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A STUDY OF β-ACETYLGLUCOSAMINASE AND ACID PHOSPHATASE IN PATHOLOGICAL JOINT FLUIDS*

BY

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There has recently been considerable interest in the possibility that acid hydrolases, the enzymes associated with a particular type of subcellular particle, the lysosome, may play a destructive role in connective tissue disorders (Weissmann and Dingle, 1961; Weissmann and Thomas, 1962; Dingle, 1962). Dingle (1963) has reviewed the evidence that lysosomal enzymes may be involved in the destruction of cartilage. More recently Weissmann (1964) has suggested that in various autoimmune diseases acid hydrolases may degrade normal tissue components to yield antigenic moieties which stimulate the production of antibodies to the original tissue. This hypothesis, together with several similar ones, requires that these hydrolytic enzymes come into contact with the natural tissue components, and presumably this involves release of enzymes from the lysosomal granules by either rupture or leakage. It seemed to us, therefore, to be of interest to measure the free activity of acid hydrolases in the joint fluid from patients suffering from rheumatoid arthritis and other rheumatic disorders. Two enzymes, β-acetylglucosaminase and acid phosphatase, have been studied.

Material and Methods

Synovial fluid was obtained from 43 patients receiving treatment at Manchester Royal Infirmary or the Devonshire Royal Hospital, Buxton, and from three cadavers at *post mortem* examination.

The five specimens from the three autopsy cases were designated Group A. These cases showed no evidence of, and had no clinical history of, rheumatoid arthritis.

The 43 patients were placed in five groups (B to F) according to diagnosis, as follows:

Group	No. of Patients	Diagnosis
B	6	"Non-inflammatory" 4 with osteoarthritis 1 with osteochondritis dissecans 1 with probable internal derangement of the knee
C	17	Classical rheumatoid arthritis
D	7	Definite rheumatoid arthritis
E	2	Probable rheumatoid arthritis
F	11	"Miscellaneous", 3 with ankylosing spondylitis 2 with gout 2 with Reiter's disease 2 with arthropathy associated with ulcerative colitis 1 with suppurative arthritis associated with systemic lupus erythematosus 1 with juvenile rheumatoid arthritis

The criteria of the American Rheumatism Association (Ropes, Bennett, Cobb, Jacox, and Jessar, 1959) were used to grade patients with rheumatoid arthritis.

Blood samples were obtained from more than half the patients, and also from a control group of 22 persons with a similar age and sex distribution who were either members of staff or hospital patients with fractures.

Assay of Enzymes

The synovial fluid was collected in oxalate tubes and centrifuged as soon as possible after joint aspiration and in all cases on the day of aspiration. It was found that centrifugation at 25,000 G. for 20 min. was necessary to

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remove particle-bound enzyme from the viscous synovial fluid (Caygill and Jevons, 1966). The fluid was then diluted with 3 vols of distilled water.

Blood samples were collected in oxalate tubes and centrifuged at 1,500 G. to remove particle-bound enzyme. The plasma was then diluted with 3 vols of distilled water.

β-2-Acetamido-2-deoxy-D-glucoside acetamidodeoxy-glucohydrolase (E.C.3.2.1.30) (β-acetylglucosaminase)* activity was measured using p-nitrophenyl 2-acetylamino-2-deoxy-β-D-glucopyranoside (obtained from Koch-Light Laboratories Ltd., Colnbrook, Bucks.) or by synthesis (Leaback, 1963) as described previously by Caygill and Jevons (1965).

Orthophosphoric monoester phosphohydrolase (E.C. 3.1.3.1) (acid phosphatase) activity was estimated by the method of Torriani (1960). Centrifuged and diluted fluid or plasma (0·5 ml.) was incubated with 0·04 M p-nitrophenyl disodium orthophosphate (0·5 ml.) (obtained from British Drug Houses Ltd., Poole, Dorset) and 0·2 M acetic acid—sodium acetate buffer, *p*H 4·0 (1·5 ml.). A mucin clot formed and was removed by centrifugation at 500 G. for 10 min., after the addition of Tris-NaOH buffer.

