depolymerisation and/or reduced concentration of hyaluronic acid in the synovial fluid may be responsible for the alterations in flow behavior. Single observations on viscosity with unknown shear rate, which are obtained with capillary viscosimeters, give less information than the presented method when dealing with complex material like synovial fluid. The shear rates which may exist in vivo in different joints under different functional demands may be extremely difficult to estimate, and it is possible only to speculate on the physiological significance of the existing rheologic qualities. Further investigations in this field would be an important help to a deeper understanding of the physical properties and physiological significance of synovial fluid. Viscosity measurements on equine synovial fluid should be made with equipment which makes it possible to measure flow anomalies.

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SAMMANFATTNING

Viskositet i hästsynovia.

Synoviaprover från 51 varmblodiga hästar undersöktes med avseende på deras rheologiska egenskaper. Analyserna utfördes med en Rotovisco RV3 rotationsviskosimeter. Prover från karpal-, knä- och hasleder samt från friska leder, leder med synovit och leder med infektiös artrit undersöktes. Analyserna gav vid handen, att synovia från såväl friska som sjuka leder äger komplicerade rheologiska egenskaper. I de flesta prov varierade viskositeten, när skjuvningshastigheten (shear rate) ändrades. Undantagen var framför allt synoviaproverna från leder med infektiös artrit. Resultaten tolkades så, att flytkurvans utseende snarare än enstaka viskositetsbestämningar var representativ för respektive synoviaprov.

(Received February 23, 1976).

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