

THE ASSESSMENT OF THE RHEUMATOID HAND

" The Assessment of the Function of the Hand undergoing  
corrective surgery for Rheumatoid Disease using specially  
designed biomechanical instruments and the Colour Television  
Image Analyser "

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## CONTENTS

Summary

### PART I - INTRODUCTION

#### 1. ASSESSMENT OF HAND FUNCTION

- a) Subjective methods
- b) Objective methods
- c) Laboratory methods
- d) Concept of assessment at the digital level

#### 2. BONE DENSITY

- a) Factors influencing the mineral content of bones
- b) Methods of measuring bone density
  - (i) Densitometry
  - (ii) Morphological measurements

## PART II - MATERIALS & METHOD

### 1. CONCEPTS OF TECHNIQUE AND DESIGN

- a) The Cybernometer
- b) The Torquemeter
- c) The Colour Television Image Analyser

### 2. EXPERIMENTAL

- a) Testing of Normal Hands with the Cybernometer
- b) Investigation into the Relationship between Force and Bone Density in the Normal Hand
- c) Torque of the Metacarpophalangeal Joint of the Normal Hand

### 3. CLINICAL

- a) Cybernometer v. Dynamometer
- b) Testing the Value of Surgery with the Cybernometer
- c) Testing the Value of Surgery with the Torquemeter
- d) Bone Density Loss in the Rheumatoid Hand
- e) The Effect of Synovectomy of the Metacarpophalangeal Joint on Bone Density and Hand Function

## PART III - RESULTS

### 1. EXPERIMENTAL

- a) Testing of Normal Hands with the Cybernometer
- b) Investigation into the Relationship between Force and Bone Density in the Normal Hand
- c) Torque in the Normal Hand

### 2. CLINICAL

- a) Cybernometer v. Dynamometer
- b) Testing the Value of Surgery with the Cybernometer
- c) Testing the Value of Surgery with the Torquemeter
- d) Bone Density Loss in the Rheumatoid Hand
- e) The Effect of Synovectomy of the Metacarpophalangeal Joint on Bone Density and Hand Function



## PART IV - DISCUSSION

The Need for Satisfactory Methods of Assessing Hand Function

Hand Function and Bone Density

"New Lamps for Old"

The Normal Hand

The Rheumatoid Hand

Cybernometer v. Dynamometer

Testing the Value of Surgery with the Cybernometer

Testing the Value of Surgery with the Torquemeter

Bone Density Loss in the Rheumatoid Hand

The Effect of Synovectomy of the Metacarpophalangeal  
Joint on Bone Density and Hand Function.

Conclusion

References

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SUMMARY

Present methods of assessing the function of the hand are reviewed and found to be inadequate. Two new concepts are introduced; the concept of assessing the function of the hand at the digital level, and the concept that hand function and bone density are closely related in both the hypodynamic state of disuse and the hyperdynamic state of improved function following corrective surgery.

To investigate hands in this manner, the design and use of two biomechanical instruments, the 'Cybernometer' and the 'Torquemeter', invented by the author, are described. The use of Colour Television Image Analysis as a new method of measuring bone density, developed by the author, is also described.

With this equipment a biomechanical study has been performed on normal hands and a positive relationship has been shown between function and bone density in both normal and rheumatoid hands.

A statistical analysis has been performed on 51 rheumatoid patients before and after a variety of types of corrective hand surgery in terms of function and bone density. Not only is disuse osteoporosis accompanied by a reduction in hand function but also by surgically improving function osteoporosis in the rheumatoid hand is reversed.

The author claims originality in the study for the following subjects:-

1. The design of two new instruments to assess the function of the hand.
2. The development of Colour Television Image Analysis as a new method of measuring bone density.
3. The concept of assessment at the digital level.
4. Observations on the relationship between function and bone density in both normal and rheumatoid hands.
5. A detailed statistical study on the value of surgery in rheumatoid disease of the hands.



## INTRODUCTION

Rheumatoid Arthritis is a common disease in the Western world, affecting some 5 per cent of the population (Swanson, 1969; Holt, 1970). A feature of the disease is the progressive deformity occurring in synovial joints, and, because the hands are frequently involved, the disease can lead to serious impairment of hand function. The arthritis affects four females for every one male and so, this loss of hand function frequently leads to interference with domestic tasks as it does with the patient's employment.

Management in the early stages of the disease is predominantly medical, while in the later stage of crippling hand deformity, little can be achieved by conservative measures. For this reason surgery of the Rheumatoid hand has gained increasing popularity in recent years, and many operative procedures have been described for its relief. Yet the assessment of the results has not kept pace with the expansion in such surgery. Since Steinbrocker in 1949 classified functional capacity in Rheumatoid Disease from Class I, "Complete Function", to Class IV, "Incapacitated", little of relevance has been added. The hand surgeon can claim little success with his results if only based upon the subjective impressions of both himself and the patient, unless he can show improved function based upon sound objective methods of assessment. However, it is necessary to ascertain what function is particularly important to an individual patient and what improvement is likely (Savage, 1966; Holt, 1969; Ansell, 1969; Hartetal, 1972; Nicolle et al, 1972). Nevertheless it is possible to design objective methods of assessment to suit a particular problem.

The author describes his new and original design of instruments and equipment to assess the function of the hand which have been based on a number of years of research and are now in current clinical use.

1. ASSESSMENT OF HAND FUNCTION

The methods of assessment in common use are shown in Table 1.

a) Subjective Method

A suitable proforma cataloguing the patient's views, his performance of everyday tasks, his predominantly important functions and special disabilities is commonly recommended (Savage, 1966; Ansell, 1969; Holt et al, 1972); yet no general agreement has been reached as to the exact size and content of such a method of documentation. The adoption of a universally acceptable one would facilitate a degree of control and reciprocity in results published from different centres. The need for a list of ten to twenty representative activities which would be applicable in practically all cases has already been stressed (Lansbury, 1966). A comprehensive proforma has recently been suggested and been shown to be of value in assessing the results of prosthetic joint replacement, Table 2, (Nicolle, 1972). Its use is of value while no suitable objective methods exist.

Methods of grading pain in response to treatment have been suggested including three pain categories of severity, or counting the number of analgesics required to relieve pain, (Savage, 1966). It seems unlikely that grading of such a subjective impression can be of any real quantitative value, and the same author admits that, "there is a natural inclination to put a figure on any measurement, but unless it is accurate, this should be resisted".

Table 1

METHODS OF ASSESSMENT

| <u>SUBJECTIVE</u>   | <u>OBJECTIVE</u>              | <u>LABORATORY</u>                   |
|---------------------|-------------------------------|-------------------------------------|
| Patient's views     | Clinical appraisal            | Haemoglobin concentration           |
| Everyday tasks      | Photography                   | Erythrocyte sedimentation rate      |
| Special functions   | Xray                          | Serum iron                          |
| Pain grades         | Joint tenderness              | Rheumatoid factor                   |
| Functional capacity | Duration of morning stiffness | Rosewater test                      |
| Cosmetic appearance | Joint size                    | Sheep cell agglutination test       |
|                     | Thermography                  | 17 Hydroxy-corticosteroids in urine |
|                     | Technesium clearance          |                                     |
|                     | Pinch ability                 |                                     |
|                     | Pinch strength                |                                     |
|                     | Arc of Motion                 |                                     |
|                     | Grip strength                 |                                     |
|                     | Cuff dolorimeter              |                                     |



Some authorities believe that the best method is to use the best functional hand. This may be the case but lack of evidence precludes comparison as none of the methods is listed for assessment.

Table 2

b) Objective Methods

The clinical LIST OF DAY TO DAY FUNCTIONS is an integral part of its assessment, (Flatt, 1968), and has been used as a quantitative

|                  |                    |
|------------------|--------------------|
| Occupations      | Picking up coins   |
| Hobbies          | Holding glasses    |
| Driving          | Cooking utensils   |
| Eating           | Housework          |
| Writing          | Washing up/Laundry |
| Tying shoe laces | Holding hair brush |
| Shaving          | Sewing             |
| Doing up buttons | Scissors           |
| Dressing         | Knitting           |
| Door handles     |                    |

A portable photographic device for recording progress in arthritis of the hand has been recommended (Lichten, 1966).

Dwan and Apple, also state that radiological assessment is at least as important as the clinical assessment, but stress that the appropriate views are essential. These include anterior, posterior, lateral, medial, and "finger-toe" views. Lateral views of the fingers as well as the thumb may be necessary. Methods of scoring ulnar defects and joint space narrowing in the hand and wrist in patients with rheumatoid arthritis have been devised. There is a correlation between the scores of radiological abnormalities and the clinical and laboratory

Some authorities believe that the best cosmetic hand is also the best functional hand. This may be the case but lack of evidence precludes cosmesis as more than a superficial standard for assessment.

b) Objective Methods

The clinical appraisal of the rheumatoid hand is an integral part of its assessment, (Flatt, 1968), and has been used as a quantitative evaluation of the function of the rheumatoid hand (Treuhaft, 1971). In the timing of operative treatment the progress of the disease has been usefully divided into three stages (Barron, 1969) - the early stage of "Proliferation", the intermediate stage of "Soft Tissue Destruction", and the late stage of "Skeletal Collapse" - while clinical appraisal of the suitability of operative treatment has been based on specific anatomical structures (Holt, 1969). A selection of photographs is recommended to document the clinical state of the hand (Swanson et al, 1968; Ansell, 1969) but such photographs tell little about function. They must include radial, ulnar, palmar, dorsal, and axial views, with the fingers both flexed and extended. A portable photographic device for recording progress in arthritis of the hands has even been recommended (Acheson, 1966).

Swanson and Ansell, also state that radiological assessment is at least as important as the clinical assessment, but stress that the appropriate views are essential. These include anterior, posterior, lateral, oblique, tangential, and "ball-catching" views. Lateral views of individual joints as well as the thumb may be necessary. Methods of scoring osseous defects and joint space narrowing in the hands and wrists of patients with rheumatoid arthritis have been devised, (Sharp et al, 1971), and correlations were found between the scores of radiological abnormalities and the clinical and laboratory

manifestations of rheumatoid arthritis.

Joint tenderness has been measured using an "Articular Index", (Ritchie et al, 1968), and this measurement has been recommended as one of the best six measurements in the assessment of rheumatoid disease (Hart et al, 1972). The minimal stimulus needed to produce pain has also been measured, using a Cuff Dolorimeter (Hawkins et al, 1966) and the effect of the drugs on pain noted. Tenderness has also been measured with other devices - the Palpameter, (Hollander et al, 1963), the 101b Dolorimeter (McCarty et al, 1965) and the 201b Dolorimeter (McCarthy et al, 1968). None of these methods has gained widespread acceptance due to the very varied nature of tenderness as a response to painful stimuli.

Measurement of the duration of morning stiffness has been suggested as a "Therapeutic Index" (Savage, 1966; Hart et al, 1972). Also measurement of joint size using gauges and graded sizes of jeweller's rings enjoys some degree of vogue, (Savage, 1966; Boardman et al, 1967; Hart et al, 1972). A considerable degree of error is admitted in the latter method due to difficulty in finding exactly the same point for each measurement. Moreover, there is no information to prove that the degree of disease is proportional to joint size, except, perhaps, in the acute proliferative exacerbation. In fact, progress through Barron's three stages of disease may well be accompanied by a reduction in joint size. However, joint size has been of some value in the measurement of the anti-inflammatory response to salicylate treatment in rheumatoid disease (Boardman et al, 1967).

Thermography and Technesium clearance using the Pyroscan and Bolometer have been added to the list of methods of assessment, (Cosh,

1966) but these have not been widely used.

The prehensile movements of the human hand have been divided usefully into two categories - power grip and precision grip (Napier, 1956) - and there have been many attempts to quantify these functions. Precision grip has been quantified by measurement of the ability to pinch as demonstrated by picking up coins, screwing lids on jars, and putting pegs in boards, and grading the achievement (Ansell, 1969). These simple tests are routine in many centres and occupational therapy departments. Although such tests can be adapted to suit the best needs of the patient, they lack precision, are difficult to quantify, except by measuring the accomplishment time (Greenseid et al, 1968; MacBain, 1970) and the results vary with the enthusiasm and practice of both patient and therapist.

More precise information about pinch as a hand function has been acquired by measuring the strength of pinch between thumb and fingers. Using a "standard pinch gauge" it has been shown in children that there is a significant correlation ( $P = 0.02$ ) between pinch strength and handedness provided that the right hand is the dominant (Weiss et al, 1971). When the left hand is dominant, no such correlation was achieved ( $P > 0.05$ ). A suggested explanation was that most tools and instruments are designed to be used with the right hand and therefore many left-handed people develop a level of skill and strength in their non-dominant hand that right-handed people do not find necessary. The purpose of Weiss' work was to establish meaningful measurement criteria for the study of congenital hand anomalies. MacBain has measured pinch strength using a Minimus II sphygmomanometer and assesses rheumatoid hands in this manner. However there are many faults with pressure sphygmomanometry detailed below.

By far the commonest two methods of objectively assessing function in the rheumatoid hand are measurement firstly of the arc of motion of the joints, and secondly of the grip strength of the hand. Most authorities give high priority to the measurement of the range of motion of joints. Savage found accuracy in this measurement difficult to achieve but recognised its importance by stressing that the ability to close the hands was most important to the housewife. Ansell measured the inability to fully extend the fingers recorded in centimetres, with the hand held flat on the table. Measurement of active and passive arcs of motion has been used in the diagnosis and assessment of treatment for flexor lag in preference to grip strength because the presence of pain and its relief with treatment biased the latter method (Wissinger, 1971).

The restoration of a functional range of movement has been given first priority in the requirements of successful joint replacement (Flatt et al, 1969); yet in the assessment of the results of such operative treatment (Flatt et al, 1967) an average range of metacarpo-phalangeal joint movement post-operatively of 25% was reported without any pre-operative levels included for comparison. In a more recent report on the results of flexible implant resection arthroplasty (Swanson, 1972) a post-operative range of movement of 66.1 degrees was stated, but without any pre-operative values for comparison, despite the necessity of pre-operative comparison levels having been stressed by that author (Swanson et al, 1969). Nothing can therefore be concluded in terms of improved range of motion. However, pre- and post-operative measurements of the range of motion after prosthetic joint replacement have been reported in another recent study (Nicolle et



al, 1972) and improvement was demonstrated.

Measurement of the strength of grip of the hand (Wright, 1959; Savage, 1966; Swanson et al, 1968) is probably the only quantitative measure of the function of the hand in common use today. It has been used in the assessment of the disease process, at an early stage in its development, in response to various forms of medical treatment (Boardman, 1967) and is widely used as a therapeutic criterion in hand surgery. However control and reciprocity in results from different centres suffer the absence of any form of standardisation. The most popular instrument used to measure grip strength is the pneumatic dynamometer, and, in one instance (Ansell, 1969) the bag is to be inflated to 20 mm.Hg., while another (Savage, 1966) the bag must be 6 inches by 6 inches and inflated to 30 mm.Hg., while yet another (Swanson et al, 1968) the bag must have a diameter of 2 inches and be inflated to 50 mm.Hg.

One authority suggests that the bag be squeezed once (Boardman, 1967) while another (Nicolle, 1972) derives the mean of three successive measurements. In addition, the bag must be squeezed with the whole hand, with wrist, forearm, elbow, and shoulder in a constant position. A period of familiarity between patient and instrument is necessary and at least three readings should be taken so that a mean can be derived. Furthermore, measurements should be made at the same time of day (Wright, 1959). Thus the pneumatic dynamometer involves a not inconsiderable error. Electrical and mechanical dynamometers do reduce the magnitude of this error (Swanson et al, 1968). A mechanical dynamometer with adjustable hand spacings, called the Jamar Dynamometer, was introduced in 1954 (Bechtol, 1954).. That grip strength is proportional to height and weight, and age up to 32

years, has been shown with this instrument (Schmidt et al, 1970).

The greater strength of the dominant hand, and the male hand was also demonstrated. More recently it has been shown that men lose grip strength at a greater rate than women (Kellor et al, 1972).

These studies have been performed on normal hands and there is a distinct lack of information about grip strength in the rheumatoid hand, particularly before and after surgery. Although slight improvement in grip strength six months after prosthetic joint replacement has been recently shown (Nicolle et al, 1972) the value of grip strength as an indication of improved hand function awaits confirmation.

c) Laboratory

Measurement of Erythrocyte Sedimentation Rate, Haemoglobin concentration, Rheumatoid factor, the Rose-Waaler and Sheep Cell Agglutination tests, and the 17 - hydroxycorticosteroids in urine are all used as indices of progress in rheumatoid disease (Savage, 1966; Hart et al, 1972). While of value to the general rheumatologist, such tests are of little assessment value to hand surgeons.

d) Concept of Assessment at the Digital Level

When the hand loses the function of effective pinch, as it may do in rheumatoid disease, then it has lost 80% of its value (Arden et al, 1970). Despite this recent warning, the fact that the hand comprises amongst other things four fingers and a thumb seems to have escaped the attention of most workers in this field.

Because only one digit may be operated upon or, indeed, affected by disease, the concept of the measurement of individual digital function becomes a necessity. There is no evidence that measurement

of range of motion of the joints of fingers is a measure of the function of the digits of that hand. Moreover, measurement of grip strength, a measure of the function of the hand as one integrated unit, ceases to be valid on consideration of the asymmetry in the manner in which the disease strikes the units of the hand and in the programme of surgical treatment. Table 3 shows the distribution among the digits of the operations performed on the hand for rheumatoid disease in the Minor Surgery Unit of Hammersmith Hospital over the past year. The thumb was involved in 13 operations, the index finger 36, the middle finger 38, the ring finger 39, and the little finger 24. However 46 operations involved only one digit, 18 operations involved two digits, 8 operations three digits, and 11 operations four digits. From this table it can therefore be seen that it is more than three times as common for two or less digits to be operated upon at one time. To adequately assess function in these hands at the digital level in terms of absolute units of force, the author designed and developed two new instruments - the "Cybernometer" (Dickson et al, 1972 a.b.) and the "Torquemeter" (Dickson et al, 1972 c).

## 2. BONE DENSITY

### (a) Factors influencing the mineral content of bones

"Osteoporosis is a disorder characterised by a reduction in bone mass without any known change in its chemical composition" (Barnett and Nordin, 1961). Since the clinical importance of this condition was first recognised, (Albright et al, 1940) much work has been performed to elucidate its nature and causes. That "bone is qualitatively normal in osteoporosis but there is too little of it", was emphasised by Fraser (1962), and he divided osteoporosis into three clinical groups - (i) associated with metabolic bone disease;



Table 3

BREAKDOWN OF HAND SURGERY AT HAMMERSMITH HOSPITAL IN ONE YEAR (1971-2)

| No. of    | Thumb | Index | Middle | Ring | Little |
|-----------|-------|-------|--------|------|--------|
| ops/digit | 13    | 36    | 38     | 39   | 24     |
| No. of    | 1     | 2     | 3      | 4    | 5      |
| digits/op | 46    | 18    | 8      | 11   | 0      |

(ii) idiopathic, and (iii) senile or post-menopausal. While there is clear evidence of multiple causes, endocrine disturbances can cause osteoporosis (Casuccio, 1962) and, more specifically, induced menopause (Nicholas and Wilson, 1959) pituitary-dependent or iatrogenic Cushing's disease and thyrotoxicosis (Doyle, 1967). It was believed that a reduced intake of calcium was also a cause (Nicholas and Wilson, 1959) but this is not now recognised (Garn et al, 1967). Intakes as high as 1,500 mg. per day are not protective against bone loss nor are intakes as low as 300 mg. per day associated with increased loss. Although osteoporosis has been recognised in children under ten (McCrae and Sweet, 1967) it is commonest in older age groups. Varying views are held about the relationship of osteoporosis with age and sex. Mainland (1957) showed that men had a higher bone density than women and lost 10% of the bone mineral from adulthood through old age. This loss of bone with age has been confirmed (Morgan et al, 1967) and they add that women lose bone faster and earlier. This faster bone loss by women has been quantified (Meema, 1963) and it was shown that the mean life radial cortex loss was three times greater for females. An analysis of thirty papers (Newton-John and Morgan, 1968) showed that bone loss commenced at between thirty-five and forty-five for females and progressed at a rate of 10% per decade, while for males the onset was between forty-five and sixty-five with a slightly less rapid rate of progression. The variation in the amount of bone between people stayed the same with age. From this it was concluded that "there is little justification for continuing to regard senile or post-menopausal osteoporosis as a disease, distinct from the loss of bone with age". The above ages of onset have been confirmed (Smith et al, 1969) and the greatest fall

in density was shown to occur within five years of the menopause. In a longitudinal study on a randomly sampled population (Adams et al, 1970) loss of bone was found to be usual but not universal, and loss of bone was not related to loss of height, body weight, fractures, or incidence of pain. These findings are in conflict with those of Garn (1967) who reported that bone is always lost and argued that the best natural protection against the sequence of bone loss with age is a large skeletal mass in early adult life. Opinion differs as to the nature of the porotic process in the bone. It has been stated that the main cause is reduced osteoblastic activity (Casuccio, 1962). In contradistinction, it has been shown that bone formation levels are generally normal and the osteoporotic bone differs from normal bone by an increase in the amount of resorption (Jowsey et al, 1965). Salicylates have been shown to diminish osteoblastic activity by suppressing RNA synthesis (Cooper et al, 1964). They have also been found to suppress bone resorption in Paget's Disease (Avioli and Henneman, 1964). Osteoporosis is also a feature of Rheumatoid Disease and in patients treated with salicylates depressed bone formation (Ramser et al, 1966) and active diffuse demineralisation (Duncan et al, 1965) have been shown to occur. Whether this bone loss is due to the drug or the disease process is not clear. However loss of bone mass is closely related to the severity of Rheumatoid Disease in the hand (Bjelle and Nilsson, 1971) but steroid treatment in Rheumatoid Disease also causes loss of bone by reducing the number of sites of new bone formation and by increasing the number of sites of bone resorption (Duncan, 1967). Since steroid treatment and severity of disease are closely related, the incriminating factor in bone loss is not obvious.

There is however circumstantial evidence to suggest that this incriminating factor in bone loss in the hands of patients with rheumatoid disease is progressive loss of hand function. Local disease osteoporosis occurs after fractures (Nilsson, 1966) and occurs unilaterally in long standing hemiplegia (Hodkinson et al, 1967). Metabolic studies on patients with paralytic acute anterior poliomyelitis have shown generalised osteopenia in quadriplegia (Whedon et al, 1957) and Xray scanning of the os calcis after prolonged bedrest has shown large losses of mineral paralleling the increased urinary excretion of calcium (Donaldson et al, 1970). Gravity has been shown to have an effect on the length and shape of bones (Tulloh et al, 1963) and there is a reduction in bone density when exposed to a reduced barometric pressure (Hunt et al, 1965). In a study on astronauts during a representative Apollo space flight it has been confirmed that calcium is lost from the body in prolonged hypodynamic states (Mack, 1972). That such a mechanism of bone loss can occur in the hands has been shown in a study of manual versus non-manual workers (Keane et al, 1959) where calcification of a bone near a joint depended very much on occupational stress applied to the bone over an appreciable period.

Osteoporosis in rheumatoid hands has not been extensively studied. However a highly significant correlation has been demonstrated between the progress of osteoporosis in the proximal phalanges and the grip power of the hands (Virtama et al, 1968). This study suffered several inaccuracies, including summing the cortical thicknesses of several bones and using it as an index of bone density, and the already-stated errors of grip strength measurement. Furthermore, selecting always the second and fourth digits

for morphological measurements involves a large error on consideration of the asymmetrical manner in which the disease process strikes the units of the hand as shown in Table 3.

The author shows that the incriminating factor in bone loss in the hands of patients with rheumatoid disease is loss of hand function, that hand function and bone density are closely related at the digital level, and that both these processes can be reversed by appropriate corrective surgery.