* Previously known as β-glucosaminidase.

Group	Symbol	Diagnosis
A	◪	Control
B	●	Non-inflammatory
C	○	Classical R.A.
D	△	Definite R.A.
E	□	Probable R.A.
F	▽	Ankylosing spondylitis
	▼	Gout
	▲	Reiter's disease
	■	Arthropathy with ulcerative colitis
	◑	Suppurative arthritis with S.L.E.
	◐	Still's disease

Synovial Fluid Cell Counts

Total white cell counts were performed on samples of fluid from 36 patients, and differential counts on fluids from 26 patients. The white cell counts were carried out as soon as possible after joint aspiration. The specimens were then centrifuged, and smears were made of the deposit. These were allowed to dry and then fixed with methyl alcohol. Staining was carried out as for a blood smear, using Leishman's stain.

Results

The β-acetylglucosaminase activities of the synovial fluids are shown in Fig. 1.

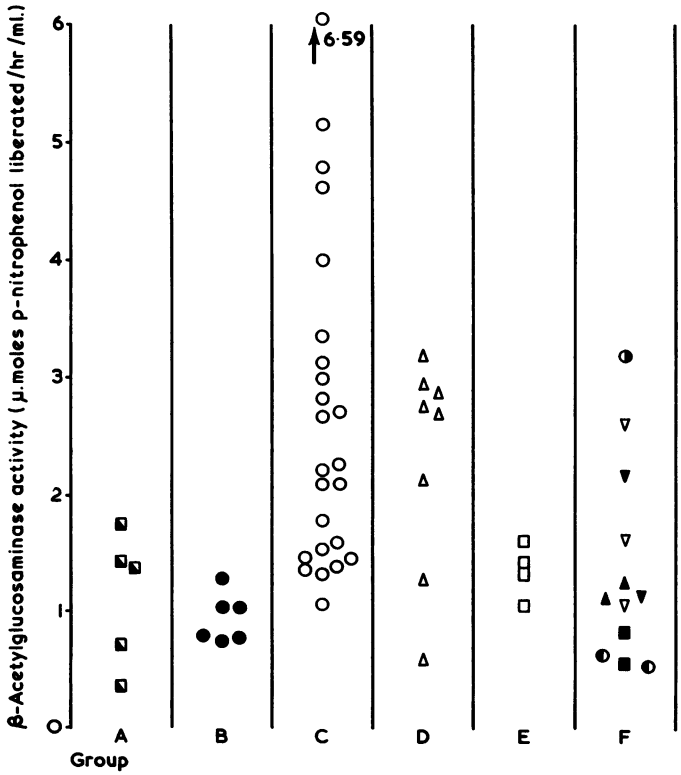

Fig. 1.—β-Acetylglucosaminase activity in synovial fluid (see key).

There is little difference between the levels found in Group A, ("Normal") and in Group B ("Non-inflammatory"), although the activities in Group B fluids, which come from knee effusions, could have been reduced by dilution. The activities found in fluids of Group C (classical rheumatoid arthritis) are, on the whole, much higher than those in Group B, and higher than in Group A. The activities in Group D (definite rheumatoid arthritis) are intermediate, and in Group E (probable rheumatoid arthritis) three out of four specimens are higher than Group B but no higher than Group A.

The activities of acid phosphatase (Fig. 2) show similar differences between the rheumatoid Groups C to E and Group B. Acid phosphatase activities of normal synovial fluid are not included because sufficient fluid could not be obtained at autopsy. In any case this enzyme was found to be more unstable than β-acetylglucosaminase so that inaccuracies may arise if the fluid is not assayed immediately after death.

It may be worth noting that the lowest value in Group D for either enzyme (Figs 1 and 2) came from a patient who had had inflammatory arthritis of the knees for 4 years. Clinically this patient's condition is low-grade, the erythrocyte sedimentation rate is normal, and a punch biopsy of the synovium showed fibrosis with virtually no chronic inflammatory cell infiltration. The next lowest values in this group for either enzyme are above the highest values found in Group B.

Turning to Group F ("Miscellaneous"), it will be seen that the β-acetylglucosaminase activities (Fig. 1) are with a few exceptions in the same range as those of Groups A and B. Acid phosphatase activities, however, are on the whole higher than those of Group B (Fig. 2). The highest values for both enzymes were found in the patient with suppurative arthritis and systemic lupus erythematosus. All four patients with acid phosphatase activities in the same range as Group B also had activities of β-acetylglucosaminase which were similar to those of

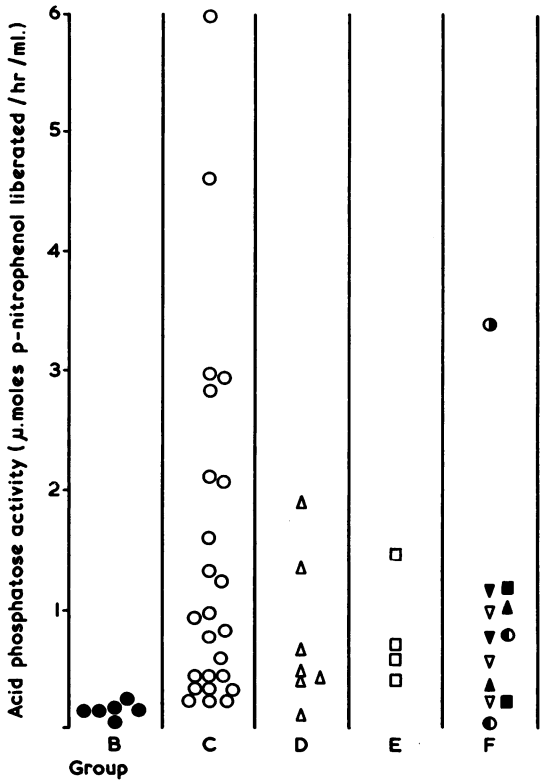

Fig. 2.—Acid phosphatase activity in synovial fluid (see key with Fig. 1).

Group B. Of these, one was a patient with ankylosing spondylitis who had a knee effusion of 3 years' duration; the low enzyme values were associated with a synovial fluid cell count of only 1,800 per c.mm. The second was a patient with Reiter's disease, in whom the cell count was also low (1,300 per c.mm.). The third patient had arthropathy associated with ulcerative colitis; fluid from this patient's knee contained 4,950 cells per c.mm. The fourth patient had juvenile rheumatoid arthritis resulting in large effusions in grossly unstable knees; the synovial fluid cell count was very low in both knees and this was associated with very low enzyme activities in one knee, but the acid phosphatase activity in the other knee was higher than the values of Group B.

In a few cases of rheumatoid arthritis (three classical and one probable), we were able to measure the enzyme activities in more than one involved joint. In each case, the activities of either enzyme were similar in the two joints.

We also measured the activities of the two enzymes in the same joint of three patients with rheumatoid arthritis (two classical and one probable) at intervals of 6 to 8 weeks. All three patients had received hydrocortisone into the joint immediately after the first aspiration, and the two patients with classical rheumatoid arthritis were receiving in-patient treatment. The Table shows that the activities of both enzymes diminished in all three patients, but the reduction was more marked in the two in-patients.

Fig. 3 (opposite) shows the activities of β-acetylglucosaminase and acid phosphatase in the blood plasma of some of these patients compared with the control group described previously. The range of β-acetylglucosaminase activity found in the patients with joint disorders is approximately the same as the range in the control group. The acid phosphatase values, however, are more variable in the inflammatory group, some values being considerably higher than those of the control group.

The activity of β-acetylglucosaminase in synovial fluid is plotted against the total leucocyte count of the fluid in Fig. 4 (opposite). While there was no precise correlation, in general, a high white cell count was associated with a high level of activity of the enzyme. Similar results were obtained with acid phosphatase. Raised levels of enzyme activity were not associated with any particular type of leucocyte.