(b) Methods of measuring bone density

The basic themes of the various methods of measuring bone density have been classified into seven categories (Doyle, 1965). These are:-

1. Densitometry using an Xray beam source.
2. Measurement of the attenuation of a highly collimated Xray beam or a photon beam from a radioactive isotope,
3. The two Kilovoltage method - based on differences in the differential absorption of Xrays in bone and soft tissue at two widely differing peak kilovoltages.
4. The photometric comparison of vertebral bodies with intervertebral discs from lateral tomograms.
5. Neutron activation of a bone followed by measurement of the radiation emission from the calcium isotopes present.
6. An ultrasonic method based on the different transit times of a sonic pulse in bone, muscle, and fat.
7. Morphological measurements on routine radiographs.

The commonest methods in use are the first, densitometry, the second, now referred to as direct photon absorptiometry (Cameron and Sorenson, 1968) and the last, morphological measurements.

(i) Densitometry

Densitometry is based on the comparison of the density produced by a standard step-wedge to the density produced by a bone simultaneously exposed on an Xray. The photographic densities of the wedge measured by a densitometer are plotted against the wedge thickness, and a calibration curve is obtained. The density of a given area of bone can then be expressed in terms of the step wedge. The first reported step wedge to determine bone radiopacity was made of copper (Price, 1901). Since then many materials have been used. Aluminium step wedges are widely used (Hodge et al, 1935; Van Huysen, 1935; Mainland, 1957; Doyle, 1961) as are ivory ones (Stein, 1937; Bywaters, 1948; Rethmeir, 1955; Dickson et al, 1972). Other materials used include beef bone (Henny, 1950), human bone (Steven, 1947), calcium chloride (Reich et al, 1958), and dipotassium hydrogen phosphate (Meema et al, 1964). These materials all have similar Atomic Numbers and hence Xray absorption (Pridie, 1967). The technical difficulties in densitometry include the contribution to density that the soft tissues make, the non-uniformity in scatter of the Xray beam, the variable intensity of the Xray source, the choice of a suitable wedge material, and the need for automatic processing (Doyle, 1965). Mainland (1956) deduced that there was a 6.5% variation with densitometry due to these factors and added the need for a specially-trained technician. Radiodensitometry of the ulna, histological studies on iliac biopsies, and measurements of ash weight have been found to be equally accurate in the determination of bone mineral (Chalmers et al, 1966) and can be correlated (Popowitz et al, 1971). The accuracy of radiographic densitometry has



been compared with that of direct photon absorptiometry in the in vitro determination of bone mineral (Colbert et al, 1970).

Wisconsin absorptiometry (Sorensen et al, 1967) was found to be twice as accurate as Fels photodensitometry (Colbert et al, 1967) having only a 3% error in predicting ash weight.

Using a new technique, Colour Television Image Analysis (Dickson et al, 1972) based on the principles of photodensitometry the author has been able to make this method of bone density measurement the most reproducible so far reported.

(ii) Morphological measurements

The use of radiographic measurements has become increasingly popular due to the simplicity of taking Xrays. That changes in the shape of bones and the thickness of their cortex could reflect changes in mineral content was described by Barnett and Nordin (1960), and provided a new approach to the radiological diagnosis of osteoporosis. They measured the ratio of the thickness of the cortex of a metacarpal to the total width of the bone and this they called the "metacarpal index". Since then many new parameters have been used as indices of bone density. The ratio of the area of the cortex to area of the remainder of the bone has been used as an estimate of mineral content (Virtama et al, 1960). More recently, (Exton-Smith et al, 1969) an "area index" based on the cross-sectional area of a cylinder, assuming a bone to be such at its mid-shaft, has been found to be a useful measure of mineral content. The author uses this new parameter in a preliminary study before the use of Colour Television Image Analysis.

PART II - MATERIALS AND METHOD

1. DESCRIPTION OF INSTRUMENT

A. The Instrument

This instrument was designed to measure the force of flexion of the hand at the wrist and the force of pinch between the thumb and index finger. The cyberometer is shown in the view in Figure 1, by and in cross-section in Figure 2. It comprises a base of aluminum (A) in which is secured a cantilever of mild steel (B) fixed at its right end. The cantilever is perforated generally every one centimetre of its length by small holes which house the upper end of a small brass button (C). The most proximal protrusion of the cantilever accommodates a small brass ball (D) which is held in place (E) from batteries of force transducers. The cantilever has a slight lateral curvature which is gradually corrected as the digit is flexed. The registration pen which records a movement of the cantilever is shown in Figure 3. The cantilever (1) rests upon the ball (2) which is held in place by the spring (3) and the lateral projection (4) of the other digit when the one digit that presses the cantilever.

**PART II - MATERIALS AND METHOD**

The instrument measures the force of flexion of the extended digit and the force of pinch between the thumb and index finger. In order to determine the force of flexion of a digit, the palm of the hand rests upon the base of the instrument and the digit is extended. The force of flexion is measured by the deflection of the cantilever. The force of pinch is measured by the deflection of the cantilever when the thumb and index finger are used to pinch the cantilever. The force of flexion is measured by the deflection of the cantilever when the digit is flexed. The force of pinch is measured by the deflection of the cantilever when the thumb and index finger are used to pinch the cantilever.



PART II - MATERIALS AND METHOD

1. CONCEPTS OF TECHNIQUE AND DESIGN

a) The Cybernometer

This instrument was designed and built to fulfil the need for the accurate assessment of hand function at the digital level. The cybernometer is shown in side view in Figure 1, and in frontal view in Figure 2. It comprises a base of aluminium (A) to which is secured a cantilever of mild steel (B) fixed at its origin only. The cantilever is perforated centrally every one centimetre of its length by small holes which house the central pin of a small brass button (C). The most proximal perforation is at the origin and this accommodates a small brass switch (D) operating a red light (E) from batteries (F). In addition, the cantilever has a small lateral projection (G) similarly perforated, and the aluminium base is grooved vertically beneath this. The aluminium base also secures a measuring clock (height gauge) (H) whose recording arm (I) rests upon the distal free end of the cantilever. A swivel arm (J) protects the lateral projection from the other digits when the one under test presses the cantilever.

The instrument measures the force of flexion of the extended digit and the force of pinch between digit and thumb. In order to determine the force of flexion of a digit, the palm of the hand rests upon the aluminium base, the metacarpal head rests upon the light switch at the origin of the cantilever, and the pulp of the finger rests in the small brass button which has been seated in one of the perforations of the cantilever, according to the length of the finger (Figure 3). Maximal force is then applied to the cantilever by the finger tip of the subject while the metacarpal head depresses the light switch. Any undue flexion occurring at the

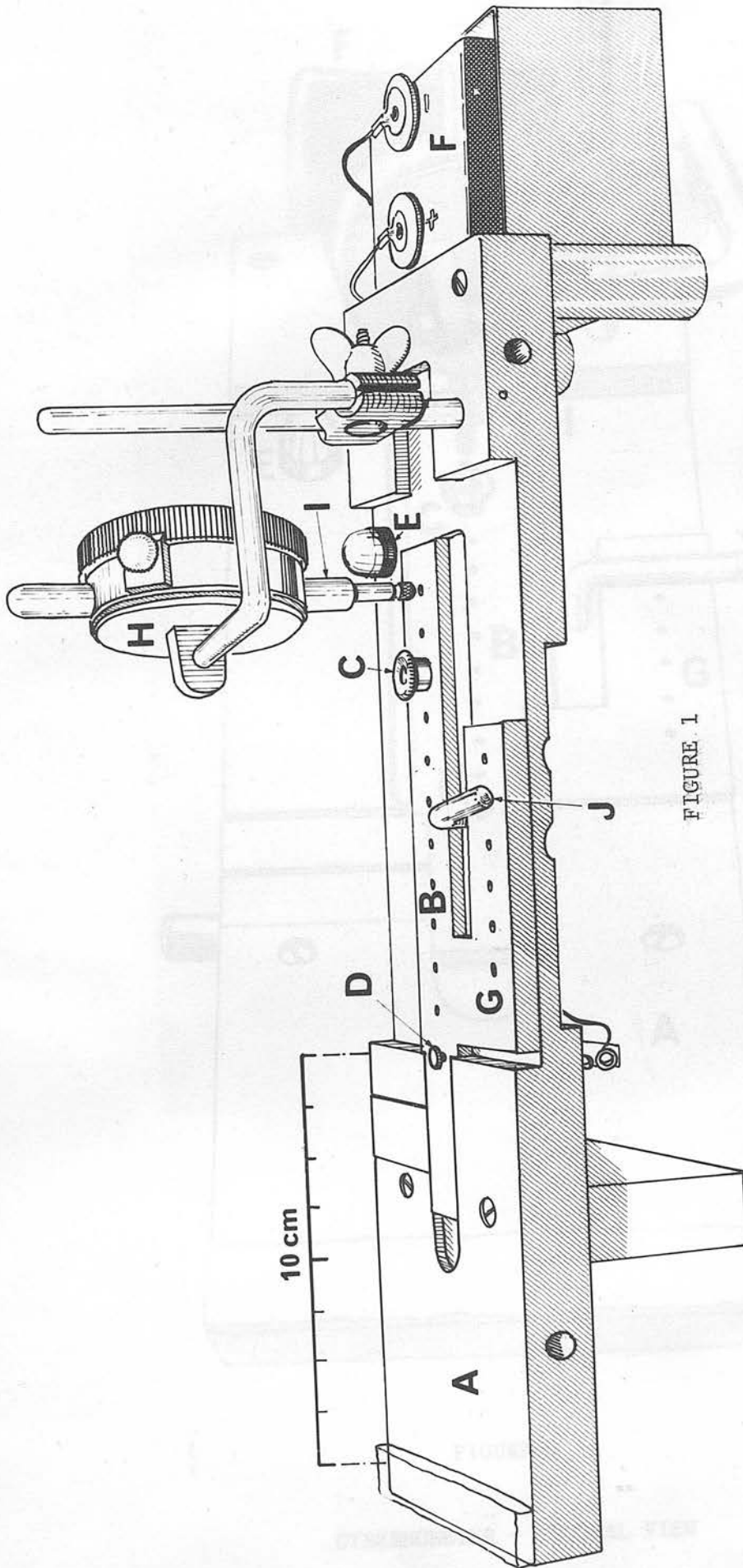


FIGURE 1

CYBERNOMETER - SIDE VIEW

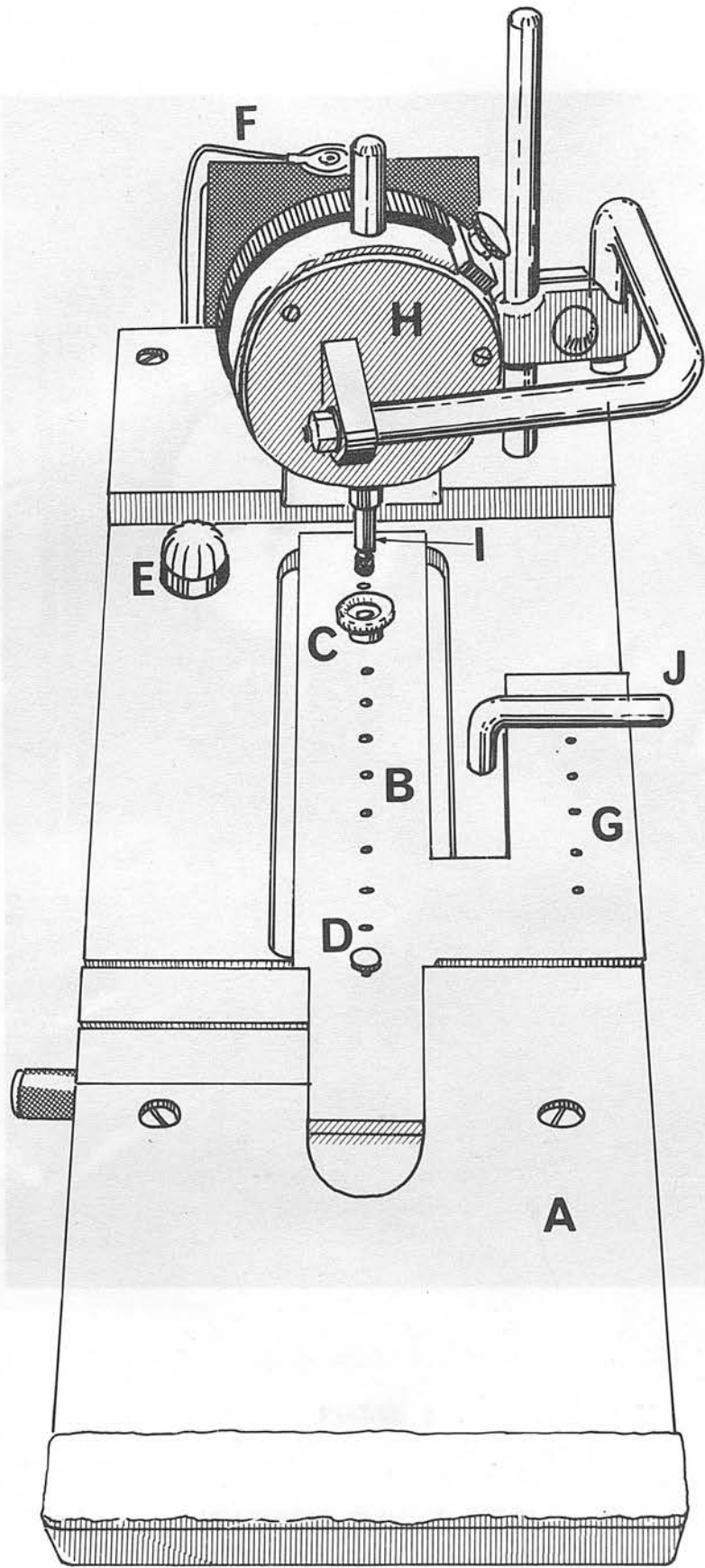


FIGURE 2

CYBERNOMETER - FRONTAL VIEW

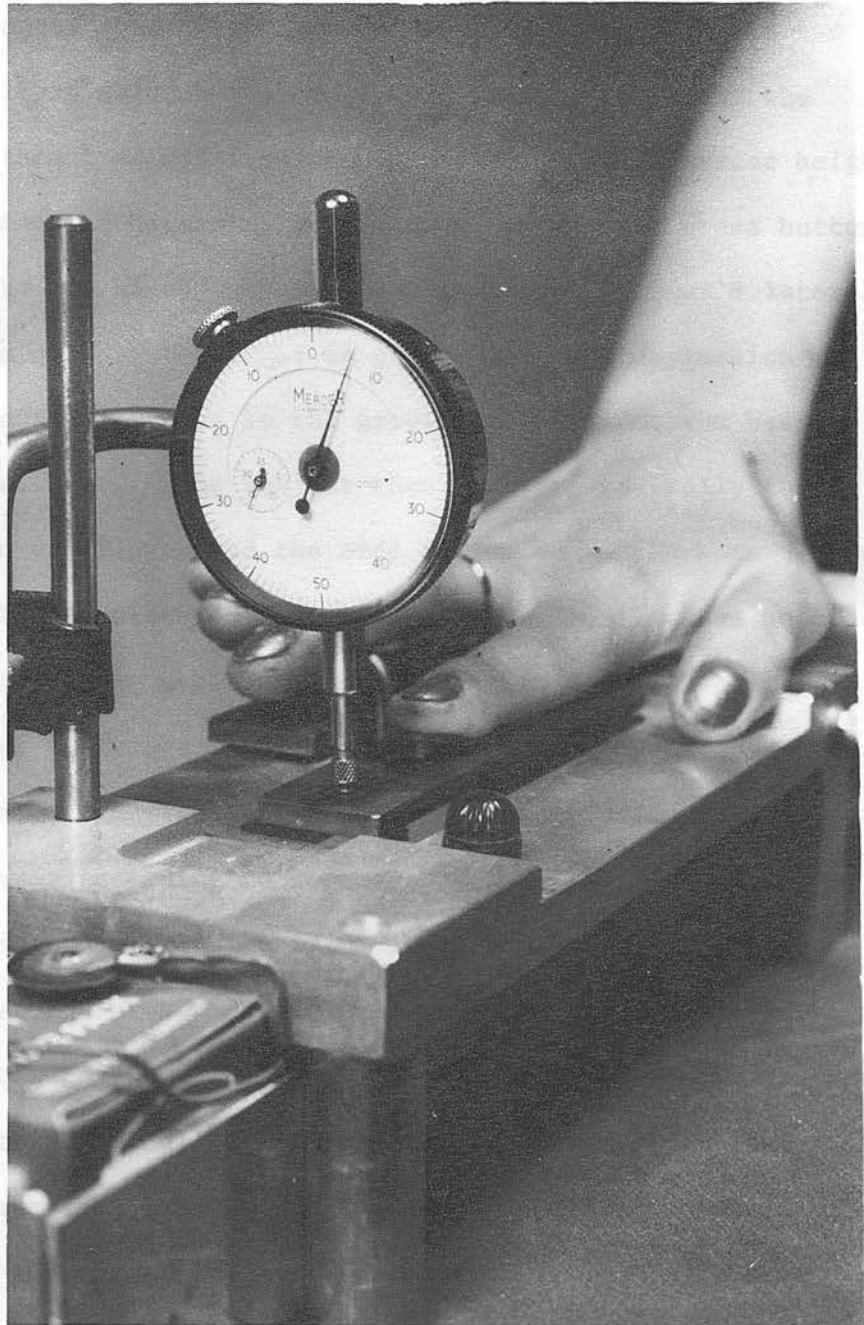


FIGURE 3

MEASURING FLEXION FORCE

metacarpophalangeal joint will then become readily apparent to the observer, the light going out at once. The displacement of the cantilever is then read off from the measuring clock (a Mercer height gauge). In order to determine the force of pinch, the brass button is inserted into one of the perforations on the cantilever's lateral projection, the pulp of the digit is placed into the depression of the button, and the thumb is in the groove in the aluminium base vertically beneath it. The subject then attempts maximally to approximate the cantilever and the side of the aluminium base (Figure 4). The displacement is read off from the clock as before.

Calibration of the cybernometer was performed by suspending weights from the different perforations in both the cantilever and its side-arm, and recording the deflection. The simply-loaded uniform cantilever behaves according to Hooke's Law in that it is perfectly elastic until its elastic limit is reached. The presence of the perforations and the attached side-arm renders the cantilever theoretically non-uniform. However, the calibration graphs for both cantilever (flexion force) (Figure 5) and side-arm (pinch force) (Figure 6) are straight lines, weight being directly proportional to deflection and therefore, for practical purposes, the cantilever remains uniform and Hookean.

The only error in the system is that associated with the measuring clock. Considering the various positions of the pointer in Figure 7, the first pointer obviously records 0. Accepting recordings in whole numbers only, the second pointer also records 0 in that it is nearer 0 than 1. The third pointer in contradiction records 1 as it is nearer 1 than 0. The fourth pointer obviously records 2. Recordings taken in this manner accept an



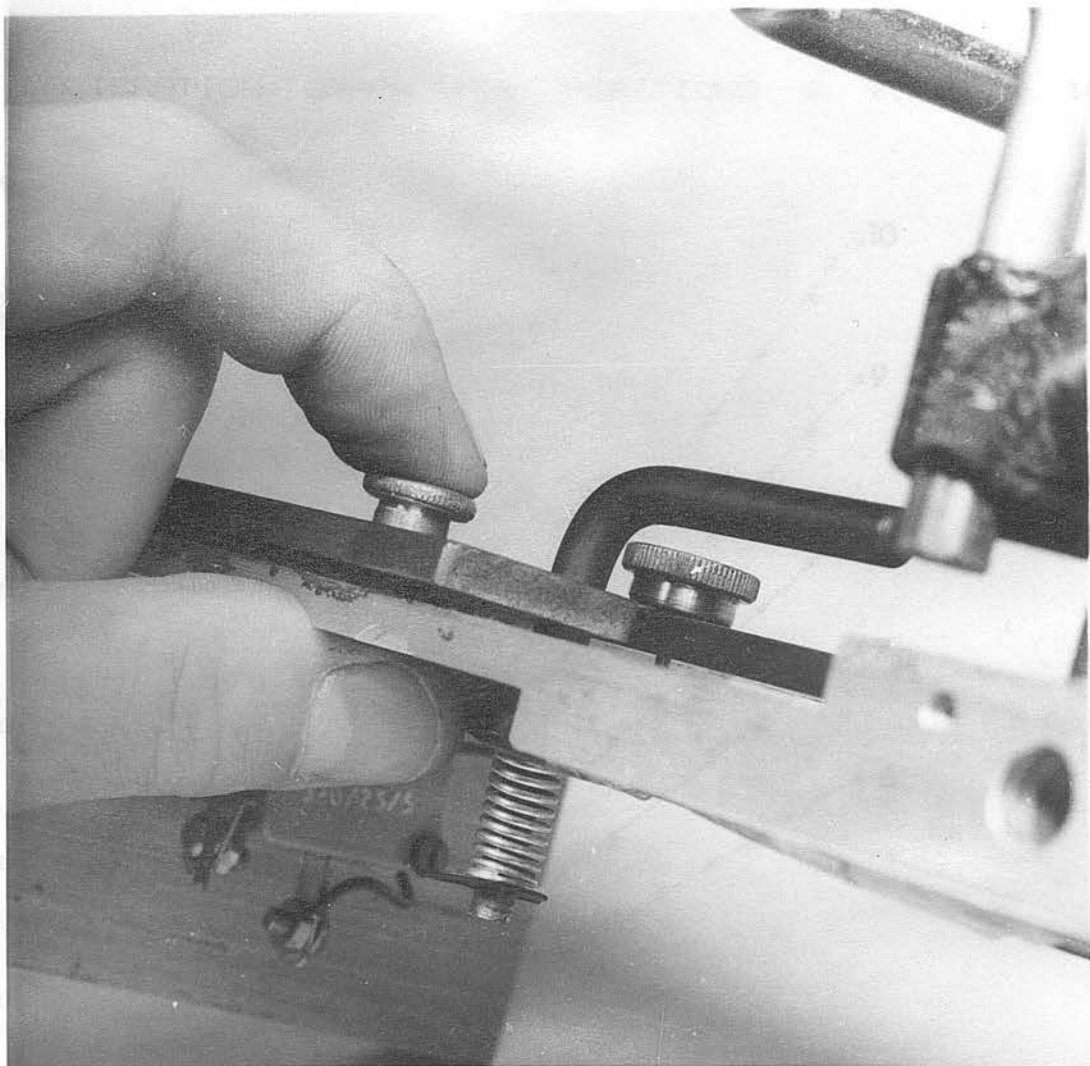


FIGURE 4

MEASURING PINCH FORCE

FIGURE 5

(POSITIONS 1, 2, 6, 9, 10, REFER TO THE FIGURE 5  
AND ONLY DISTANCE FROM THE ORIGIN OF THE GRAPH)