No correlations were found between the levels of enzyme activity in the joints and the age and sex of the patient, the duration of the disease in general, the duration of the disease in the particular joint involved, and the levels of serum rheumatoid factor.

Discussion

Certain factors must be borne in mind in considering these results:

(1) Both β-acetylglucosaminase and acid phosphatase activity are present in leucocytes, and therefore adequate centrifugation of the inflammatory exudate is necessary if the "free" enzyme activity is to be measured.

(2) Although β-acetylglucosaminase was a relatively stable enzyme, in that previously centrifuged fluid could be stored overnight at 5° C. without detectable loss of activity, acid phosphatase activity fell on storage overnight in a refrigerator.

(3) β-Acetylglucosaminase activity is competitively inhibited by low concentrations of hyaluronic acid (Caygill, 1966). The extent of inhibition varies with *p*H and with the concentration of hyaluronic acid. At *p*H 4·3 the inhibition reaches a maximum of just under 50 per cent. at concentrations of hyaluronic acid of 100 to 200 μg./ml. The concentration of hyaluronic acid in pathological synovial fluid is of the order of 1 mg./ml. (Seppälä, 1964), so that inhibition will be little affected by relatively large changes in hyaluronic acid concentration.

Thus the activities reported here are not a true measure of the quantity of enzyme present, but they are a true measure of the "free" activity of the enzyme in the fluid.

TABLE

ENZYME ACTIVITIES OF SYNOVIAL FLUID BEFORE AND AFTER TREATMENT

Diagnosis	Joint	Interval (wks)	β-Acetylglucosaminase (μ moles/hr/ml.)	Acid Phosphatase (μ moles/hr/ml.)
Classical Rheumatoid Arthritis	Right Elbow	8	6·59 4·62	4·60 1·31
	Right Knee	6	2·32 1·80	0·97 0·24
Probable Rheumatoid Arthritis	Left Knee	8	1·59 1·44	0·60 0·43

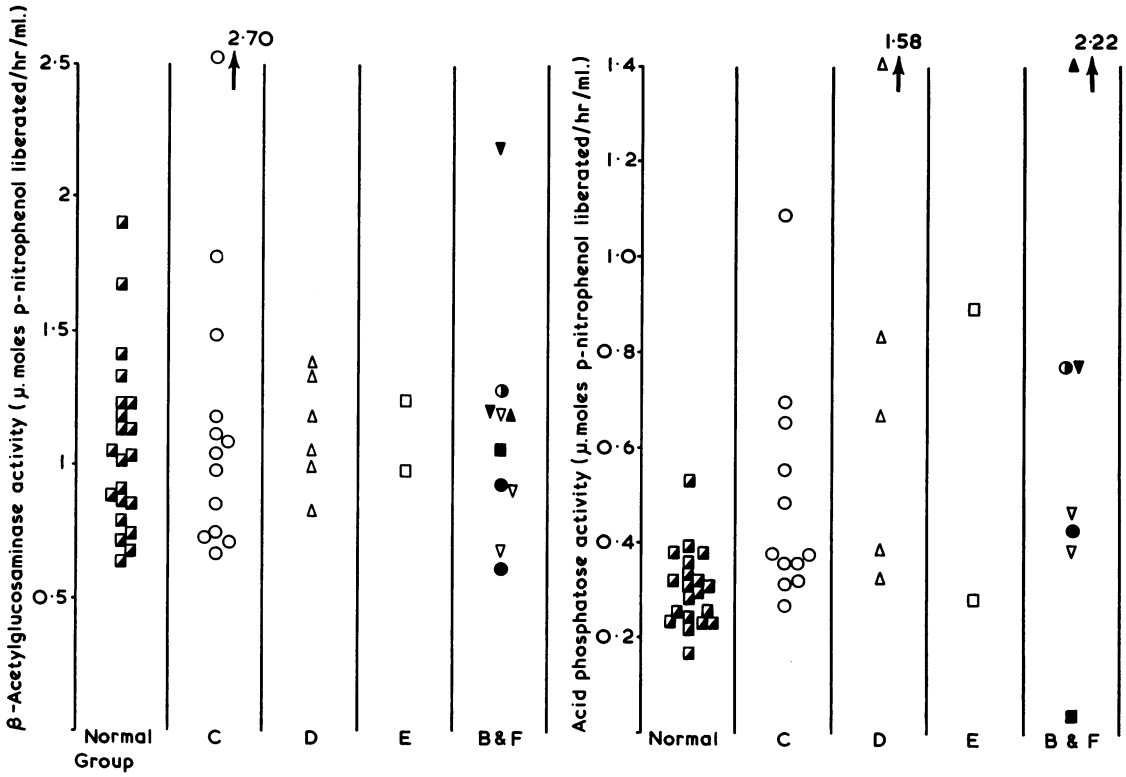

Fig. 3.—β-Acetylglucosaminase and acid phosphatase activities in blood plasma (see key).

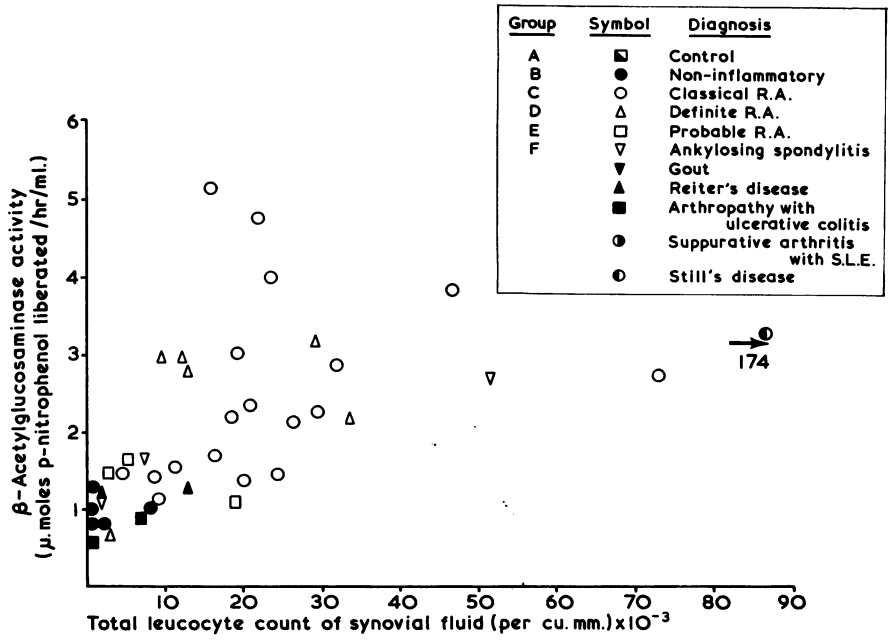

Fig. 4.—β-Acetylglucosaminase activity and total leucocyte count of synovial fluid (see key).

From the point of view of assay, β-acetylglucosaminase activity is easier to measure than acid phosphatase activity, as both the enzyme and its substrate are more stable. Both enzymes are more active than other acid hydrolases. Thus we have found that β-glucuronidase, β-galactosidase, acid ribonuclease, and acid protease activities in the synovial fluid to be low, necessitating long incubation periods to obtain measurable activities. This finding is compatible with their relative concentrations in rat liver lysosomes. Jacox and Feldmahn (1955), who estimated β-glucuronidase, incubated for 16 or 24 hrs. to obtain measurable activity.