CALIBRATION GRAPH FOR POSITIONS 6, 7, 8, 9, 10

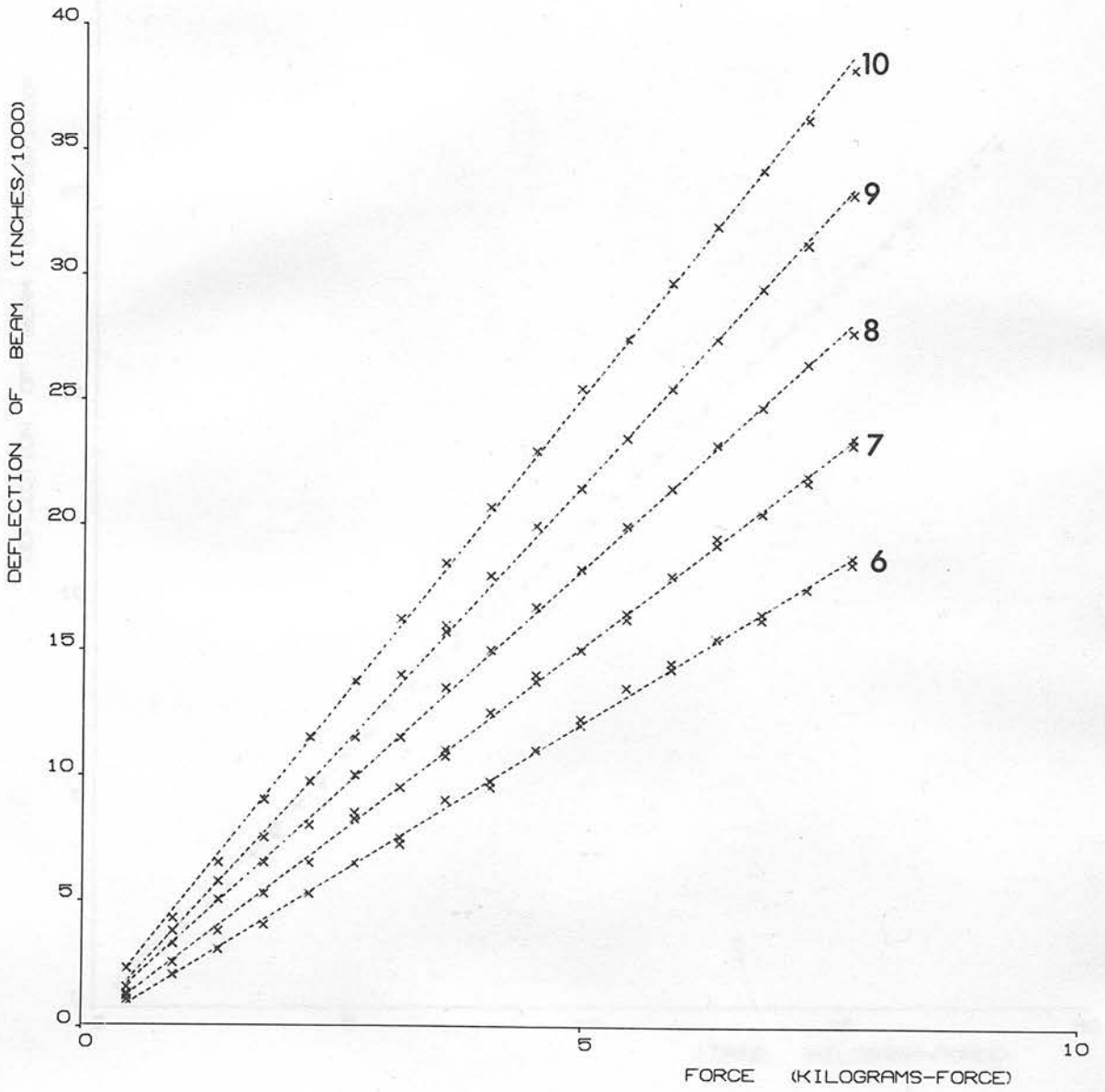


FIGURE 5

(POSITIONS 6, 7, 8, 9, 10, REFER TO THE PERFORATIONS  
AND THEIR DISTANCE FROM THE ORIGIN OF THE CANTILEVER)

MEASURING CLOCK

CALIBRATION GRAPH FOR PINCH

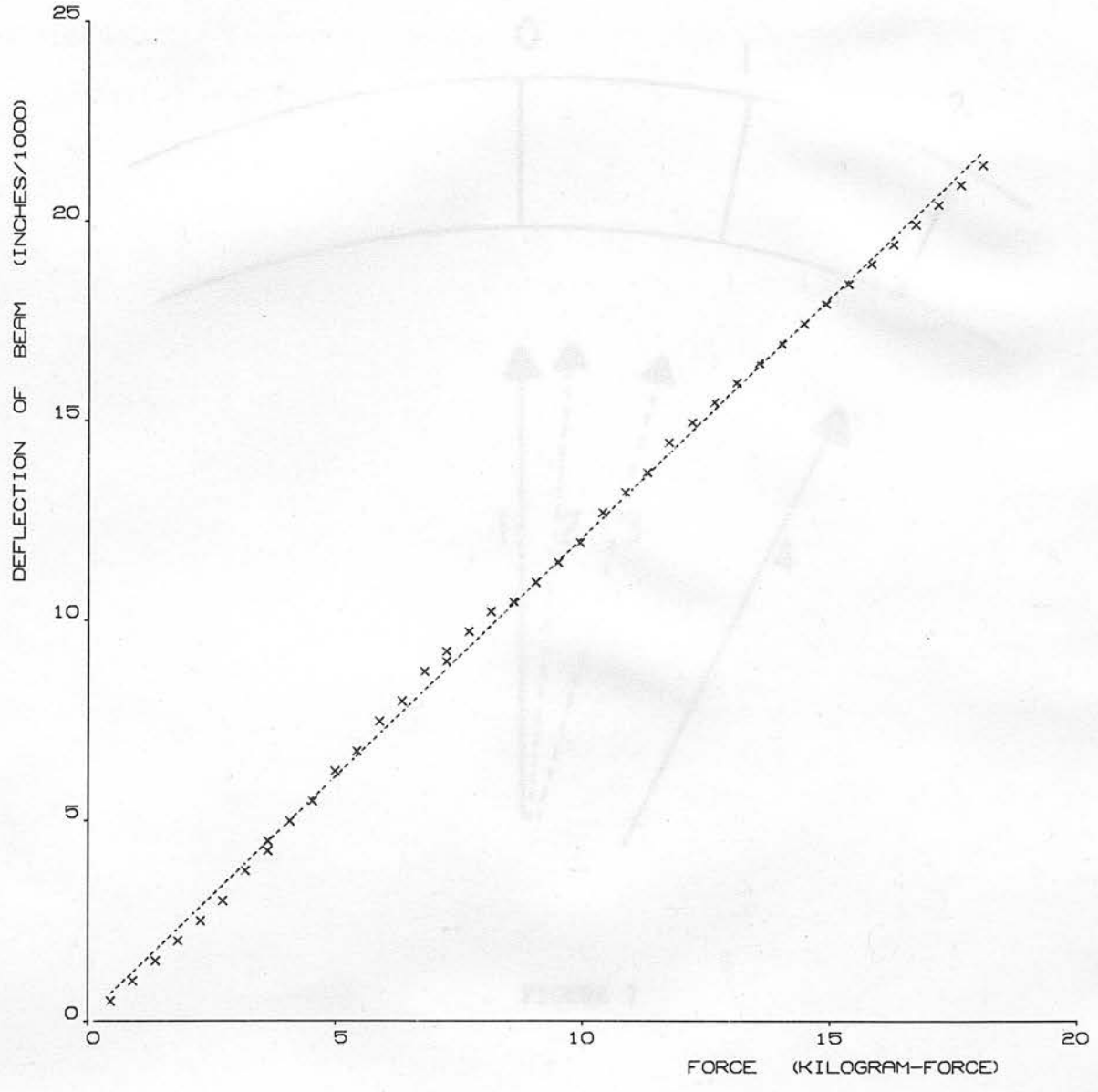


FIGURE 6



error of  $\pm 0.0003$  inches  
of  $\pm 0.1$  kg. force.

# MEASURING CLOCK

With this instrument slight changes in slope forces have been investigated in normal action, and the results are shown before and after corrective surgery.

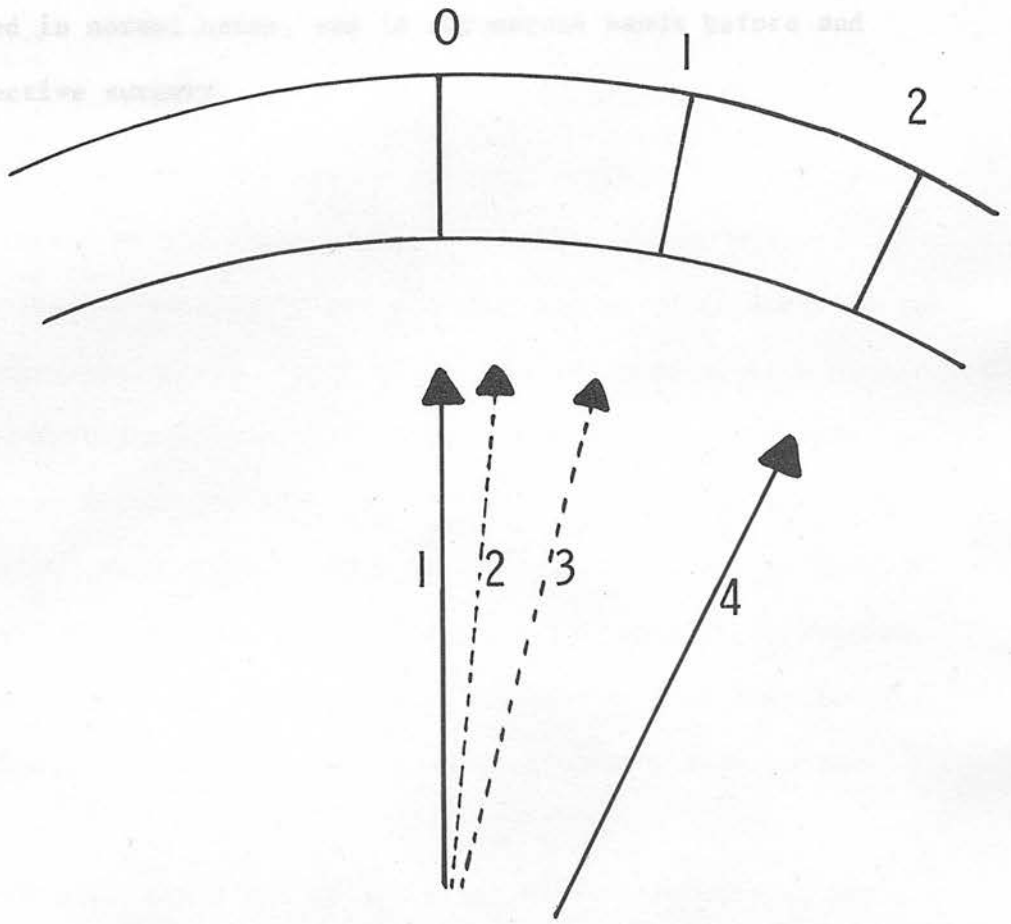


FIGURE 7



b) The Torquemeter

Wright (1960) pointed out the continuing need for quantitative assessment of the hand in the rheumatoid patient and devised a 'portable arthrograph' to measure torque in the metacarpophalangeal joint of the index finger.

This joint was the only one in the hand which could be studied due to the design of the arthrograph. For this reason a new instrument, the 'Torquemeter', was designed and built to study torque in the metacarpophalangeal joints of all four fingers of both hands. Furthermore, by the nature of its design, torque in these joints can be investigated throughout their entire range of movement from full extension to 90° of flexion. This has allowed a study to be made of the manner in which torque varies from extension through to flexion, has quantified the contribution to joint resistance that the diseased synovium makes, and has assessed the value of synovectomy in the rheumatoid hand.

The instrument makes use of the principle of the torsion bar and is shown photographically in Figure 8. It comprises a base of aluminium, A, with padded clamps, B, to secure the forearm. The hand grasps the vertical torsion system, C, as it would do the handle of a pistol. By pressure of a finger on a horizontally attached side-arm, D, the torsion bar is wound up. A second side-arm, E, moves in sympathy with the one pressed upon and its deflection is registered on a Vernier dial gauge, F. The torsion system pivots on the aluminium base and can be locked by a lever, G, in any position of rotation, allowing a recording to be made in any position of the joint. Furthermore, the side-arm, D, slides up and down so that any finger can be tested.

The requirements for the instrument are shown in Figure 8. The instrument rests comfortably on the standard base and is clamped in position. The hand grips the vertical torsion system and a finger is extended

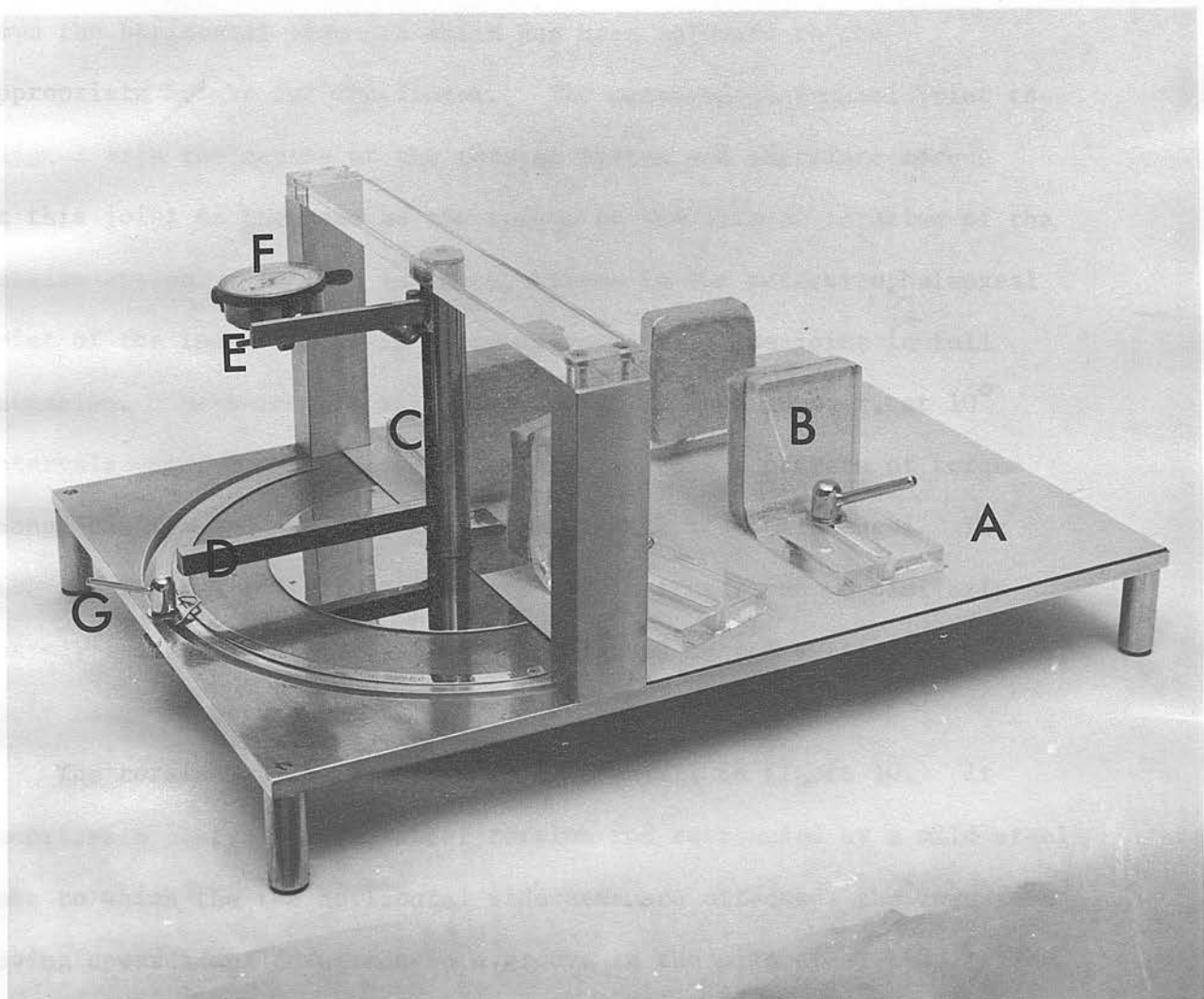


FIGURE 8

THE TORQUEMETER

solid steel tube is attached to the silver steel torsion rod only at its upper end and, furthermore, is rigid, thus providing for uniform readings in any vertical position. In addition, the mild steel tube is held in the vertical position by means of a brass socket which can be used for the torsion bar for angular movement. A stainless steel wire torsion system.

The torsion bar was calibrated against a standard and the resultant calibration graph is shown in Figure 9. The calibration of the

The torquemeter is shown in use in Figure 9. The forearm rests comfortably on the aluminium base and is clamped in position. The hand grasps the vertical torsion system and a finger is extended down the horizontal side-arm which has been adjusted to the appropriate height for the finger. The metacarpophalangeal joint is aligned with the centre of the torsion system and therefore torque at this joint is the same as the torque at the axis of rotation of the torsion system. In this instance, torque in the metacarpophalangeal joint of the index finger is being measured with the joint in full extension. Measurements will continue to be made however, at  $10^{\circ}$  intervals until full flexion is reached, so that a pattern of torque change can be seen as the joint moves through its full range. The side-arm is then lowered so that the middle finger can be similarly tested, and so on until all fingers have been tested throughout their range of motion.

The torsion system is shown in more detail in Figure 10. It comprises a central silver steel torsion rod surrounded by a mild steel tube to which the two horizontal side-arms are attached, the lower one moving upwards and downwards in a groove in the mild steel tube. The mild steel tube is attached to the silver steel torsion rod only at its upper end and, furthermore, is rigid, thus providing for uniform readings in any vertical position of the lower side-arm. In addition, the mild steel tube is fixed to the aluminium base by means of a brass socket which can be made to rotate by adjusting the mild steel bar for angular movement. A stainless steel tube surrounds the entire torsion system.

The torsion bar was calibrated against known weights and the resultant calibration graph is shown in Figure 11. Deflection of the