The earliest study of enzyme activities in synovial fluid which we have found was that of Podkaminsky (1931), who reported the presence in bovine synovial fluid of enzymes capable of degrading starch, protein (in acid solution), and lipids. The presence in human pathological synovial fluid of an enzyme which hydrolysed casein or tracheal cartilage in neutral solution was noted 4 years later by Keefer, Holmes, and Myers (1935). The activity of a pseudocholinesterase in synovial fluid was measured by Oka (1954), who found that the variation between thirteen patients with rheumatoid arthritis was greater than that between five patients with traumatic effusions of the knee. Julkunen and Ruutsalo (1958) studied glutamate-oxaloacetate transaminase in the serum and synovial fluid of patients with rheumatoid arthritis. There was no increase in serum levels, but raised values were found in the synovial fluid. These levels could be reduced by the administration of ACTH, but not by gold therapy. Aspartate- and glutamate-oxaloacetate transaminases were found by Salomone and Quatrini (1960) to be higher in inflammatory effusions than in fluids of traumatic origin, but in both cases the levels were below those of serum. Gerlach and Kronsbein (1959) investigated the activities of a number of enzymes (lactate dehydrogenase, glutamate-oxaloacetate transaminase, fructose 1-6 diphosphate aldolase, and cholinesterase) in a number of body fluids, including four specimens of synovial fluid, and found values to be higher in fluids containing large numbers of cells. Lactate dehydrogenase was also studied by Quatrini and Pignataro (1962), who found higher activities in inflammatory synovial effusions than in blood. The same enzyme was studied by Vesell, Osterland, Bearn, and Kunkel (1962), who found raised synovial fluid levels but normal serum levels. The iso-enzyme pattern was abnormal in both synovial fluid and serum, with a raised proportion of iso-enzyme 5. Synovium and synovial fluid leucocytes showed the same iso-enzyme pattern as the joint fluid.

Proteolytic enzymes, designated pepsin, cathepsin, and trypsin, were estimated by Vartio (1960) in synovial fluid from patients suffering from rheumatoid arthritis, osteo-arthritis, and traumatic hydrarthrosis. Peptic activity was found to be higher than that of the other two enzymes, and this and catheptic activity were greater in fluids from patients with osteo-arthritis and traumatic hydrarthrosis than in those with rheumatoid arthritis. Enzymes concerned with glycolysis and the tricarboxylic acid cycle were investigated by Greiling, Kisters, and Peter (1962) and by West, Poske, Black, Pilz, and Zimmerman (1963). Both groups of workers found raised levels in inflammatory joint effusions. The latter group found the highest values in the synovial fluid of rheumatoid patients with intermediate values in Reiter's disease and gout. Fluid from osteo-arthritic patients and cadavers was similar to normal serum. In contrast to previous work, the levels of two transaminases in all the fluids examined were normal, or only slightly raised.

Lysozyme, an enzyme known to split 1- 4 β -*N*-acetylglucosamine bonds within chains, was found to be present in synovial fluid by Caselli and Schumacher (1955), who reported that it formed an insoluble complex with acid mucopolysaccharides, and by Falcone (1952), who found that high activity of lysozyme was associated with synovial fluid of lower than normal viscosity. Secchi (1953), however, found that the enzyme did not reduce the viscosity of the fluid.

An enzyme capable of splitting glycylglycylglycine at *p*H 7·8 was measured by Ziff, Simson, Scull, Smith, Shatton, and Mainland (1955) in synovial fluid from 98 patients with a wide variety of arthritic diseases. Values were highest in rheumatoid arthritis, intermediate in rheumatic fever, Reiter's disease, and gout, and low in degenerative joint disorders. The enzyme activity was positively correlated with the prior duration of symptoms in the affected joint, and the authors concluded that the activity of this enzyme was an index of the state of joint inflammation which might be of value in following the progress of the disease.

Alkaline phosphatase activity in synovial fluid was found to be similar to that in serum by Quatrini and Salomone (1961). There were no statistically significant differences between fluids of traumatic, degenerative, or inflammatory origin, and in fluids of the last group the activity of the enzyme was inversely proportional to the viscosity of the fluid.

Turning to commonly-studied lysosomal enzymes, the work of Jacox and Feldmahn (1955) on β-glucuronidase has already been referred to. Smith and Hamerman (1962) and Lehman, Kream, and

Brogna (1964) have studied acid phosphatase. The activities in synovial fluid of both enzymes were generally higher in inflamed joints than in normal or non-inflamed joints.