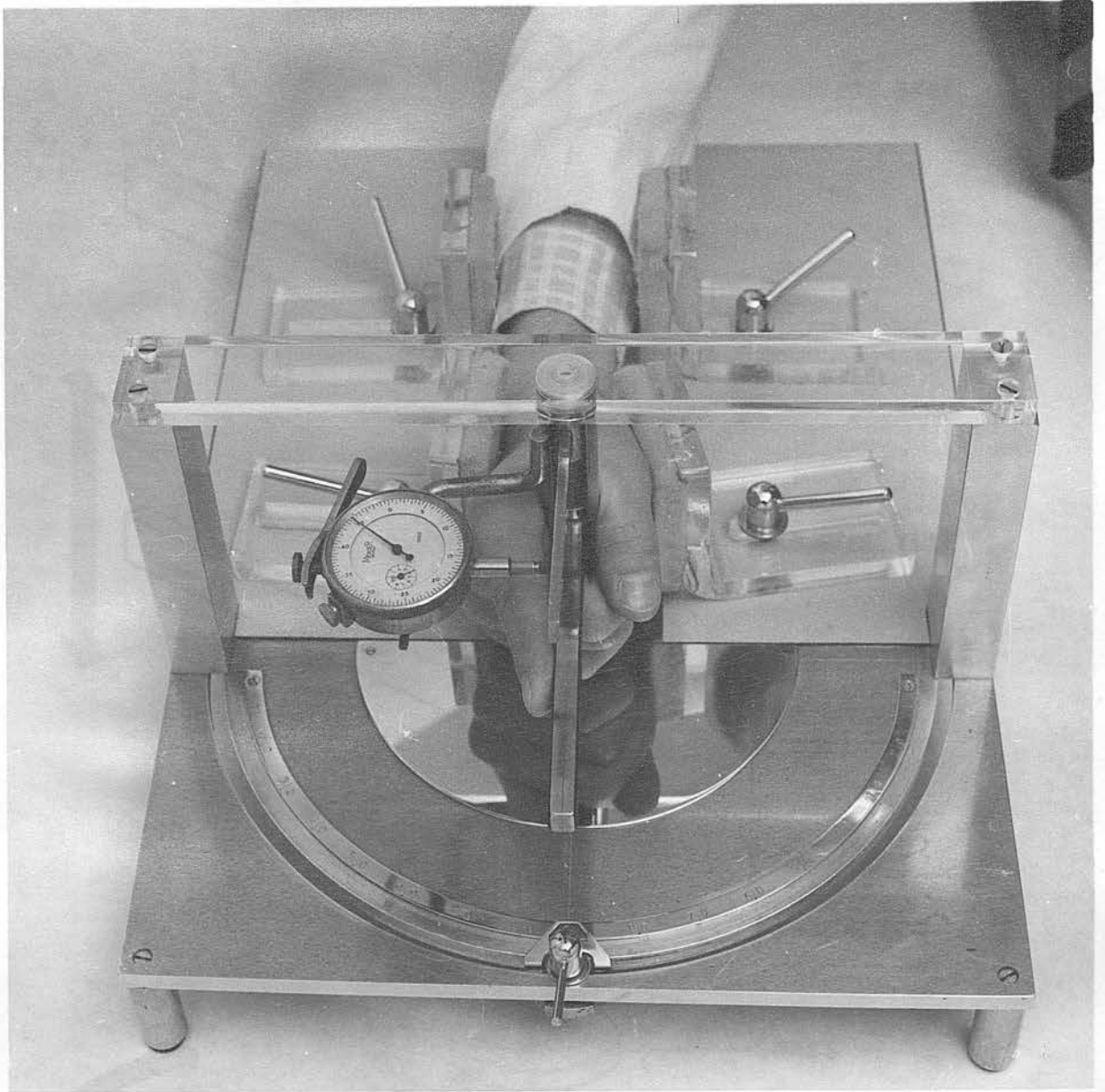


FIGURE 9

TORQUEMETER IN USE



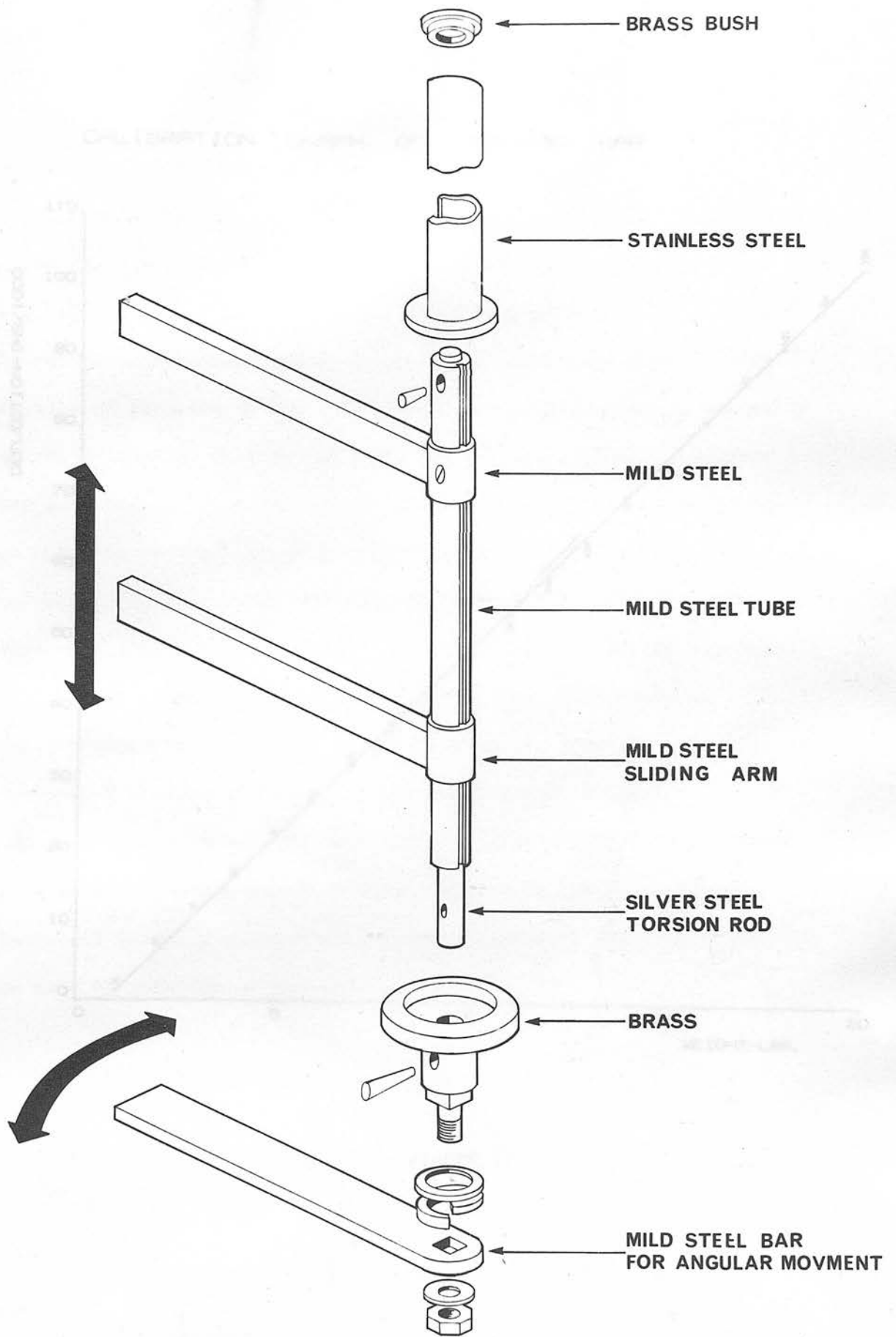


FIGURE 10

DETAIL OF TORSION SYSTEM



CALIBRATION GRAPH OF TORSION BAR

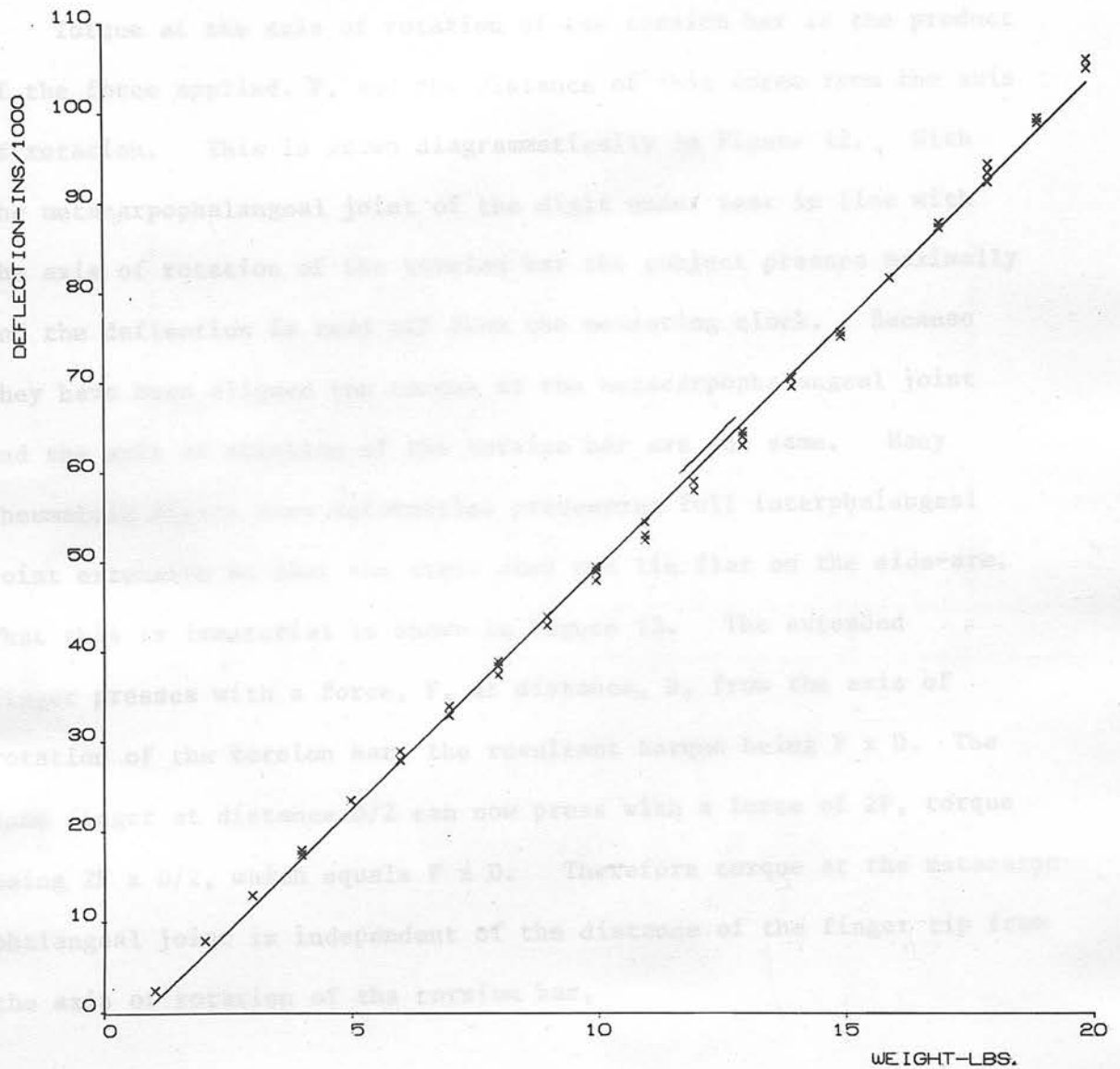
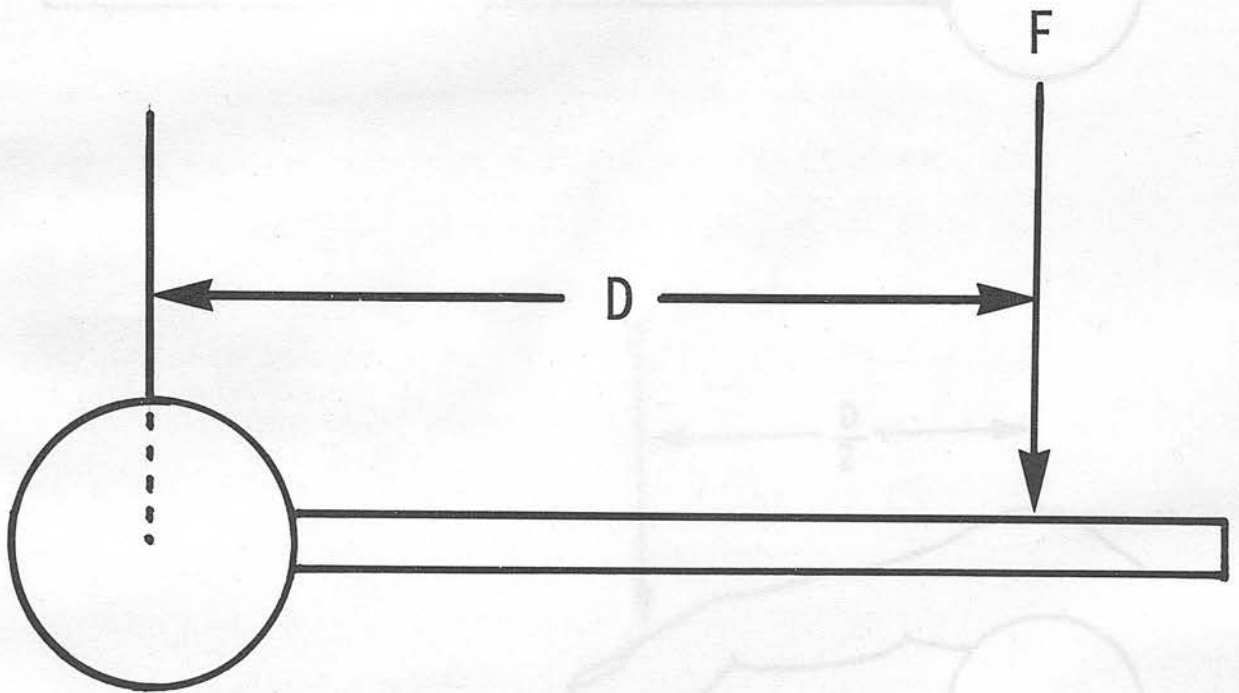


FIGURE 11

upper side-arm is plotted on the vertical axis while weight is plotted on the horizontal axis. The straight line relationship so produced confirms the instrument to be perfectly elastic.

Torque at the axis of rotation of the torsion bar is the product of the force applied,  $F$ , and the distance of this force from the axis of rotation. This is shown diagrammatically in Figure 12. With the metacarpophalangeal joint of the digit under test in line with the axis of rotation of the torsion bar the subject presses maximally and the deflection is read off from the measuring clock. Because they have been aligned the torque at the metacarpophalangeal joint and the axis of rotation of the torsion bar are the same. Many rheumatoid digits have deformities preventing full interphalangeal joint extension so that the digit does not lie flat on the side-arm. That this is immaterial is shown in Figure 13. The extended finger presses with a force,  $F$ , at distance,  $D$ , from the axis of rotation of the torsion bar, the resultant torque being  $F \times D$ . The same finger at distance  $D/2$  can now press with a force of  $2F$ , torque being  $2F \times D/2$ , which equals  $F \times D$ . Therefore torque at the metacarpophalangeal joint is independent of the distance of the finger tip from the axis of rotation of the torsion bar.



$$\text{TORQUE} = F \times D$$

FIGURE 12

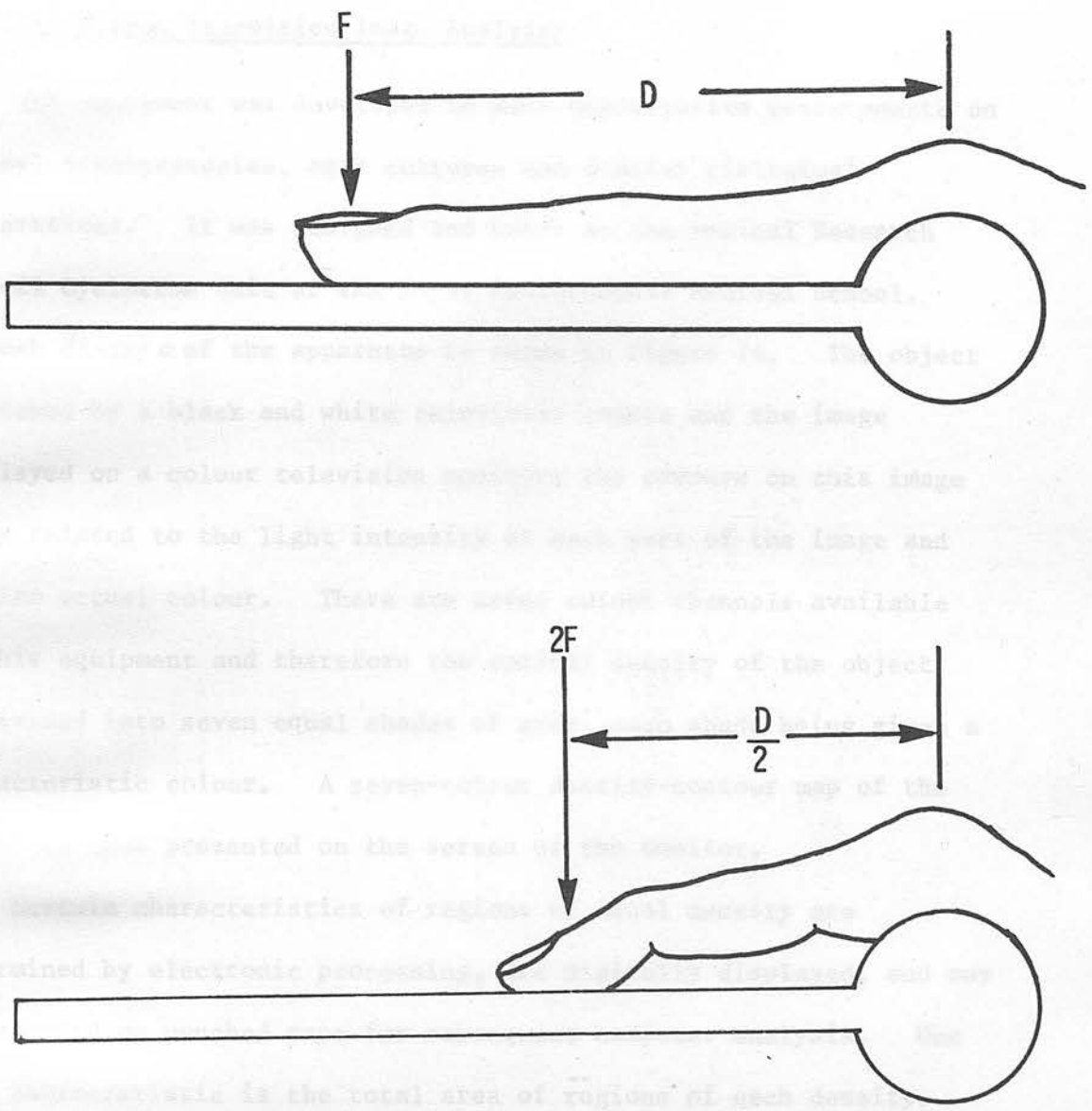


FIGURE 13

$$\text{TORQUE} = F \times D = 2F \times \frac{D}{2}$$

The bone to be investigated is placed with a reference step wedge to allow comparison of the results as they change in contrast. The contrast will affect the wedge equally as it does the bone. The ivory teeth originally designed by Spencer are shown radiographically in Figure 14. It suggests a method of

c) The Colour Television Image Analyser

The equipment was developed to make quantitative measurements on slides, transparencies, agar cultures and similar biological preparations. It was designed and built at the Medical Research Council Cyclotron Unit at the Royal Postgraduate Medical School. A block diagram of the apparatus is shown in Figure 14. The object is viewed by a black and white television camera and the image displayed on a colour television monitor; the colours on this image being related to the light intensity at each part of the image and not its actual colour. There are seven colour channels available in this equipment and therefore the optical density of the object is divided into seven equal shades of grey, each shade being given a characteristic colour. A seven-colour density-contour map of the object is thus presented on the screen of the monitor.

Certain characteristics of regions of equal density are determined by electronic processing, are digitally displayed, and may be recorded on punched tape for subsequent computer analysis. One such characteristic is the total area of regions of each density.

The layout of the equipment is shown in Figure 15. A, is the black and white television camera, B, the colour monitor, C, the parameter electronics, and D, the teletype for subsequent computer analysis. This equipment has been adapted for the accurate measurement of bone density.

The bone to be investigated is Xrayed with a reference step-wedge to allow comparison between films as any change in exposure and contrast will affect the wedge equally as it does the bones. The ivory wedge originally designed by Bywaters was used, and is shown radiographically in Figure 16. It comprises eighteen ivory discs

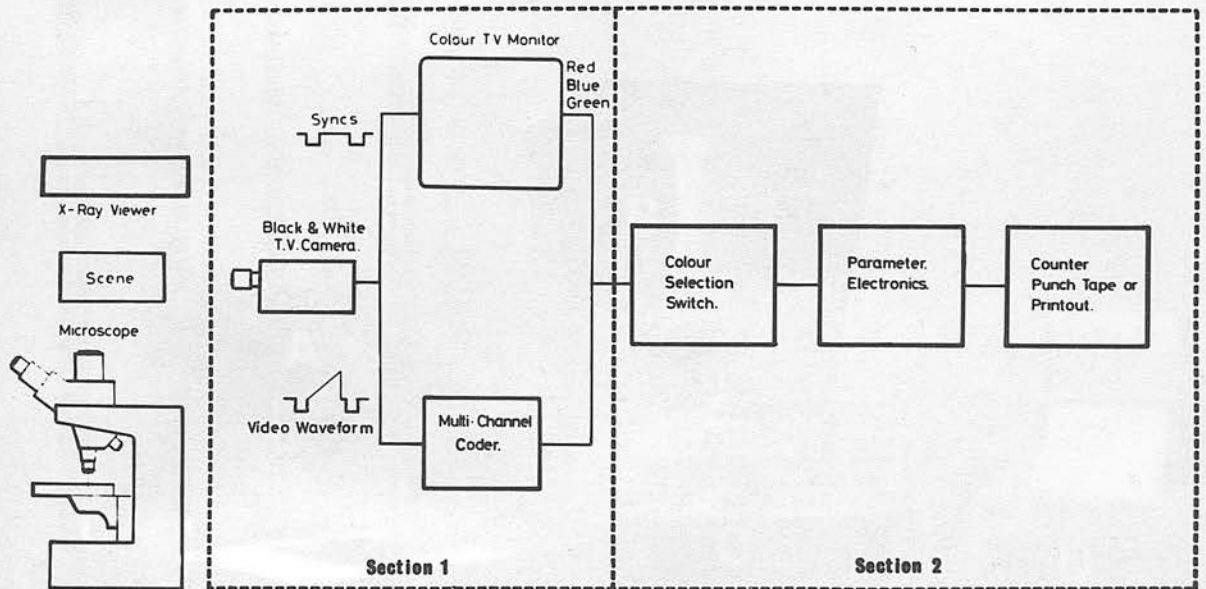


FIGURE 14

BLOCK DIAGRAM OF COLOUR TELEVISION IMAGE ANALYSER

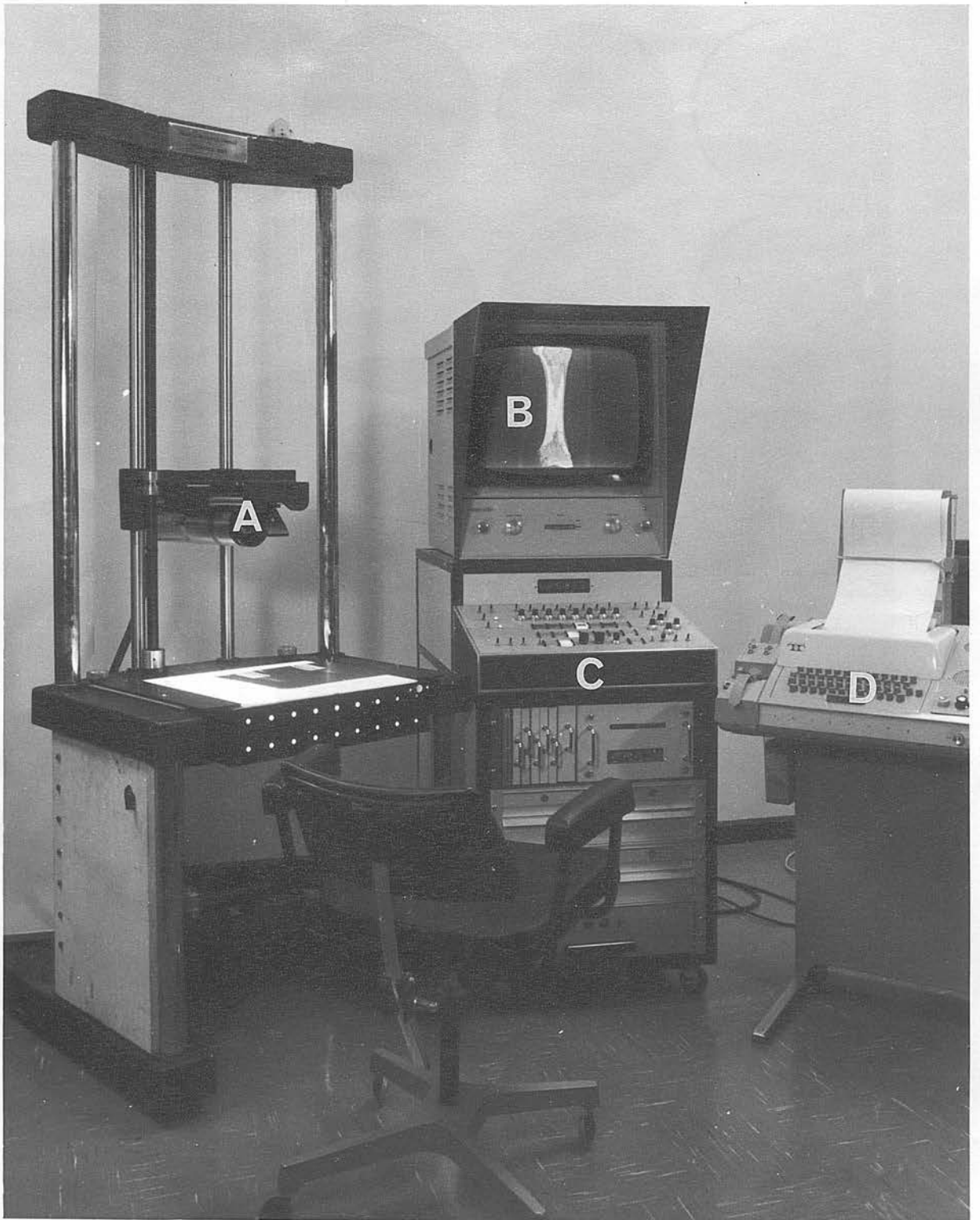


FIGURE 15

LAYOUT OF COLOUR TELEVISION IMAGE ANALYSER



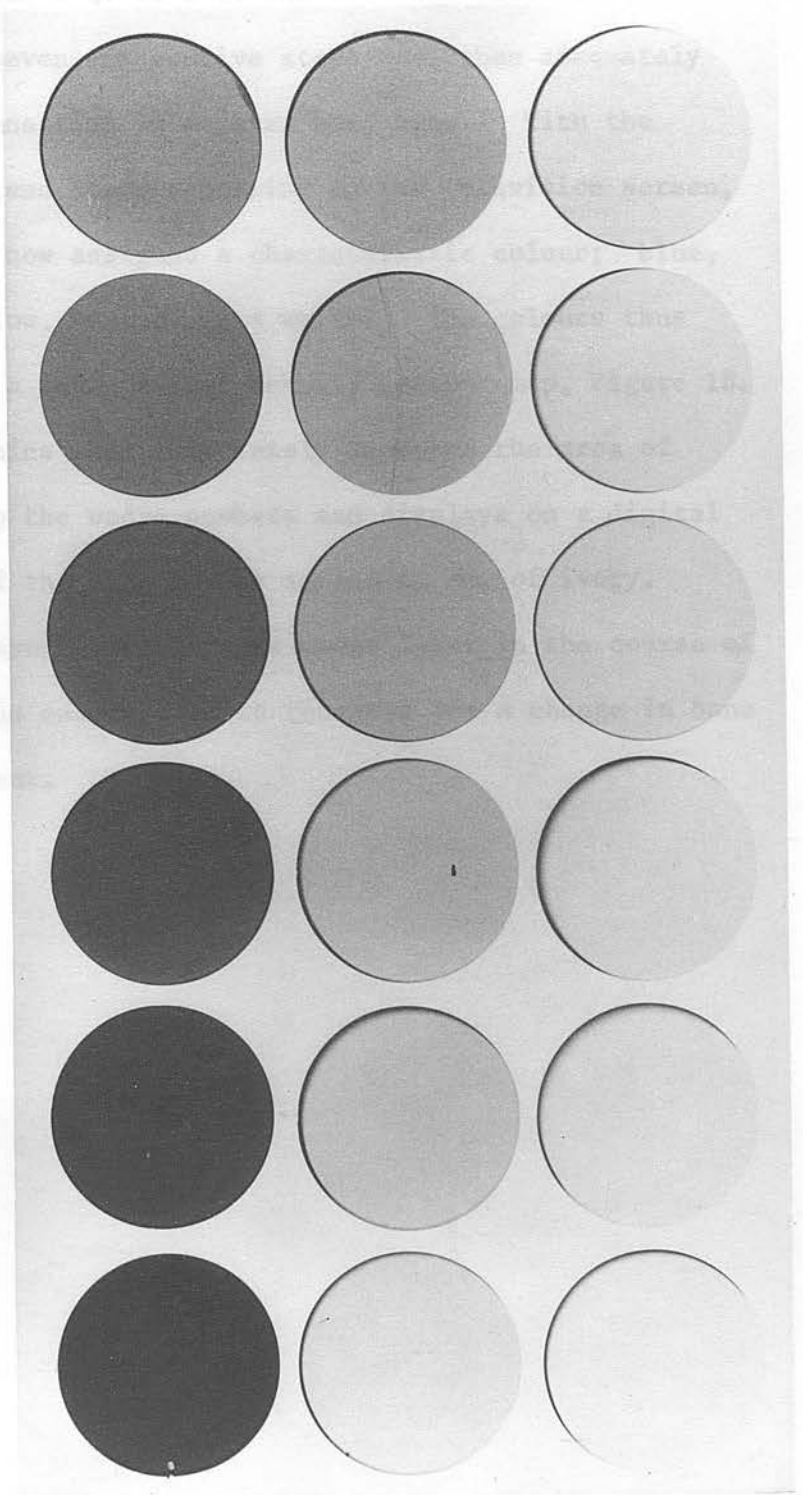
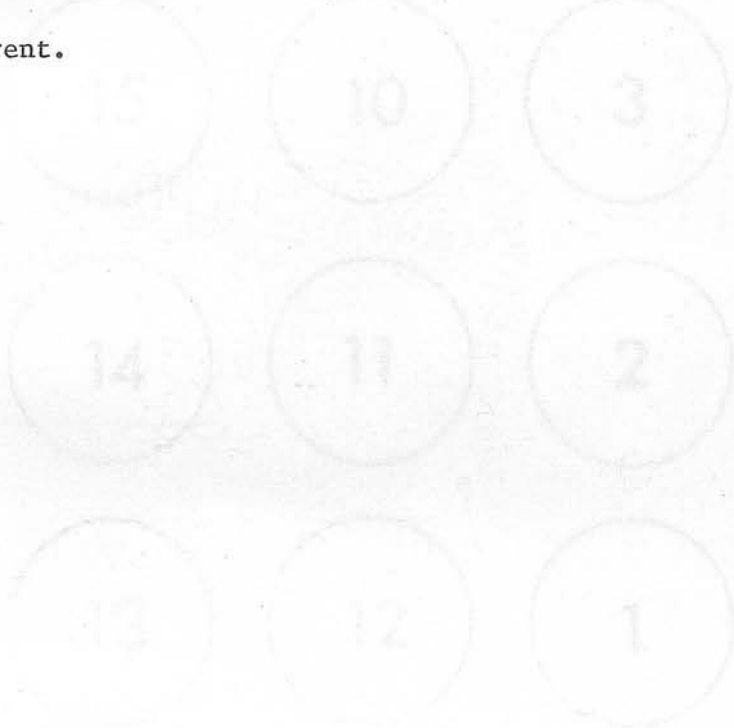


FIGURE 16

THE BYWATER WEDGE

of graded thickness from 1 to 18 mm., and are thus numbered as in Figure 17. A given seven consecutive steps more than adequately covers the range of densities in a given hand bone. With the Xray under the camera and hence appearing on the television screen, these seven steps are now assigned a characteristic colour; blue, green, red, cyan, yellow, magenta, and white. The colours thus appear in the bone as a seven colour density-contour map, Figure 18. The parameter electronics then immediately measures the area of each colour, refers to the wedge numbers and displays on a digital counter the density of the bone on the screen in mm. of ivory. The bone is then reXrayed with the same wedge later in the course of disease or therapy, the examination is repeated and a change in bone density becomes apparent.



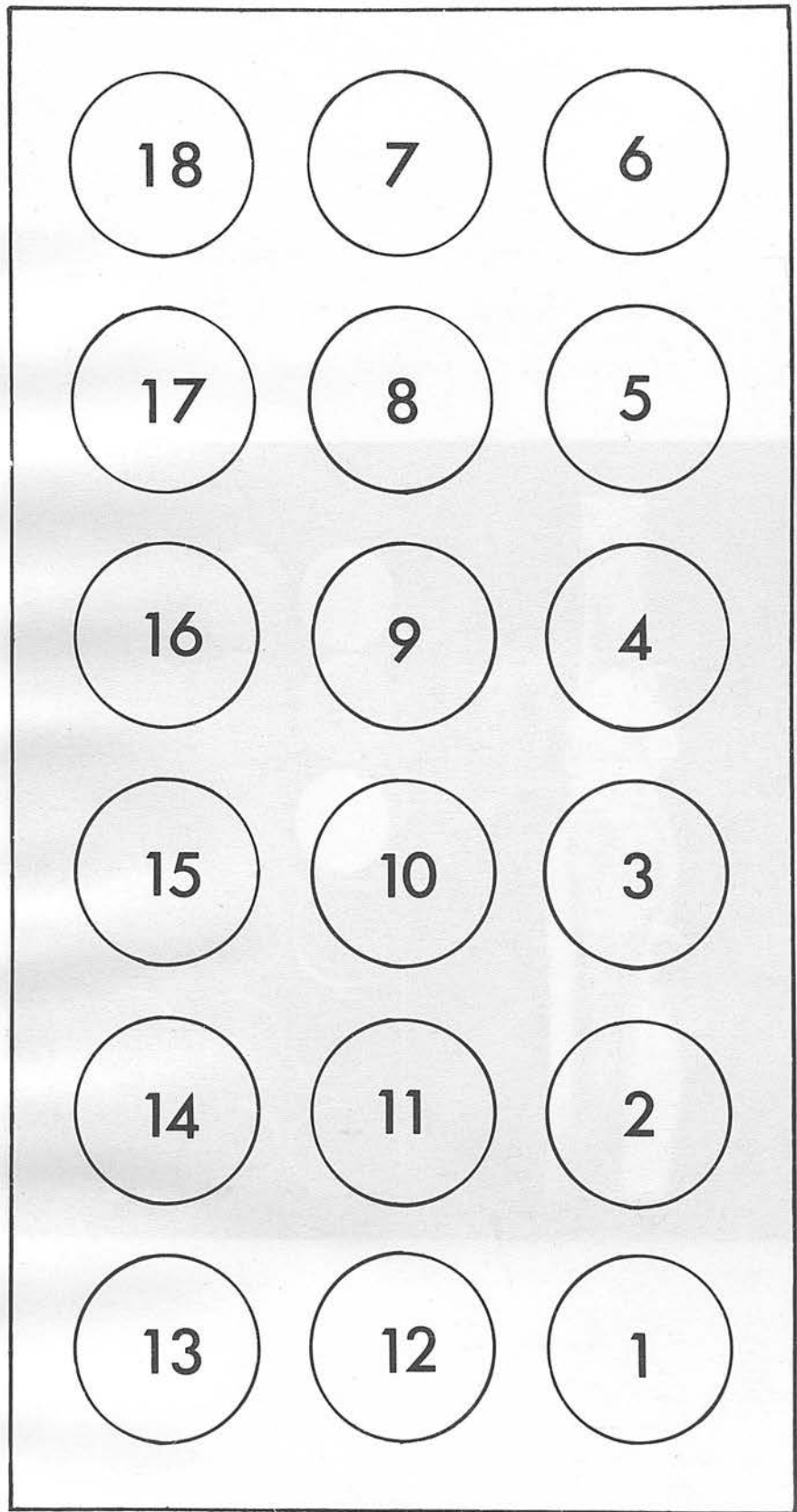


FIGURE 17

THE NUMBERED STEP-WEDGE

2. EXPERIMENTAL

a) Testing of normal rats with the chronometer

Knowledge of normal heart function is necessary as a basis for any evaluation of the pathological. Therefore, using the chronometer in conjunction with the perfused chronometer method earlier, the same 20 rats were used for the present study.

- 1. Is there a change in the rate of a single beat?
- 2. Is there a change in the rate of the day?
- 3. Is there a change in the rate of the day?
- 4. Is there a change in the rate of the day?
- 5. Is there a change in the rate of the day?
- 6. Is there a change in the rate of the day?
- 7. Is there a change in the rate of the day?
- 8. Is there a change in the rate of the day?
- 9. Is there a change in the rate of the day?
- 10. Is there a change in the rate of the day?

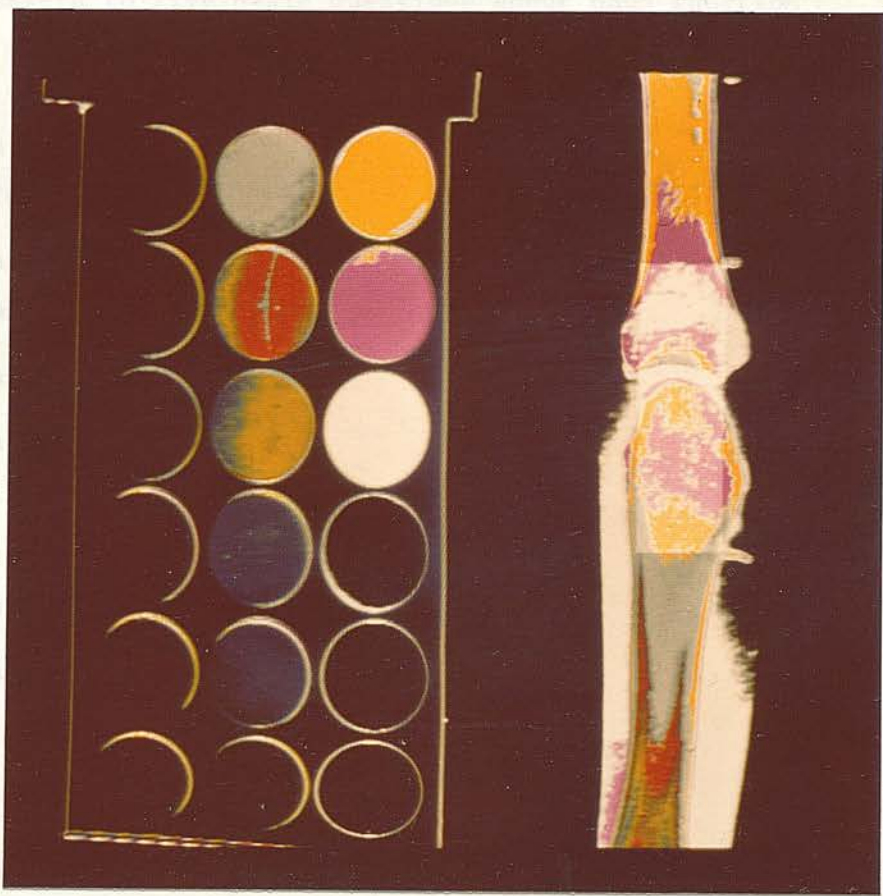


FIGURE 18

EXAMPLE OF A SEVEN-COLOUR CONTOUR MAP

A two-way analysis of variance with the contour map was performed on the data obtained.



2. EXPERIMENTAL

a) Testing of Normal Hands with the Cybernometer

Knowledge of normal hand function is necessary as a baseline for any examination of the pathological. Therefore, using the cybernometer in conjunction with the pneumatic dynamometer mentioned earlier, the answers to five basic questions about hand function were sought.

1. Is there a difference between the strengths of the fingers of a single hand?
2. Is there a difference between the strengths of the fingers of the dominant and non-dominant hands?
3. Is there a biological day to day variation in strength?
4. Is there a variation in strength during the course of a single day?
5. Is there any correlation among flexion force, pinch force, and grip strength?

Twenty healthy adult males between the ages of 20 and 45 volunteered to have their hand function assessed. The experiment was conducted in 3 parts. In Experiment 1, three recordings of flexion force and three of pinch force for all fingers, and three recordings of the grip strength of each hand, were made in random order at one sitting. In Experiment 2, similar readings were taken but at the same time on three separate days. In Experiment 3, three recordings of flexion force and pinch force of the index finger of each hand, and three recordings of the grip strength of each hand were made during the course of a working day.

A two-way analysis of variance with replication was then performed on the data obtained.

b) Investigation into the Relationship between Force and Bone Density in the Normal Hand

Attempts at relating hand function to bone density have relied on investigations into the association of the grip strength of a hand with the cortical thickness of its individual bones. The errors in this work of Virtama have already been pointed out and furthermore, grip strength is an overall measurement of a number of separate forces, namely those of the individual digits of the hand. With the introduction of the cybernometer to measure these forces, the relationship between bone density and force at the digital level can be examined. If hand function and bone density can be correlated in the rheumatoid patient as disease progresses, may there not already be an existing relationship in the normal hand - the stronger a digit, the greater its bone density?

Force and bone density studies were carried out on the hands of fifteen normal healthy adult males between the ages of 20 and 40.

Measurement of Forces

The forces of the individual digits were measured using the Cybernometer. Three recordings of both flexion and pinch forces of all fingers of both hands were made in random order at one sitting, corresponding measurements for the fifteen individuals being made at the same time of the day.

Measurement of Bone Density

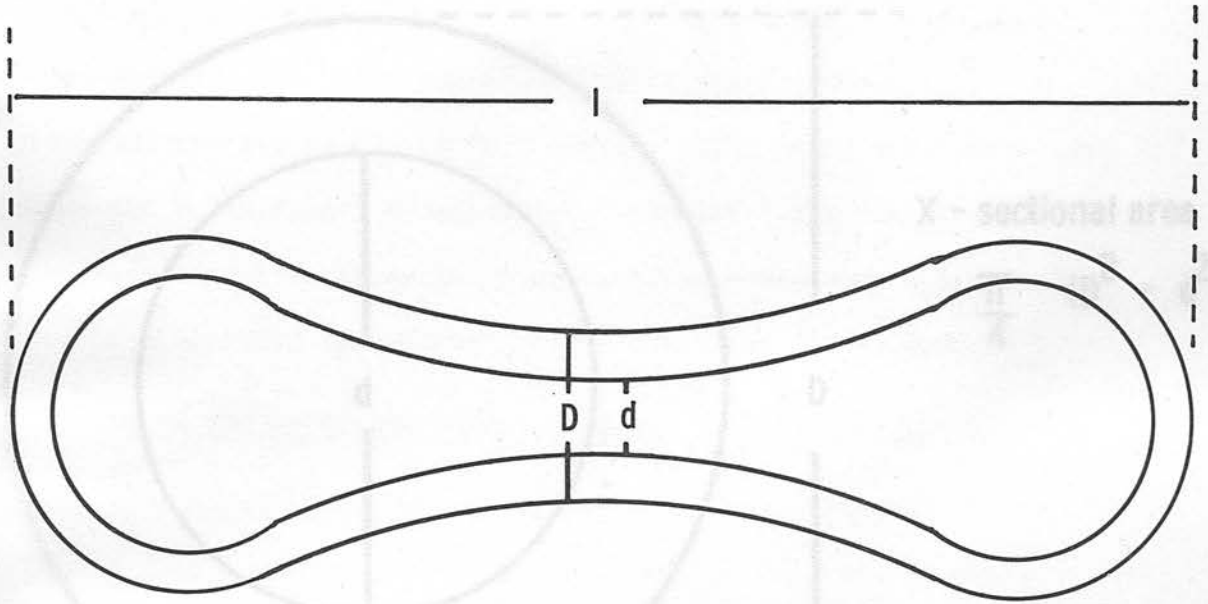
This part of the study was performed during the development of Colour Television Image Analysis. Therefore an alternative method of measuring bone density was used. Of the seven basic methods (Doyle, 1965) that of Exton-Smith et al (1969a) was selected for its simplicity.

AP radiographs of the hands of these fifteen subjects were taken under standard conditions. Two bones of each digit were studied, the metacarpal and the proximal phalanx. Dial-reading calipers accurate to 1/10 mm. were used to measure certain bone dimensions. These are shown in Figure 19 - the total bone width,  $D$ , the medullary width,  $d$ , and the length of each bone,  $l$ . In Figure 20,  $\pi / 4 (D^2 - d^2)$  is the cross-sectional area of the bone at its midshaft assuming this bone to be cylindrical.  $D^2 - d^2$  can thus be taken as an index of this area,  $\pi / 4$  being a constant. Exton-Smith et al (1969a) found that a good correlation was obtained between  $D^2 - d^2$  and ash per unit length ( $r = 0.85$ ), and therefore, was a satisfactory measure of bone density.

In order to take into account variations in skeletal size enabling direct comparisons between bones of different individuals to be made, a related parameter, the Dimensionless Ratio, was calculated. In this instance the product of the external shaft diameter,  $D$ , and the length,  $l$ , may be taken as a measure of the size of the bone. In fact, Exton-Smith et al (1969b) showed this quantity to be well correlated with the cortical area ( $r = 0.86$ ). Thus the ratio of the cortical area, represented by  $D^2 - d^2$ , to the surface area, represented by  $Dl$ , yields this new parameter which is independent of bone size. Thus, although a relationship may be conceived between the Area Index and digital force, this independence of bone size in the new parameter may lead to the supposition that there is no relationship between Dimensionless Ratio and digital force.

The Area Index,  $D^2 - d^2$ , and the Dimensionless Ratio,  $\frac{D^2 - d^2}{Dl}$ , were thus determined. Correlation coefficients of all possible combinations of these cortico-medullary expressions with digital forces were



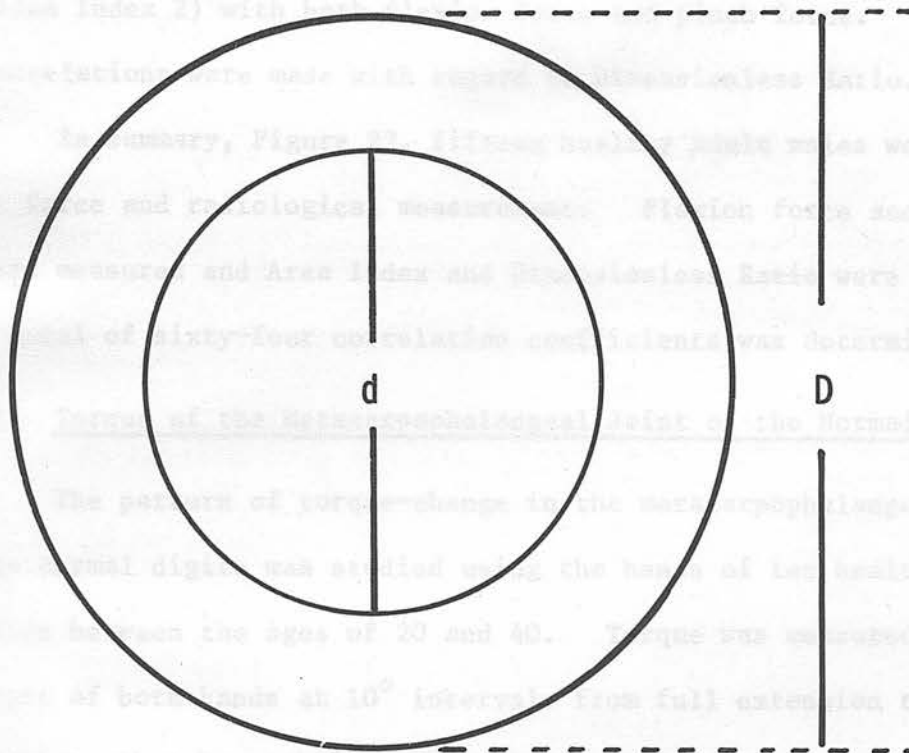


$$D^2 - d^2 = \text{Area Index}$$

$$\frac{D^2 - d^2}{DI} = \text{Dimensionless Ratio}$$

FIGURE 19

BONE DIMENSIONS AND PARAMETERS DETERMINED



X - sectional area =

$$\frac{\pi}{4} (D^2 - d^2)$$

FIGURE 20

DETERMINATION OF THE CROSS-SECTIONAL AREA

calculated for each digit of each hand, summing the individual readings over the fifteen subjects. More specifically, as shown in Figure 21, these correlations were between both the Area Index of metacarpal (Area Index 1) and the Area Index of the proximal phalanx (Area Index 2) with both flexion force and pinch force. Similar correlations were made with regard to Dimensionless Ratio.

In summary, Figure 22, fifteen healthy adult males were subjected to force and radiological measurement. Flexion force and pinch force were measured and Area Index and Dimensionless Ratio were calculated. A total of sixty-four correlation coefficients was determined.

c) Torque of the Metacarpophalangeal Joint of the Normal Digit

The pattern of torque-change in the metacarpophalangeal joints of the normal digits was studied using the hands of ten healthy adult males between the ages of 20 and 40. Torque was measured for each digit of both hands at  $10^{\circ}$  intervals from full extension to  $90^{\circ}$  of flexion, thereby enabling torque to be studied throughout the range of movement of the metacarpophalangeal joints investigated. In each case the metacarpophalangeal joint was aligned with the centre of the torsion bar and maximal force was applied by the finger tip to the side-arm. All recordings were made under standard conditions and corresponding readings for the 10 individuals were made at the same time of day.

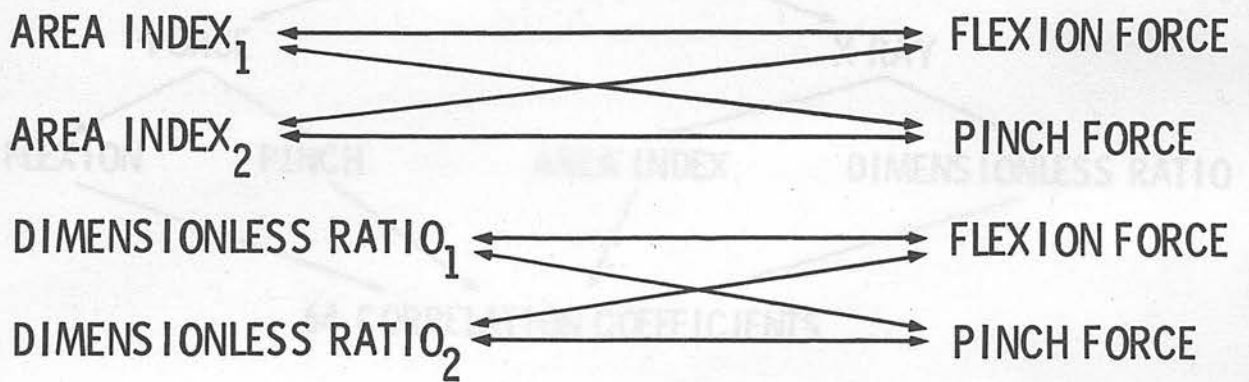


FIGURE 21

THE CORRELATIONS

### 3. CLINICAL

#### a) Cyberometer vs. Dynamometer

The concept of measurement of digital function at the digital level had been introduced. To be of greatest value the cyberometer should be able to demonstrate its superiority over the dynamometer in the clinical situation. The efficacy of the two instruments was therefore tested out.

10 patients suffering from rheumatoid disease in the hands were selected using both the cyberometer and the dynamometer.

At each hand, all patients were tested with the dynamometer and the cyberometer.

The measurement of digital force was made at the same time of day.

The R hands were measured under standard conditions. The same dynamometer was used for all patients, who were seated comfortably at a table with the elbow and forearm resting on the table. The hand was pulled to a pressure of 20 mm. Hg. The patient was taken to ensure that all patients gripped with the whole hand. Three recordings were made for each hand, and readings for the 10 subjects were done at the same time of day.

The measurement of digital force was made at the same time of day.

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The measurement of digital force was made at the same time of day.

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The measurement of digital force was made at the same time of day.

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The measurement of digital force was made at the same time of day.

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The measurement of digital force was made at the same time of day.

The R hands were measured under standard conditions. The same dynamometer was used for all patients, who were seated comfortably at a table with the elbow and forearm resting on the table. The hand was pulled to a pressure of 20 mm. Hg. The patient was taken to ensure that all patients gripped with the whole hand. Three recordings were made for each hand, and readings for the 10 subjects were done at the same time of day.

The measurement of digital force was made at the same time of day.

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The measurement of digital force was made at the same time of day.

The R hands were measured under standard conditions. The same dynamometer was used for all patients, who were seated comfortably at a table with the elbow and forearm resting on the table. The hand was pulled to a pressure of 20 mm. Hg. The patient was taken to ensure that all patients gripped with the whole hand. Three recordings were made for each hand, and readings for the 10 subjects were done at the same time of day.

The measurement of digital force was made at the same time of day.