Summarizing the main conclusions of the papers cited, it appears that the activity of many enzymes in "normal" synovial fluid are approximately the same as, or slightly lower than, the corresponding activities in serum. On the other hand, in effusions of inflamed joints, these levels are often raised. These differences could be accounted for by the breakdown of leucocytes present in the inflammatory joint exudates, by release from necrotic areas of inflamed synovium, or by altered production or release by the synovium. In almost all cases where enzyme levels are raised, the fluid contains many leucocytes, and this has tempted many authors to infer that the enzymes are derived from the destruction of leucocytes (*e.g.* West and others, 1963). However, we have little information about the enzymic constitution of the synovial membrane in either the normal or the altered state, and it is therefore not possible to distinguish the source of the enzymes on the basis of available data.

For example, the enzyme β-acetylglucosaminase, which has been studied in this report, has been found in human leucocytes (Caygill and Jevons, 1966), and in synovial membrane (Pugh and Walker, 1961). The activity in the synovial membrane of patients, with rheumatoid arthritis has been found to be higher than in that of other patients where the synovium had to be removed surgically for other reasons (Hendry and Carr, 1963). Thus the enzyme in synovial fluid could have been derived from either source.

The present work, and other work on lysosomal enzymes (Jacox and Feldmahn, 1955; Smith and Hamerman, 1962; Lehman, Kream, and Brogna, 1964), whilst not refuting the hypothesis that disruption of lysosomes induces rheumatoid arthritis and other diseases of connective tissue, do not provide any convincing support. It would appear that lysosomal enzymes are present in apparently normal joints, and that their activities are not grossly raised in rheumatoid arthritis. Furthermore, the activities of these enzymes can be raised in other inflammatory joint disorders, such as gout and Reiter's disease, and from our review of the literature it would seem that there are comparable increases in the activities of other enzymes in pathological joint fluids.

Summary

β-Acetylglucosaminase and acid phosphatase activities were measured in the synovial fluid of 43 patients suffering from rheumatoid arthritis and a variety of other rheumatic disorders. The highest values were found in those with classical rheumatoid arthritis, with intermediate values in those with definite and probable rheumatoid arthritis. The activities of β-acetylglucosaminase in a miscellaneous group of inflammatory joint disorders were, on the whole, similar to those of five autopsy specimens and of a "Non-inflammatory" group. Values for acid phosphatase in the "Miscellaneous" group were mostly higher than those of the "Non-inflammatory" group.

The same enzymes were measured in the plasma of the majority of these patients and in that of a control series of comparable age and sex. β-acetylglucosaminase activities were similar in the two series. Acid phosphatase levels, however, were more variable in the patients with rheumatic disease than in the control series, the highest values being found in patients with rheumatoid arthritis.

The enzyme activities in synovial fluid were not related to the age and sex of the patient, to the duration of the disease in general, or to the particular joint involved; fluids with high leucocyte counts, however, were found to have the higher enzyme activities.

Previous work on enzymes in synovial fluid is briefly reviewed.

We wish to thank Prof. J. H. Kellgren for his invaluable advice and encouragment throughout this study, and Miss K. Broady and the Dept. of Medical Illustration, Manchester Royal Infirmary, for technical assistance.

DISCUSSION

PROF. E. G. L. BYWATERS (*Taplow*): I should like to ask Dr. Caygill if he has any idea of the origin of these hydrolytic enzymes; are there any hydrolytic enzymes peculiar to white cells as against synovial membrane? If you inject white cells into a joint with low hydrolase content, is the hydrolase content increased, and could these hydrolases merely come from the disintegration of leucocytes in the synovial fluid?

DR. CAYGILL: We have not tried putting white cells into joints and I do not know of this type of experiment having been done. Nor am I aware of any differences in the enzymic content of synovial cells and leucocytes which would enable us to decide where these enzymes come from.