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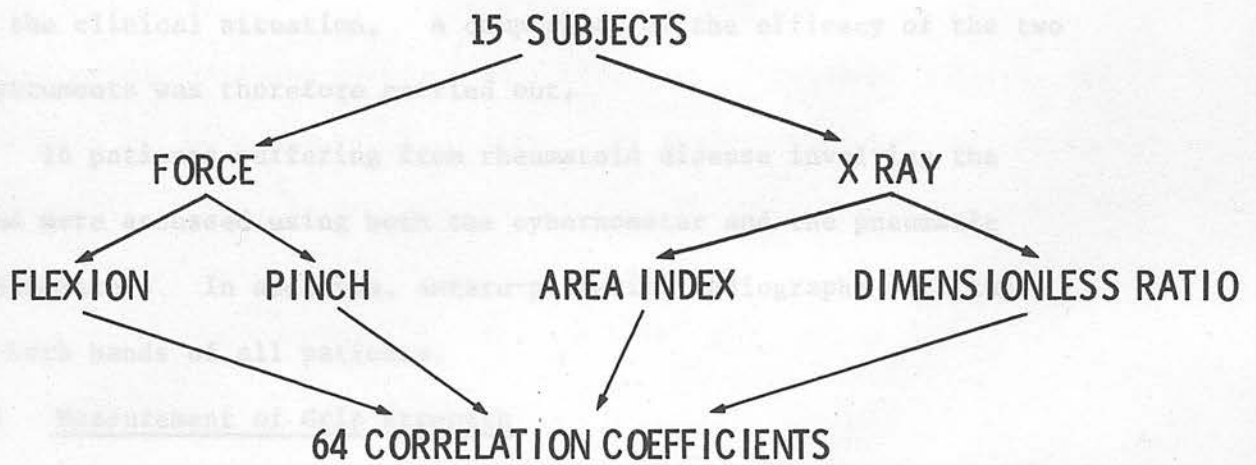


FIGURE 22

#### SUMMARY OF METHOD

3. CLINICAL

a) Cybernometer v. Dynamometer

The concept of measurement of hand function at the digital level has been introduced. To be of greater value the cybernometer should be able to demonstrate its superiority over the dynamometer in the clinical situation. A comparison of the efficacy of the two instruments was therefore carried out.

16 patients suffering from rheumatoid disease involving the hand were assessed using both the cybernometer and the pneumatic dynamometer. In addition, antero-posterior radiographs were taken of both hands of all patients.

(i) Measurement of Grip Strength

The 32 hands were measured under standard conditions. The same dynamometer was used for all patients, who were seated comfortably at a table with the elbow and forearm resting on the table. The bag was inflated to a pressure of 20 mm.Hg. and care was taken to ensure that all patients gripped with the whole hand. Three recordings were made for each hand, and readings for the 16 subjects were taken at the same time of day.

(ii) Measurement of Digital Forces

The forces of individual finger flexion and pinch were measured with the cybernometer under standard conditions. Three recordings each, of flexion force and pinch force, of all four fingers of both hands, were made in random order at one sitting, corresponding readings for the 16 subjects being taken at the same time of day.

b) Testing the Value of Surgery with the Cybernometer

51 patients undergoing hand surgery for rheumatoid disease were assessed just before and again six months after, operation. These patients were consecutive volunteers acquired at the Combined Rheumatoid Hand Clinic at the Royal Postgraduate Medical School, where rheumatologists and hand surgeons together examine the patients. Their average age was 47 years and, with the exception of 3 Asians and 9 males, all were Caucasian females. 19 had synovectomies of metacarpophalangeal joints, 18 had metacarpophalangeal joint replacements (Calnan-Nicolle prosthesis), 10 had proximal interphalangeal joint synovectomy, 3 had tendon synovectomies and/or tenolysis, and one had a thumb metacarpophalangeal joint fusion.

Each patient was assessed under standard conditions using the same cybernometer. All four fingers of the hand undergoing surgery were measured in terms of flexion force and pinch force, three recordings each, corresponding measurements for the 51 subjects being made at the same time of day. A total of 204 fingers were therefore assessed.

All joints undergoing prosthetic replacement had the typically severe joint lesions seen in rheumatoid disease. Figure 23 shows a typical example with a combination of erosions, volar subluxation, and ulnar drift. All joints undergoing synovectomy had clinical evidence of proliferative synovitis but no Xray evidence of erosions. Each patient undergoing synovectomy had a prior unsuccessful trial of medical treatment. In all cases histological evidence of rheumatoid disease was obtained.





FIGURE 23

TYPICAL HAND RADIOGRAPH IN ADVANCED RHEUMATOID DISEASE

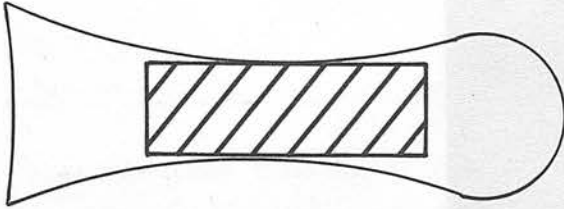
c) Testing the Value of Surgery with the Torquemeter

The same 19 patients who underwent cybernometer measurements before and after metacarpophalangeal joint synovectomy were also assessed with the torquemeter. A total of 44 joints were synovectomised and torque in each joint was studied just before and again six months after operation. In each case torque was measured at  $10^{\circ}$  intervals from full extension to  $90^{\circ}$  of flexion so that a pattern of torque change could be determined as the joint passed through its functional range. Each patient was assessed under standard conditions sitting in front of the table supporting the torquemeter, and corresponding measurements for the 19 patients were made at the same time of day. Torque for each position of each metacarpophalangeal joint was determined in random order at one sitting.

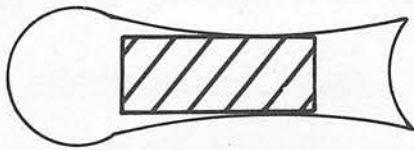
d) Bone Density Loss in the Rheumatoid Hand

Using the method of Colour Television Image Analysis bone density was studied in the 20 hands of 10 patients with Rheumatoid disease over a one year period. The 2 hands of each patient were Xrayed with the reference step wedge of Bywaters, and for each digit three fields were examined - the middle  $2/4$  of the metacarpal, the middle  $2/4$  of the proximal phalanx, and the metacarpalphalangeal joint plus  $1/4$  of a bone on each side, as shown in Figure 24. This was made possible by the use of an electronic window whose dimensions can be varied according to the size of the field to be examined. The fields of the middle  $2/4$  of the bones, therefore excluded the articular surfaces which might be directly involved with synovial disease, whereas the field of the metacarpophalangeal joint specifically concentrates on such an area. Figure 25 shows the window as a rectangle set on the metacarpophalangeal joint. All area measurements

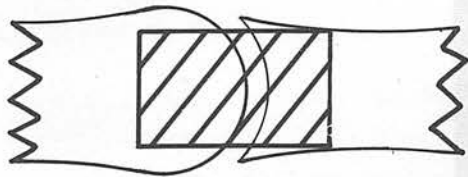
THE THREE WINDOW POSITIONS



METACARPAL - MIDDLE 2/4



PROXIMAL PHALANX - MIDDLE 2/4



METACARPO-PHALANGEAL - PLUS 1/4 BONE  
JOINT ON EACH SIDE

FIGURE 24

will now be seen which the degree of... of the I.V. screen... therefore determined making a... process was repeated using the

a) The Effect of Exercise on Bone Density and Joint

Force and bone density sta... digits one year before, immedi... prophylactic synovectomy of the

(i) Measurement of forces

Flexion and pinch forces w... the cybarometer. Three revers... random order at one sitting, ha... individuals being both at the s...

(ii) Measurement of bone density

The bone density of the met... sisted by the method of... of the electronically controlled... of the bone was studied thus... surface might be involved direct



FIGURE 25

WINDOW ON METACARPOPHALANGEAL JOINT

will now be made within the window to the exclusion of the remainder of the T.V. screen. The bone density of these three fields was therefore determined making a total of 240 fields examined. This process was repeated using the films obtained one year later.

e) The Effect of Synovectomy of the Metacarpophalangeal Joint on Bone Density and Hand Function

Force and bone density studies were performed on 15 rheumatoid digits one year before, immediately before, and one year after prophylactic synovectomy of the metacarpophalangeal joint.

(i) Measurement of forces

Flexion and pinch forces of these 15 digits were measured using the cybernometer. Three recordings of both forces were made in random order at one sitting, corresponding measurements for the fifteen individuals being made at the same time of day.

(ii) Measurement of bone density

The bone density of the metacarpals of the 15 digits was investigated by the method of Colour Television Image Analysis. By means of the electronically controlled inset window, only the middle 2/4 of the bone was studied thus excluding each end whose articular surface might be involved directly with disease.

PAGE 36 - 48

1. EXPERIMENT 1

2. Testing of Grasp Force with the GFR Computer

In this experiment, the subjects were asked to exert a pinch force of the index finger and thumb with a 2.0 Kg. weight, the middle finger 3.0, ring finger 3.0, and the little finger 2.0 Kg. weight, for the dominant hand. The forces of the non-dominant hand were all less. Pinch force was almost twice as great as flexion forces for each finger.

Experiment 1

For flexion forces a significant difference at the 0.10 level of significance between the fingers was noted for both the dominant and non-dominant hands. The middle fingers were stronger than the ring and little fingers. Figure 26.

PART III - RESULTS

A significant difference at the 0.10 level was also observed in pinch force. The fingers of the dominant hand were significantly stronger at the 0.10 level than those of the non-dominant hand (GFR) in terms of flexion force and pinch force, Figure 27. The difference between the presence of the grip of the hands was significant at the 0.10 level, the dominant hand again being stronger than the non-dominant hand.

The difference between the dominant and non-dominant hands was significant for the middle finger, ring finger, and little finger. The middle finger was significantly stronger than the ring and little fingers. The difference between the dominant and non-dominant hands was significant for the middle finger, ring finger, and little finger. The middle finger was significantly stronger than the ring and little fingers.



PART III - RESULTS

1. EXPERIMENTAL

a) Testing of Normal Hands with the Cybernometer

In this group of 20 healthy adult males the mean digital flexion force of the index finger was 4.6 Kg. weight, the middle finger 4.4, ring finger 3.2, and the little finger 2.8 Kg. weight, for the dominant hand. The forces of the non-dominant hand were all less. Pinch force was almost twice as great as flexion force for each finger.

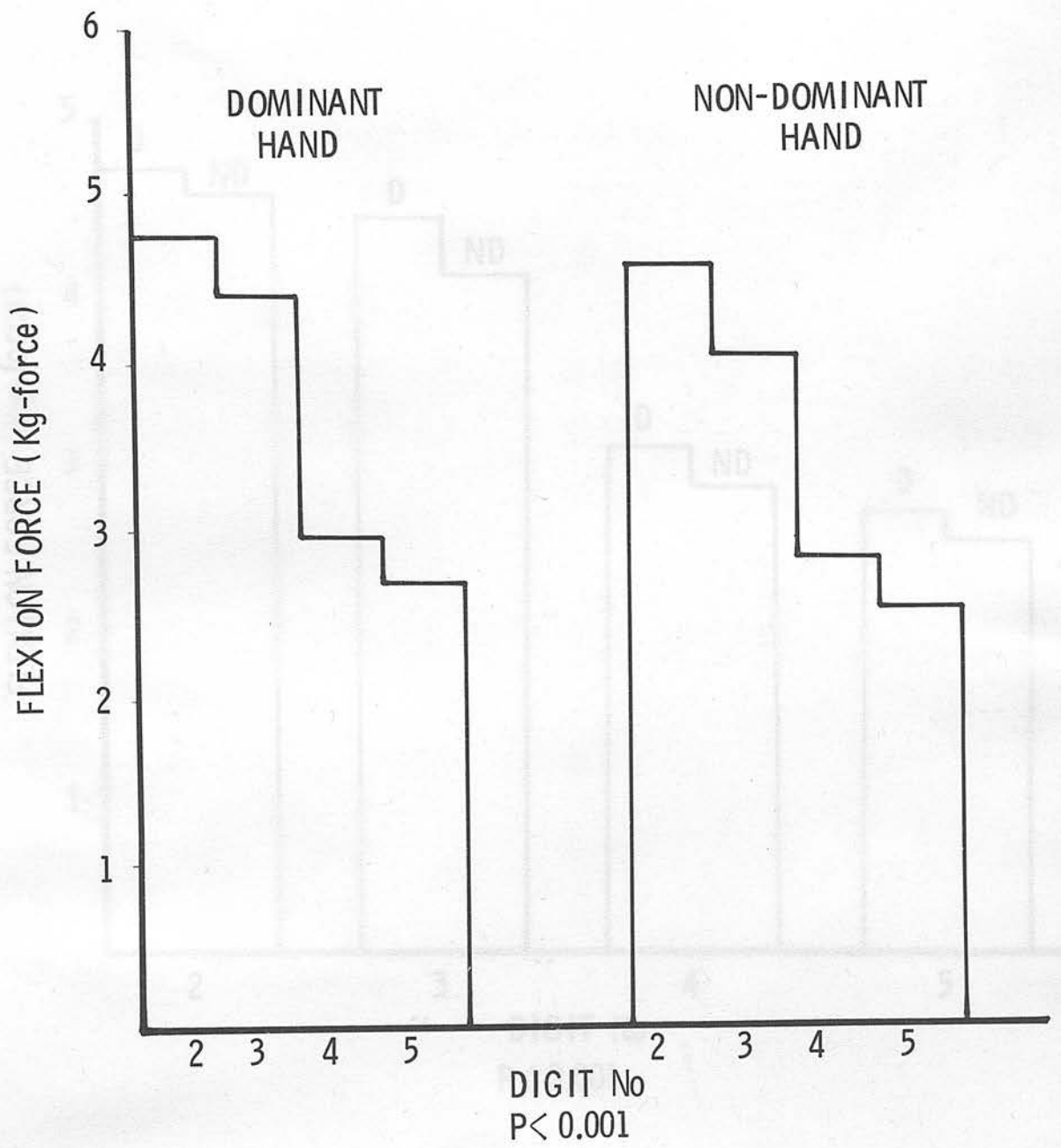
Experiment 1

For flexion force a significant difference at the 0.1% level of significance between the fingers was noted for both the dominant and non-dominant hands; the index and middle fingers were stronger than the ring and little fingers, Figure 26.

A significant difference between the fingers of both hands at the 0.1% level was also observed in pinch force. The fingers of the dominant hand (D) were significantly stronger at the 0.1% level than those of the non-dominant hand (ND) in terms of flexion force and pinch force, Figure 27. The difference between the pressures of the grip of the hands was significant at the 0.1% level, the dominant hand again being stronger than the non-dominant hand.

In the dominant hand, the correlation coefficients between grip strength and pinch force and between pinch force and flexion force were significant ( $P = 0.045$  and  $0.035$ , respectively) but that between grip strength and flexion force was not significant ( $P > 0.05$ ), Table 4. In the non-dominant hand the correlation coefficient between grip strength and pinch force was significant ( $P = 0.049$ ) but not





DIGIT No  
 $P < 0.001$

FIGURE 26

FLEXION FORCE IN THE NORMAL HAND

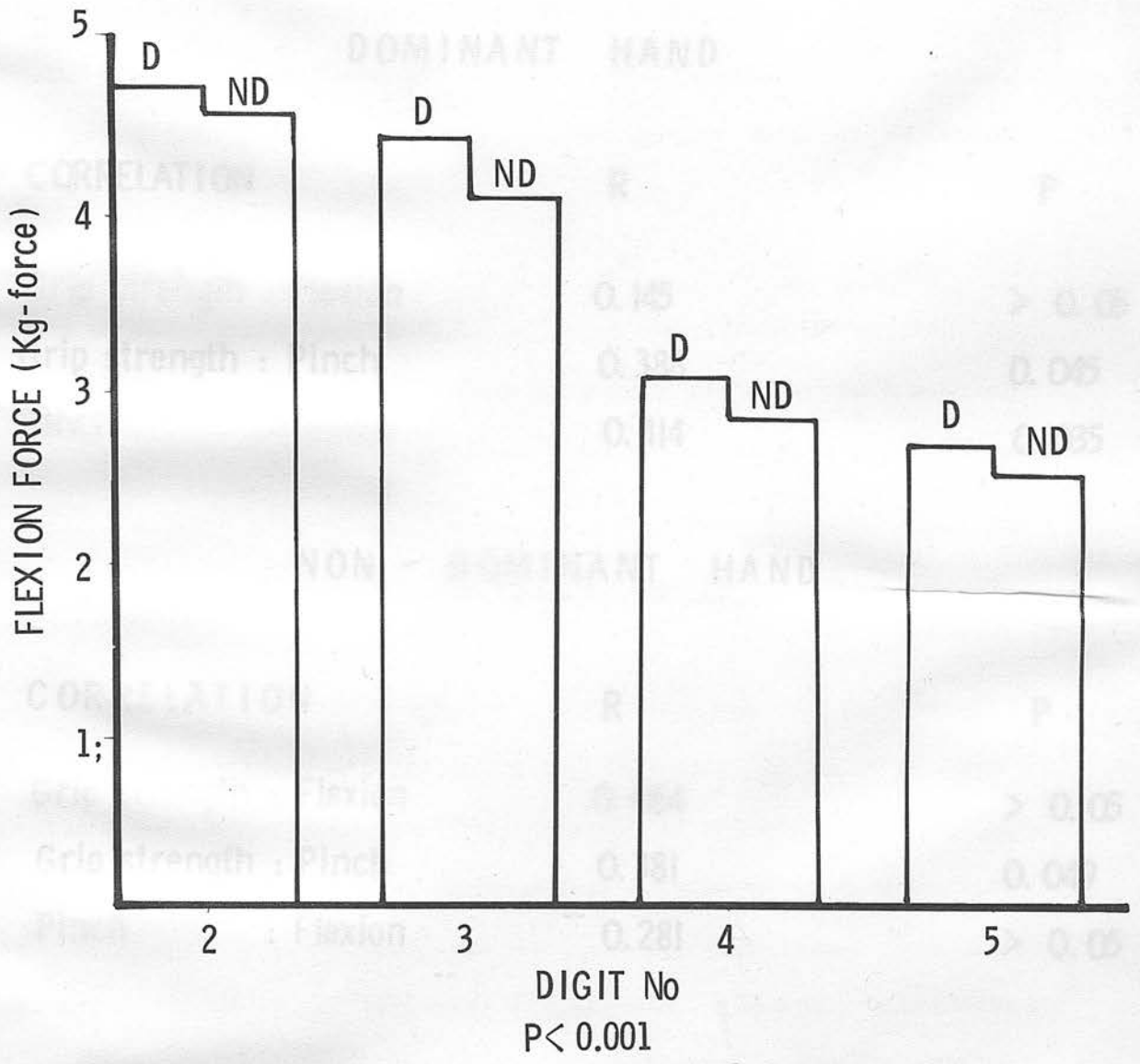


FIGURE 27

HISTOGRAM TO SHOW THE SUPERIOR STRENGTH OF THE DOMINANT DIGIT

between pinch force and flexion force ( $p < 0.05$ ).

Experiment 2

A significant difference at the 1% level was observed in the residual variation between experiments 1 and 2, indicating that the day-to-day variation in hand function was greater than the variation between subjects.

**DOMINANT HAND**

| CORRELATION             | R     | P      |
|-------------------------|-------|--------|
| Grip strength : Flexion | 0.145 | > 0.05 |
| Grip strength : Pinch   | 0.388 | 0.045  |
| Pinch : Flexion         | 0.414 | 0.035  |

Figure 2B.

**NON - DOMINANT HAND**

b) Investigation of the relationship between the density of the normal hand

| CORRELATION             | R     | P      |
|-------------------------|-------|--------|
| Grip strength : Flexion | 0.084 | > 0.05 |
| Grip strength : Pinch   | 0.381 | 0.049  |
| Pinch : Flexion         | 0.281 | > 0.05 |

TABLE 4

**CORRELATIONS IN THE NORMAL HAND**

Figure 11 shows the correlations between the density of the normal hand and the pinch force of that hand. In this instance there is a similar trend but at the 1% level.

No significant trends were observed with flexion force nor was there any significant relationship between the forces measured and the dimensionless ratio, either of the metacarpal or the proximal

between pinch force and flexion force ( $P > 0.005$ ).

### Experiment 2

A significant difference at the 1% level was observed in the residual variation between experiments 1 and 2, indicating that the day-to-day variation in hand function was greater than the variation occurring at one sitting.

### Experiment 3

A significant change at the 0.1% level in flexion force and pinch force of both hands was observed during the course of a working day, but no significant change ( $P > 0.05$ ) was observed in grip strength, Figure 28.

#### b) Investigation into the Relationship between Force and Bone Density in the Normal Hand

Figure 29 shows a scattergram of correlation coefficients between the Area Index of the metacarpal,  $A.I._1$ , and the pinch force of that digit. Each correlation is thus portrayed by one point on the graph. Although the distribution of these points appears to be concentrated on the positive side of zero, the coefficients when tested individually did not prove to be statistically significant. However, a Binomial Sign Test confirmed the tendency for the correlation coefficients to be positive,  $P$  lying between 0.01 and 0.05.

Figure 30 shows another scattergram, this time of correlation coefficients between the Area Index of the proximal phalanx,  $A.I._2$  and the pinch force of that digit. In this instance there is a similar trend but at the 1% level.

No significant trends were observed with flexion force nor was there any significant relationship between the forces measured and the dimensionless ratio, either of the metacarpal or the proximal

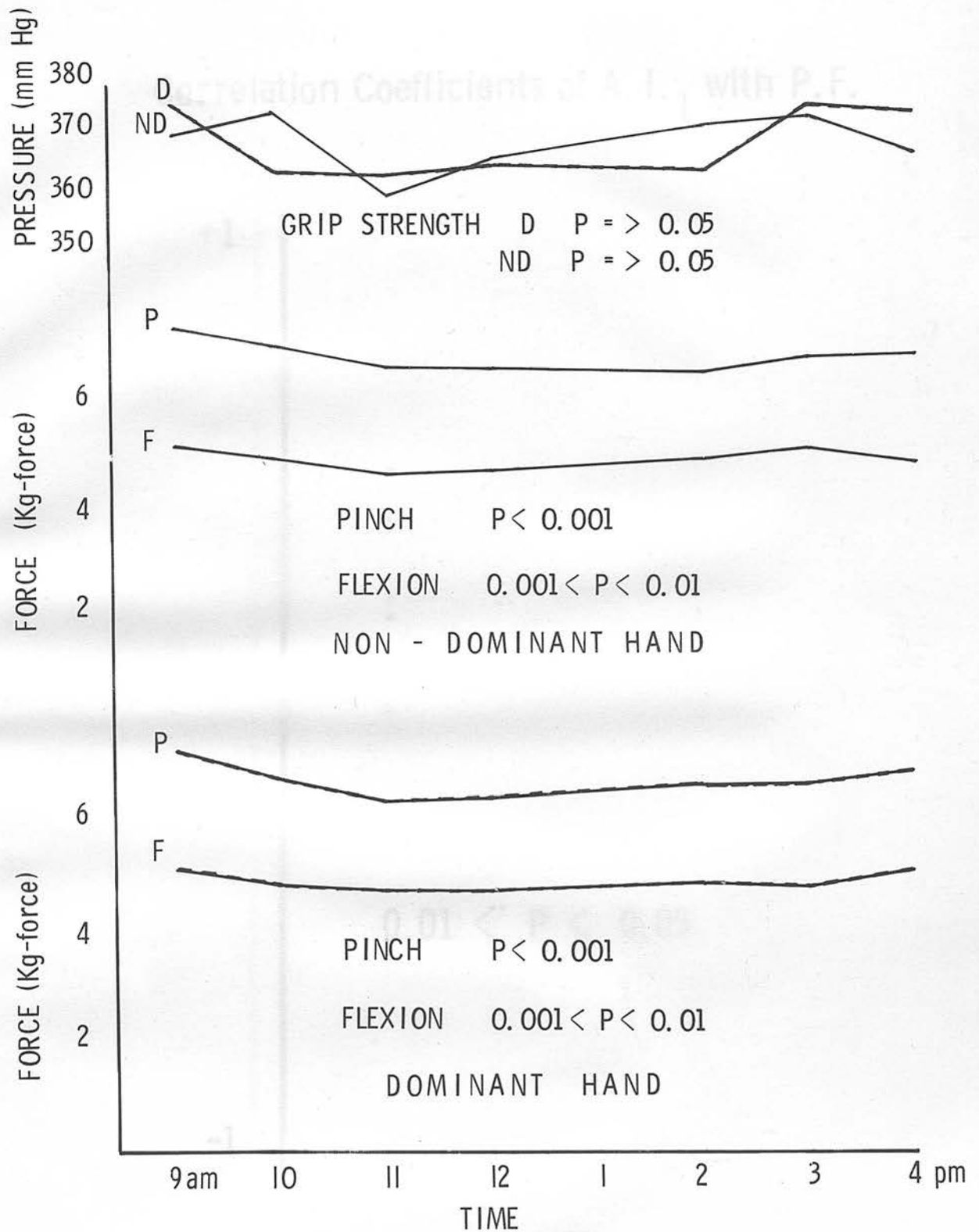


FIGURE 28

GRAPH SHOWING DIURNAL VARIATION IN FLEXION FORCE (F), PINCH FORCE (P), AND GRIP STRENGTH

# Correlation Coefficients of $A. I. 1$ with P.F.

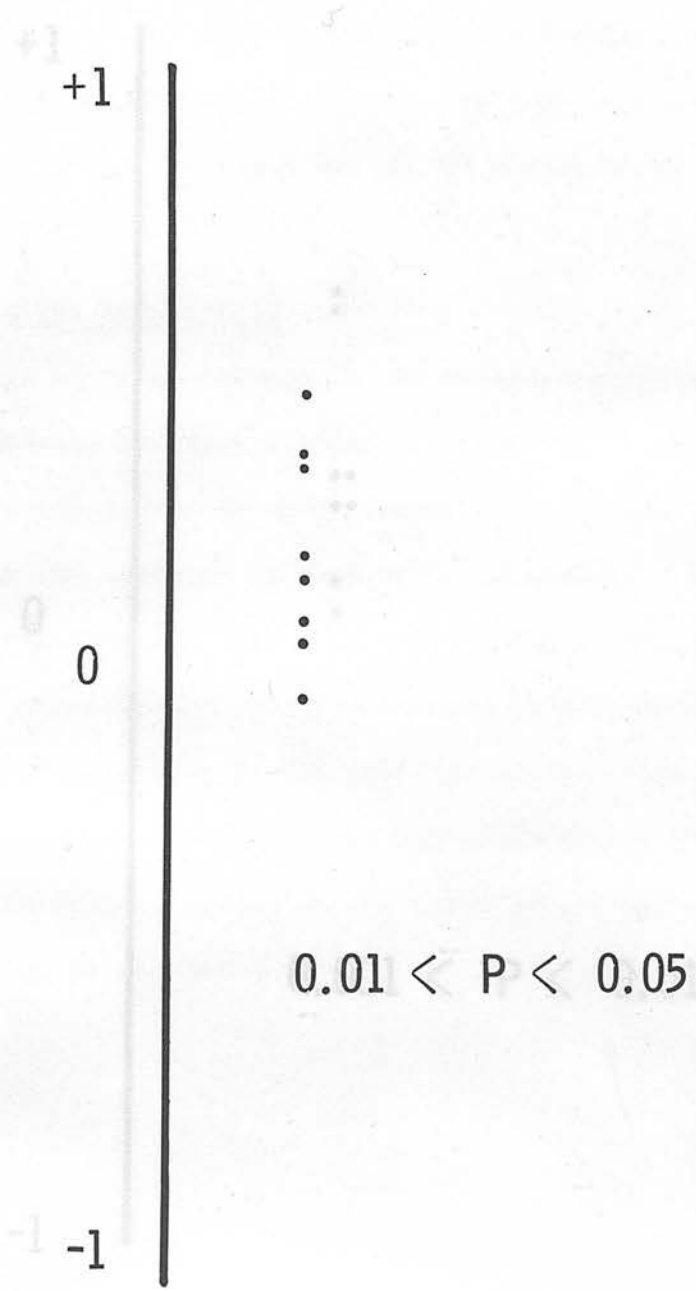


FIGURE 29

SCATTERGRAM



# Correlation Coefficients of A. I.<sub>2</sub> with P.F.

Figure 31 summarizes the results. Statistically significant trends were observed for the correlation coefficients of the Area Index with pinch force to be positive. No such trends were observed with flexion forces nor any of the correlations concerning Dimensionless Ratio.

## c) Torque in the Metacarpophalangeal Joint

The pattern of torque change in the metacarpophalangeal joints of the ten subjects was very similar. Figure 32 is an example of this and shows the manner in which torque (taken as the joint passes from extension (90 degrees) to flexion (10 degrees)). In this diagram torque has been illustrated in two joints, the index and little finger metacarpophalangeal joints. In each case torque is seen to fall off gradually as the position of the joint changes from extension to flexion. Furthermore, the index finger being stronger than the little finger, torque in the index finger metacarpophalangeal joint is greater.

+1

0

-1

0.001 < P < 0.01

FIGURE 30

SCATTERGRAM

phalanx, considering the values of  $r$  individually and the trend for  $r$  to be positive or negative.

Figure 31 summarises the results. Statistically significant trends were observed for the correlation coefficients of the Area Index with pinch force to be positive. No such trends were observed with flexion force nor any of the correlations concerning Dimensionless Ratio.

c) Torque in the Normal Hand

The pattern of torque-change in the metacarpophalangeal joints of the ten subjects was very similar. Figure 32 is an example of this and shows the manner in which torque fades as the joint passes from extension (90 degrees) to flexion (10 degrees). In this diagram torque has been illustrated in two joints, the index and little finger metacarpophalangeal joints. In each case torque is seen to fall off gradually as the position of the joint changes from extension to flexion. Furthermore, the index finger being stronger than the little finger, torque in the index finger metacarpophalangeal joint is greater.

TORQUE FADE - NORMAL

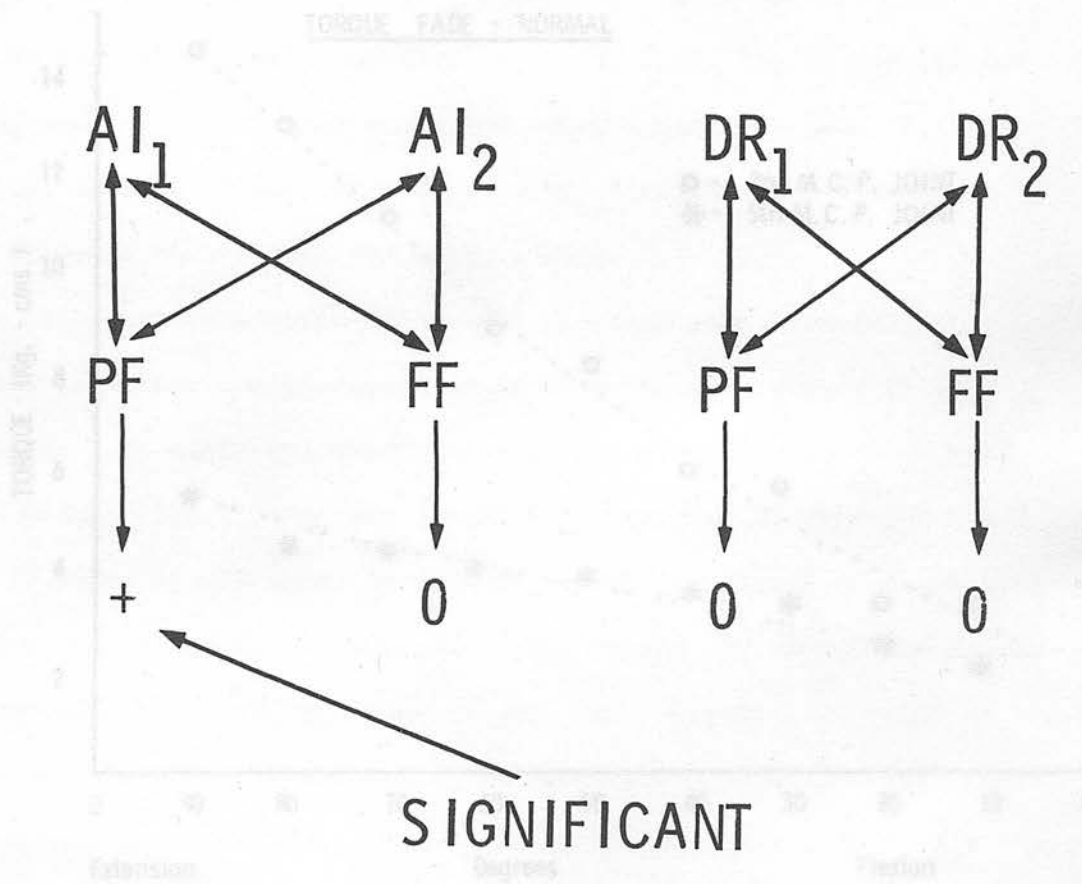


FIGURE 31

RESULTS OF CORRELATIONS

2. CLINICAL

a) Cyberometer or Dynamometer

The grip strengths of the 16 patients are shown in Table 3. It can be seen that 8 patients (Nos. 1, 4, 5, 7, 9, 11, 13 and 14) had hands of equal grip strength while the other 8 patients (Nos. 2, 3, 6, 8, 10, 12 and 16) had hands whose grip strength was unequal. The 16 patients thus formed two equal groups.

In all patients whose hands were of equal grip strength, at least one hand was considerably weaker than its counterpart in the other hand. In addition, there was radiologic evidence of disease in this weaker digit. Patient Number 1 was typical of this group and Figure 32 shows by histogram the difference between the two hands of this patient. With the dominant hand, D, and the non-dominant hand, ND, have equal grip strengths of 100 gm. In cases of both flexion

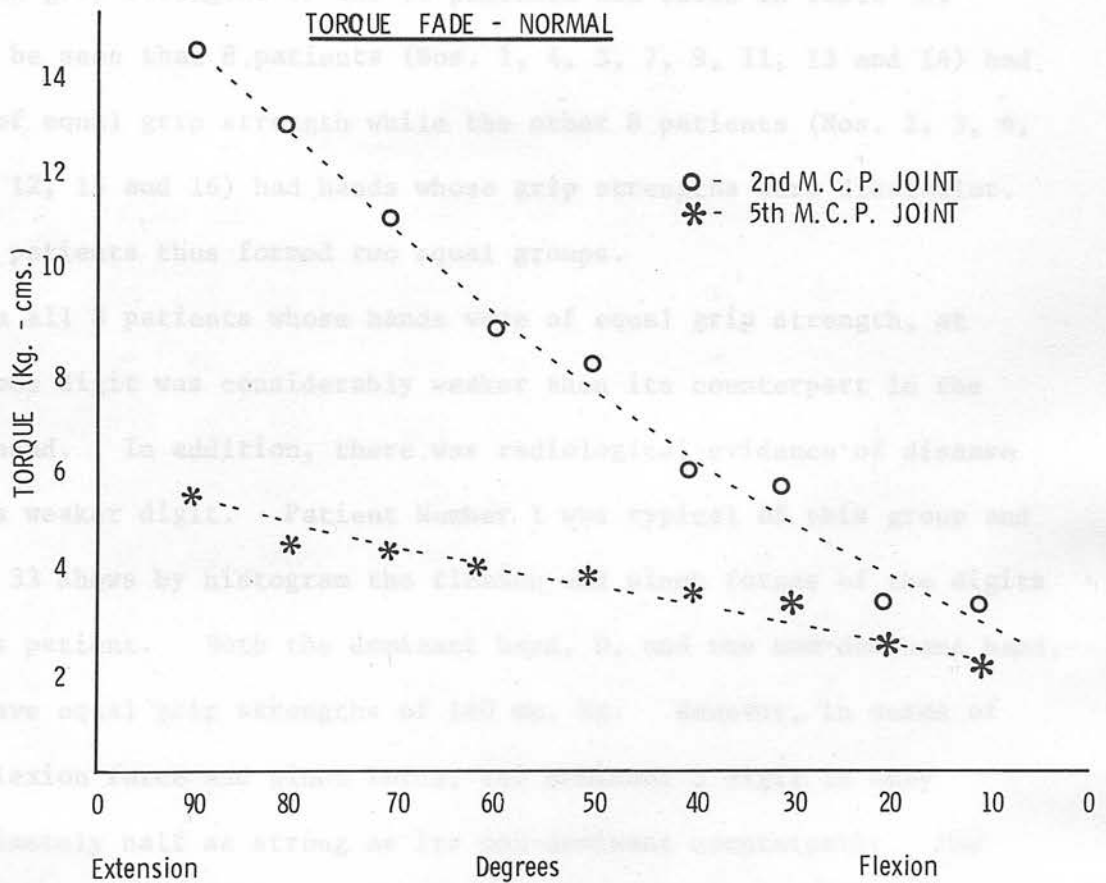


FIGURE 32

The antero-posterior radiograph of this patient's hand is shown in Figure 34, and confirms the presence of degenerative pathology in this weakened digit. Specifically, the distal ring middle finger metacarpophalangeal joint shows the presence of joint space narrowing - distention of joint space, subluxation of joint

In this instance the cyberometer was registered on the hand not revealed by measurement of the other hand, and the offending digit. Radiographs were rather difficult to

## 2. CLINICAL

### a) Cybernometer v. Dynamometer

The grip strengths of the 16 patients are shown in Table 15. It can be seen that 8 patients (Nos. 1, 4, 5, 7, 9, 11, 13 and 14) had hands of equal grip strength while the other 8 patients (Nos. 2, 3, 6, 8, 10, 12, 15 and 16) had hands whose grip strengths were dissimilar. The 16 patients thus formed two equal groups.

In all 8 patients whose hands were of equal grip strength, at least one digit was considerably weaker than its counterpart in the other hand. In addition, there was radiological evidence of disease in this weaker digit. Patient Number 1 was typical of this group and Figure 33 shows by histogram the flexion and pinch forces of the digits of this patient. Both the dominant hand, D, and the non-dominant hand, ND, have equal grip strengths of 140 mm. Hg. However, in terms of both flexion force and pinch force, the dominant 3 digit is only approximately half as strong as its non-dominant counterpart. The dominant middle finger had only 0.37 Kg. force compared with 0.97 Kg. force of the non-dominant finger in flexion force, and 0.46 Kg. force compared with 0.75 Kg. force in pinch force.

The antero-posterior radiograph of this patient's hands is shown in Figure 34, and confirms the presence of destructive pathology in this weakened digit. More specifically, the dominant right middle finger metacarpo-phalangeal joint shows the changes of gross rheumatoid disease - obliteration of joint space, subluxation and erosions.

In this instance the cybernometer has highlighted weakness in a hand not revealed by measurement of grip strength, and has specified the offending digit. Radiography has further confirmed the presence

Table 5

Grip Strengths

| PATIENT | RIGHT HAND |     |     | LEFT HAND |     |     | EQUAL | P     |
|---------|------------|-----|-----|-----------|-----|-----|-------|-------|
| 1       | 140        | 126 | 154 | 134       | 142 | 144 | =     | 0.378 |
| 2       | 102        | 96  | 102 | 150       | 164 | 136 | ≠     | 0.007 |
| 3       | 72         | 72  | 72  | 110       | 120 | 116 | ≠     | 0.007 |
| 4       | 202        | 190 | 198 | 210       | 200 | 192 | =     | 0.176 |
| 5       | 86         | 92  | 80  | 90        | 84  | 82  | =     | 0.622 |
| 6       | 160        | 172 | 166 | 112       | 120 | 114 | ≠     | 0.007 |
| 7       | 200        | 198 | 190 | 194       | 204 | 200 | =     | 0.109 |
| 8       | 120        | 126 | 122 | 164       | 166 | 170 | ≠     | 0.007 |
| 9       | 184        | 190 | 192 | 186       | 190 | 188 | =     | 0.732 |
| 10      | 170        | 174 | 168 | 202       | 196 | 198 | ≠     | 0.007 |
| 11      | 92         | 98  | 90  | 96        | 90  | 94  | =     | 0.5   |
| 12      | 90         | 100 | 88  | 132       | 140 | 138 | ≠     | 0.007 |
| 13      | 210        | 198 | 196 | 212       | 200 | 190 | =     | 0.378 |
| 14      | 152        | 160 | 160 | 160       | 160 | 154 | =     | 0.378 |
| 15      | 92         | 100 | 96  | 150       | 140 | 146 | ≠     | 0.007 |
| 16      | 100        | 110 | 106 | 70        | 74  | 72  | ≠     | 0.007 |



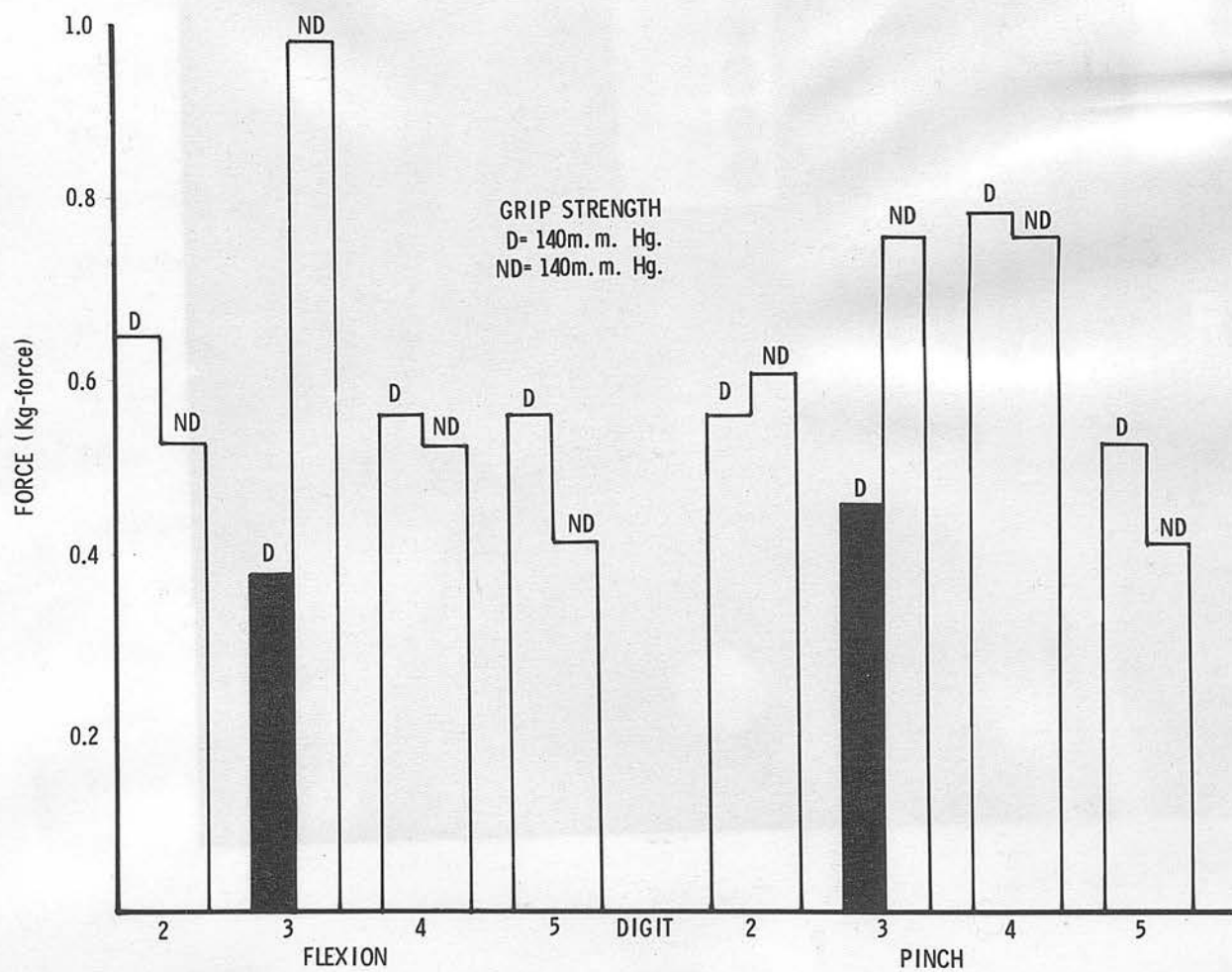


FIGURE 33

HISTOGRAM OF DIGITAL FORCES - PATIENT 1

(BLACK COLUMNS DENOTE WEAKNESS)

of disease in that digit,

In the group of patients whose hand has the following  
strength, again at least two digits are

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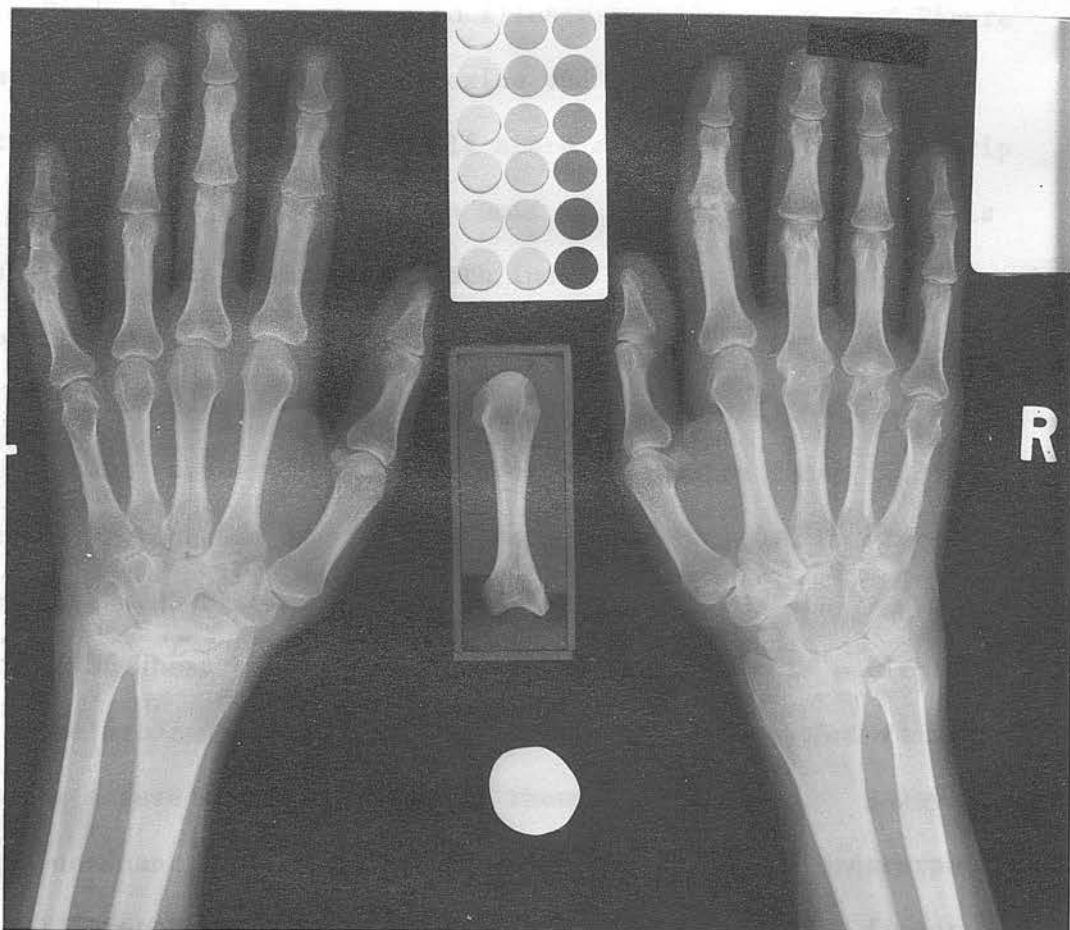
shows evidence of severe disease - subluxation, loss of joint space  
and erosions.

FIGURE 34

In this instance the cybersometer has highlighted the specific  
unit of the hand resp

HAND RADIOGRAPH - PATIENT NO. 1

again radiographic - as the presence of disease in that digit.



of disease in that digit.

In the group of 8 patients whose hands had dissimilar grip strengths, again at least one digit was considerably weaker than its fellow. Patient Number 2 serves to illustrate this group, and Figure 35 shows histogrammatically the flexion and pinch forces of this patient. The dominant hand is half again as strong in terms of grip as the non-dominant hand, but which unit of the non-dominant hand is responsible for this weakness? Both index fingers are equally reduced particularly in terms of flexion force but also with regard to pinch force. The non-dominant middle finger however is only half as strong as its dominant counterpart, in terms of both flexion force (0.35 Kg. force compared with 0.8 Kg. force) and pinch force (0.5 Kg. force compared with 0.95 Kg. force).