DR. J. BALL (*Manchester*): In the case of acid phosphatase, at least some of the free enzymes have been derived from the synovial cell. Whether they also contain β-glucosaminidase, I do not know.

DR. CAYGILL: They do, they are quite rich in it.

DR. V. WRIGHT (*Leeds*): Did you attempt any correlation with the protein content of the synovial fluid? Did you find any effect of local hydrocortisone on these enzyme factors? What was the white count in the synovial fluid of the patient with the arthropathy of ulcerative colitis?

DR. CAYGILL: We did not measure the protein content of the fluid. In one or two cases—we measured enzyme activity in a joint and some time later the activity after hydrocortisone. These results indicated that the activity was, if anything, lower but not very much.

We had two cases of arthropathy associated with ulcerative colitis. The white cell count in one was less than 200, and in the other 4,950—this was the case with the slightly higher β-glucosaminidase activity.

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Les hydrolases acides dans les liquides articulaires pathologiques

RÉSUMÉ

On mesura l'activité de la β-acétylglucosaminase et de la phosphatase acide dans le liquide synovial de 43 malades atteints d'arthrite rhumatismale et de divers autres désordres rhumatismaux. Les taux les plus élevés furent trouvés dans les cas d'arthrite rhumatismale classique et les valeurs moyennes dans les cas d'arthrite rhumatismale "certaine" et "probable". L'activité de la β-acétylglucosaminase dans un groupe mixte d'affections articulaires inflammatoires fut, en général, similaire à celle obtenue dans cinq prélèvement d'autopsie et dans le groupe "non-inflammatoire". Les taux de la phosphatase acide dans le groupe "mixte" furent généralement plus élevés que ceux dans le groupe "non-inflammatoire".

On titra les mêmes enzymes dans le plasma de la plupart de ces malades ainsi que de témoins d'âge et de sexe comparables. L'activité de la β-acétylglucosaminase fut similaire dans les deux séries les taux de la phosphatase acide furent, toutefois, plus variables chez les rhumatisants que chez les témoins, avec des taux le plus élevés chez les malades atteints d'arthrite rhumatismale.

On ne trouva aucun rapport entre les taux des enzymes dans le liquide synovial et l'âge et le sexe du malade, la durée de la maladie ou l'atteinte d'une articulation particulière, mais les liquides riches en leucocytes presentaient une activité enzymatique plus forte.

On passe en revue les travaux antérieurs sur les enzymes dans le liquide synovial.

Las hidrolasas ácidas en líquidos articulares patológicos

SUMARIO

Se midió la actividad de la β-acetilglucosaminasa y de la fosfatasa ácida en el líquido sinovial de 43 enfermos con artritis reumatoide y con varios otros disturbios reumáticos. Las cifras más altas fueron encontradas en los casos de artritis reumatoide clásica y las medias en los casos de artritis reumatoide "cierta" y "probable". La actividad de la β-acetilglucosaminasa en un grupo misceláneo de afecciones articulares inflamatorias fué en general similar al obtenido en cinco espécimenes de autopsia y en el grupo "non-inflamatorio". Las cifras de la fosfatasa ácida en el grupo "misceláneo" fueron generalmente mayores que las en el grupo "non-inflamatorio".

Se determinaron las mismas enzimas en el plasma de la mayoría de estos enfermos así como en testigos de edad y sexo comparables. La actividad de la β-acetilglucosaminasa fué similar en ambas series. Las cifras de la fosfatasa ácida fueron, sin embargo, más variables en los reumáticos que en los testigos, siendo lo más altas en enfermos con artritis reumatoide.

No se encontró relación alguna entre las cifras de las enzimas en el líquido sinovial y la edad o el sexo de los enfermos, la duración de la enfermedad o la implicación de una articulación particular, pero los líquidos con muchos leucocitos desempeñaban una actividad enzimática mayor.

Se pasa revista a los trabajos anteriores sobre las enzimas en el líquido sinovial.