Figure 36 shows the radiographic appearances of this patient's hands. The metacarpophalangeal joints of both indices show fairly equally the severe erosive changes of rheumatoid disease. However, while the dominant right middle finger has a near normal metacarpophalangeal joint, that of the non-dominant hand left middle finger shows evidence of severe disease - subluxation, loss of joint space and erosions.

In this instance the cybernometer has highlighted the specific unit of the hand responsible for the reduction in grip strength, and again radiography has confirmed the presence of disease in that digit.

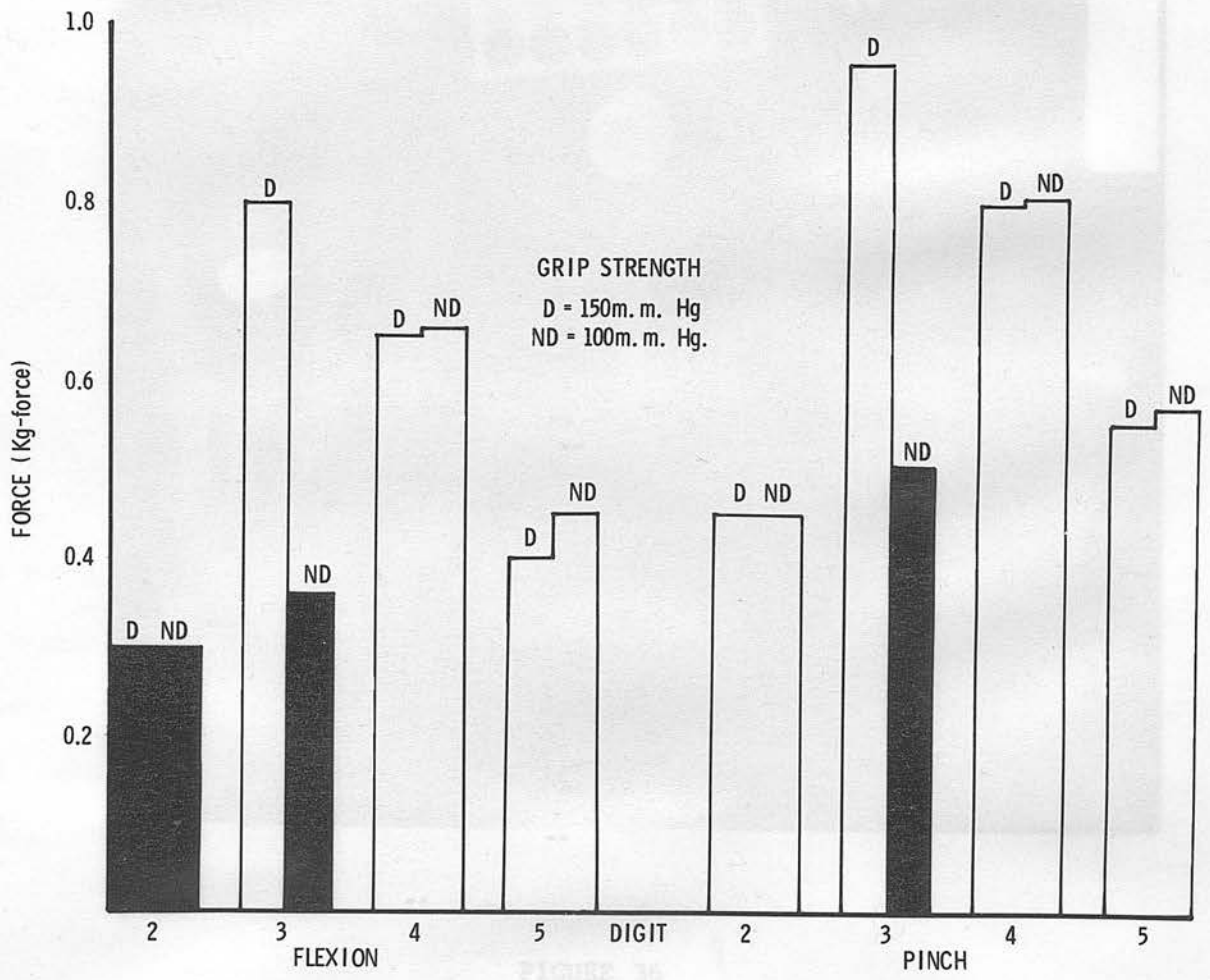


FIGURE 35

HISTOGRAM OF DIGITAL FORCES - PATIENT 2

(BLACK COLUMNS DENOTE WEAKNESS)

2) Testing the Value of Surgery with the Prosthesis

Table 5 summarizes the response of patients and the operative procedure.

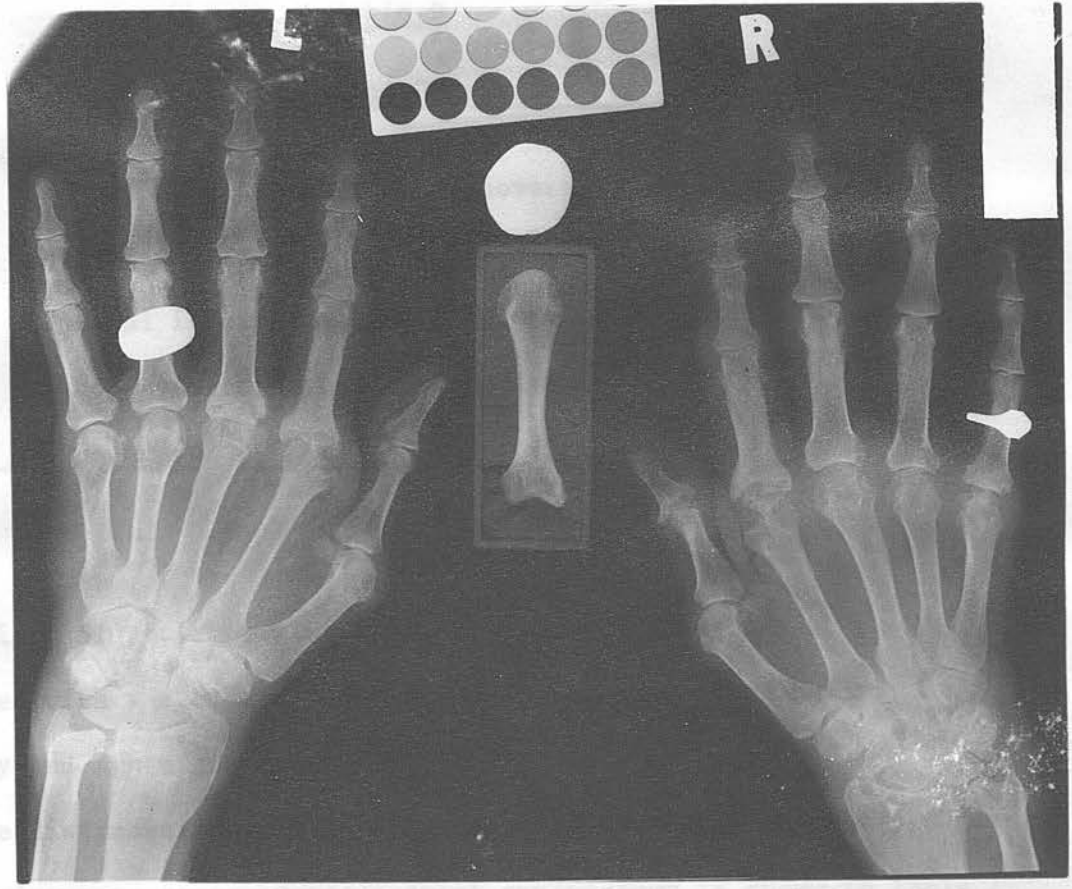


FIGURE 36

Metacarpophalangeal Joint Synovitis

HAND RADIOGRAPH - PATIENT NO. 2

3 patients had 1 joint  
" 2 joints  
" 3 "  
" 4 "

PATIENTS TOTAL

b) Testing the Value of Surgery with the Cybernometer

Table 6 summarises the numbers of patients and the operations performed.

Table 6

Numbers of Patients and Operations Performed

|   |           |
|---|-----------|
| Metacarpophalangeal joint synovectomy         | 19        |
| Metacarpophalangeal joint replacement         | 18        |
| Proximal interphalangeal joint synovectomy    | 10        |
| Tendon synovectomy and/or tenolysis           | 3         |
| <u>Thumb metacarpophalangeal joint fusion</u> | <u>1</u>  |
| Total   | <u>51</u> |

A total of 51 patients were operated upon and their hands were assessed with the cybernometer on two occasions - just before surgery and again six months later.

The distribution of the joints synovectomised among the 19 patients undergoing metacarpophalangeal joint synovectomy is shown in Table 7.

Table 7

Metacarpophalangeal Joint Synovectomies

|   |
|---|
| 3 patients had 1 joint synovectomised = 3 joints synovectomised |
| 9 " " 2 joints " = 18 " "                                       |
| 5 " " 3 " " = 15 " "  |
| 2 " " 4 " " = 8 " "   |

19 PATIENTS

TOTAL

44 JOINTS



19 patients therefore underwent a total of 44 metacarpophalangeal joint synovectomies. Thus, of the 76 fingers assessed in this group of patients, 44 underwent operation and 32 belonged to the hand operated upon but did not undergo synovectomy themselves.

The flexion and pinch forces of these 76 digits measured just before and six months after surgery were analysed by paired T test in two groups - the 44 digits which underwent surgery and the 32 which did not.

Table 8 shows the results of the statistical analysis on the 44 digits which underwent operation.

Table 8

Digits whose Metacarpophalangeal Joints were Synovectomised

|               |              |       |           |
|---------------|--------------|-------|-----------|
| FLEXION FORCE | Preop. Mean  | 3.74  | Kg. force |
|               | Postop. Mean | 5.03  | " "       |
|               | T            | 6.01  |           |
|               | P <          | 0.001 |           |
| PINCH FORCE   | Preop. Mean  | 4.76  | Kg. force |
|               | Postop. Mean | 6.29  | " "       |
|               | T            | 9.20  |           |
|               | P <          | 0.001 |           |

In terms of both flexion and pinch forces there has been a statistically significant improvement in hand function in the six months following metacarpophalangeal joint synovectomy in the digits which underwent synovectomy.

Table 9 shows the results of the statistical analysis on the 32 digits belonging to the hands which underwent operation but not synovectomised themselves.

Table 9

Digits whose Metacarpophalangeal Joints were not Synovectomised

|               |              |      |       |           |
|---------------|--------------|------|-------|-----------|
| FLEXION FORCE | Preop. Mean  | = 10 | 3.26  | Kg. force |
| "             | Postop. Mean | = 3  | 3.52  | " "       |
|               | T            | = 3  | 3.51  | "         |
|               | P            | <    | 0.001 |           |

|             |              |   |       |           |
|-------------|--------------|---|-------|-----------|
| PINCH FORCE | Preop. Mean  |   | 6.07  | Kg. force |
|             | Postop. Mean |   | 6.36  | " "       |
|             | T            |   | 4.08  |           |
|             | P            | < | 0.001 |           |

In terms of both flexion and pinch forces there has been a statistically significant improvement in hand function in the six months following metacarpophalangeal joint synovectomy in the digits belonging to the hand which underwent surgery but not operated upon themselves.

The distribution of the joints replaced among the 18 patients undergoing metacarpophalangeal joint replacement is shown in Table 10.

Table 10

Metacarpophalangeal Joint Replacements

|   |          |     |   |        |          |   |    |        |          |
|---|----------|-----|---|--------|----------|---|----|--------|----------|
| 8 | patients | had | 1 | joint  | replaced | = | 8  | joints | replaced |
| 5 | "        | "   | 2 | joints | "        | = | 10 | "      | "        |
| 3 | "        | "   | 3 | "      | "        | = | 9  | "      | "        |
| 2 | "        | "   | 4 | "      | "        | = | 8  | "      | "        |

---

18 PATIENTS                      TOTAL                      35 JOINTS

18 patients therefore underwent a total of 35 metacarpophalangeal joint replacements. Therefore in this group of 72 digits assessed, 35 underwent surgery and 37 belonged to the hand operated upon but did not undergo surgery themselves. Only pinch force was assessed in these patients as many had difficulty in straightening their fingers so that reliable figures for flexion force could not be obtained.

The pinch forces of these 72 digits measured just before and again six months postoperatively were analysed by paired T test in two groups - the 35 digits which underwent surgery and the 37 which did not.

The results of the statistical analysis on the 35 digits operated upon are shown in Table 11.

Table 11

Digits whose Metacarpophalangeal Joints were Replaced

|             |              |       |           |
|-------------|--------------|-------|-----------|
| PINCH FORCE | Preop. Mean  | 1.49  | Kg. force |
|             | Postop. Mean | 2.77  | " "       |
|             | T            | 7.48  |           |
|             | P <          | 0.001 |           |

A considerable increase in pinch force is thus demonstrated in these digits undergoing metacarpophalangeal joint replacement, which is highly significant statistically.

The results of the analysis on those 37 digits which belonged to the hand which underwent surgery but were not themselves operated upon are shown in Table 12.

Table 12

Digits whose Metacarpophalangeal Joints were not Replaced

|             |              |       |           |
|-------------|--------------|-------|-----------|
| PINCH FORCE | Preop. Mean  | 3.30  | Kg. force |
|             | Postop. Mean | 3.65  | Kg. force |
|             | T            | 3.45  |           |
|             | P <          | 0.001 |           |

Hand function in terms of pinch force has therefore increased in the digits whose metacarpophalangeal joints were not replaced but which belonged to the hand which underwent operation. This increase in function is statistically significant.

Of the 51 patients assessed 10 underwent proximal interphalangeal joint synovectomy. Table 13 shows the distribution of the joints synovectomised among the 10 patients.

Table 13

Proximal Interphalangeal Joint Synovectomies

|   |
|---|
| 4 patients had 1 joint synovectomised = 4 joints synovectomised |
| 6 " " 2 joints synovectomised = 12 " "                          |

---

|                    |       |                  |
|--------------------|-------|------------------|
| <u>10</u> PATIENTS | TOTAL | <u>16</u> JOINTS |
|--------------------|-------|------------------|

The 10 patients therefore underwent a total of 16 proximal interphalangeal joint synovectomies. In the 40 fingers assessed in this group, 16 thus underwent surgery and 24 belonged to the hand operated upon but did not undergo synovectomy themselves. The flexion and pinch forces of these 40 fingers measured just before and again six months postoperatively, were analysed by paired T test in two groups - the 16 digits operated upon and the 24 digits which were not.

The results of the statistical analysis on the 16 digits belonging to the hand operated upon but not in fact synovectomised themselves are shown in Table 14.

The results of the statistical analysis on the 16 digits operated upon are shown in Table 14.

Table 14

Digits whose Proximal Interphalangeal Joints were Synovectomised

|               |              |       |           |
|---------------|--------------|-------|-----------|
| FLEXION FORCE | Preop. Mean  | 2.74  | Kg. force |
|               | Postop. Mean | 3.67  | " "       |
|               | T            | 4.88  |           |
|               | P <          | 0.001 |           |
| PINCH FORCE   | Preop. Mean  | 4.70  | Kg. force |
|               | Postop. Mean | 5.51  | " "       |
|               | T            | 4.00  |           |
|               | P <          | 0.001 |           |

Both flexion and pinch forces have therefore increased in the six months following surgery and these increases are statistically significant.

The results of the statistical analysis on the 24 digits belonging to the hand operated upon but not in fact synovectomised themselves are shown in Table 15.



Table 15

Digits whose Proximal Interphalangeal Joints were not Synovectomised

|               |              |       |           |
|---------------|--------------|-------|-----------|
| FLEXION FORCE | Preop. Mean  | 3.65  | Kg. force |
|               | Postop. Mean | 3.78  | " "       |
|               | T            | 3.59  | "         |
|               | P <          | 0.001 |           |
| PINCH FORCE   | Preop. Mean  | 3.56  | Kg. force |
|               | Postop. Mean | 3.77  | " "       |
|               | T            | 3.12  |           |
|               | P <          | 0.004 |           |

Again in the digits belonging to the hand operated upon but not themselves synovectomised there has been a significant increase in hand function as evidenced by improved flexion and pinch forces six months after surgery.

Metacarpophalangeal joint synovectomy or replacement and proximal interphalangeal joint synovectomy have accounted for 47 of the 51 patients assessed. Three of the remaining four patients had flexor tendon synovectomies with or without tenolysis and the last patient had a thumb metacarpophalangeal joint fusion. None of these four patients had similar operations and therefore, because of this and the small number of patients, a statistical analysis was not performed. However, Tables 16 and 17 indicate the type of improvement demonstrable after flexor tendon synovectomy and thumb fusion respectively in two of the patients.

Table 16

Patient J.M. Flexor Tendon Synovectomy

|         | <u>FLEXION FORCE</u> |        |      |        |
|---------|----------------------|--------|------|--------|
| DIGIT   | INDEX                | MIDDLE | RING | LITTLE |
| PREOP.  | 3.2                  | 2.1    | 2.3  | 3.0    |
| POSTOP. | 3.5                  | 3.6    | 3.4  | 3.2    |

(Units are Kg. force)

In this instance all four fingers show improvement six months after operation. These increases in flexion force had first been observed as early as three months after flexor tendon synovectomy.

Table 17

Patient R.J. Thumb Fusion

|         | <u>PINCH FORCE</u> |        |      |        |
|---------|--------------------|--------|------|--------|
| DIGIT   | INDEX              | MIDDLE | RING | LITTLE |
| PREOP.  | 4.0                | 4.5    | 3.7  | 2.9    |
| POSTOP. | 6.1                | 6.0    | 5.7  | 4.1    |

(Units are Kg. force)

This table shows the result following fusion of the metacarpophalangeal joint of the thumb in a patient with rheumatoid disease. Six months after fusion the thumb can provide a much firmer pillar against which the pulps of the digits can pinch.

c) Testing the Value of Surgery with the Torquemeter

The 19 patients who underwent metacarpophalangeal joint synovectomy for rheumatoid disease were also assessed with the torquemeter, before and six months after surgery. In each case torque in the digits involved with synovitis was seen to fall rapidly to zero long before full flexion was reached in contrast to the normal pattern of gradual torque fade when a normal joint passes from extension to flexion. Following surgery the pattern of torque fade was seen to revert towards the normal pattern. Figure 37 serves to illustrate this point and is the torque fade pattern of a rheumatoid patient who underwent index finger metacarpophalangeal joint synovectomy. Torque is plotted on the vertical axis in Kg. cms. and the position of the joint on the horizontal axis in degrees. The bottom graph of the three, whose co-ordinates are represented by crosses, is the torque fade pattern in the index finger just before synovectomy. Here torque is seen to fade rapidly to zero by the time the digit has flexed by only  $30^{\circ}$ . The top graph whose co-ordinates are represented by asterisks is the torque fade pattern of the unaffected index finger of the other hand. Here, torque is seen to fall off gradually in the normal fashion. The middle graph, whose co-ordinates are represented by small circles, is the torque fade pattern of the affected digit six months after synovectomy which can be seen to have reverted towards the normal pattern.



4) Bone Density      Rheumatoid Hand

Bone density was studied by Colour Television Image Analysis in the 20 phalanges of 10 patients with Rheumatoid Arthritis over a one year period. Changes in Bone Density were found to be of two types.

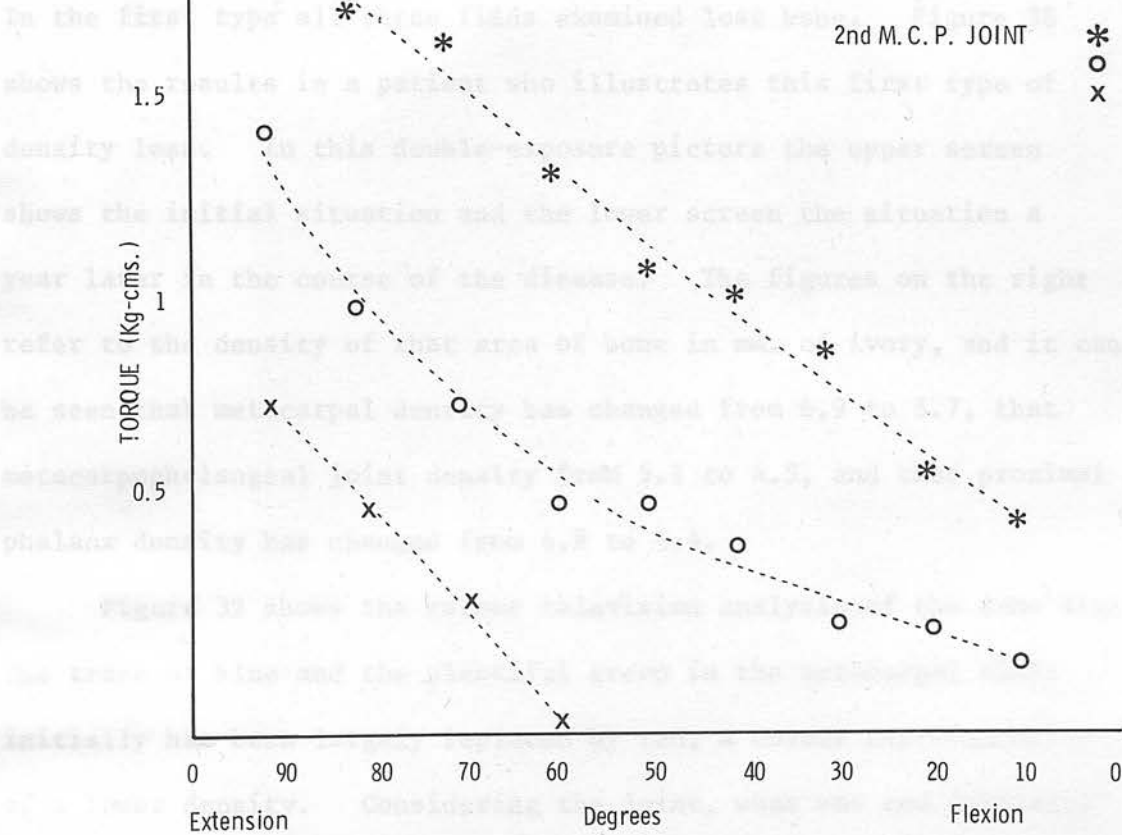


FIGURE 37

To more closely inspect the phalanges, the hand can be examined individually. In Figure 40, this is the same digit but all the other phalanges have been excluded. Red can be seen to occupy much of the proximal shaft, some of the middle, and a little in the course of the proximal phalanx, this is the same phalanx. Figure 41 shows that red is not seen in the distal phalanx. Figure 42 shows exposure colour picture. Figure 43 is one of the films taken by a colour television camera of a lower density.

d) Bone Density Loss in the Rheumatoid Hand

Bone density was studied by Colour Television Image Analysis in the 20 hands of 10 patients with Rheumatoid disease over a one year period. Changes in bone density were found to be of two types. In the first type all three fields examined lost bone. Figure 38 shows the results in a patient who illustrates this first type of density loss. In this double-exposure picture the upper screen shows the initial situation and the lower screen the situation a year later in the course of the disease. The figures on the right refer to the density of that area of bone in mm. of ivory, and it can be seen that metacarpal density has changed from 6.9 to 5.7, that metacarpophalangeal joint density from 5.1 to 4.5, and that proximal phalanx density has changed from 4.8 to 4.4.

Figure 39 shows the colour television analysis of the same digit. The trace of blue and the plentiful green in the metacarpal shaft initially has been largely replaced by red, a colour representative of a lower density. Considering the joint, what was red initially is now nearly all cyan, one step lower on the wedge.

To more closely inspect a particular density range, each colour can be examined individually. Taking red as an example, as in Figure 40, this is the same digit but all the other colours have been excluded. Red can be seen to occupy much of the metacarpal shaft, some in the joint, and a little in the cortex of the proximal phalanx. This is the situation initially. Figure 41 clearly shows that red is much reduced a year later and from the double exposure colour picture, Figure 39, it was clear that its place had been taken by a colour representative of a lower density.

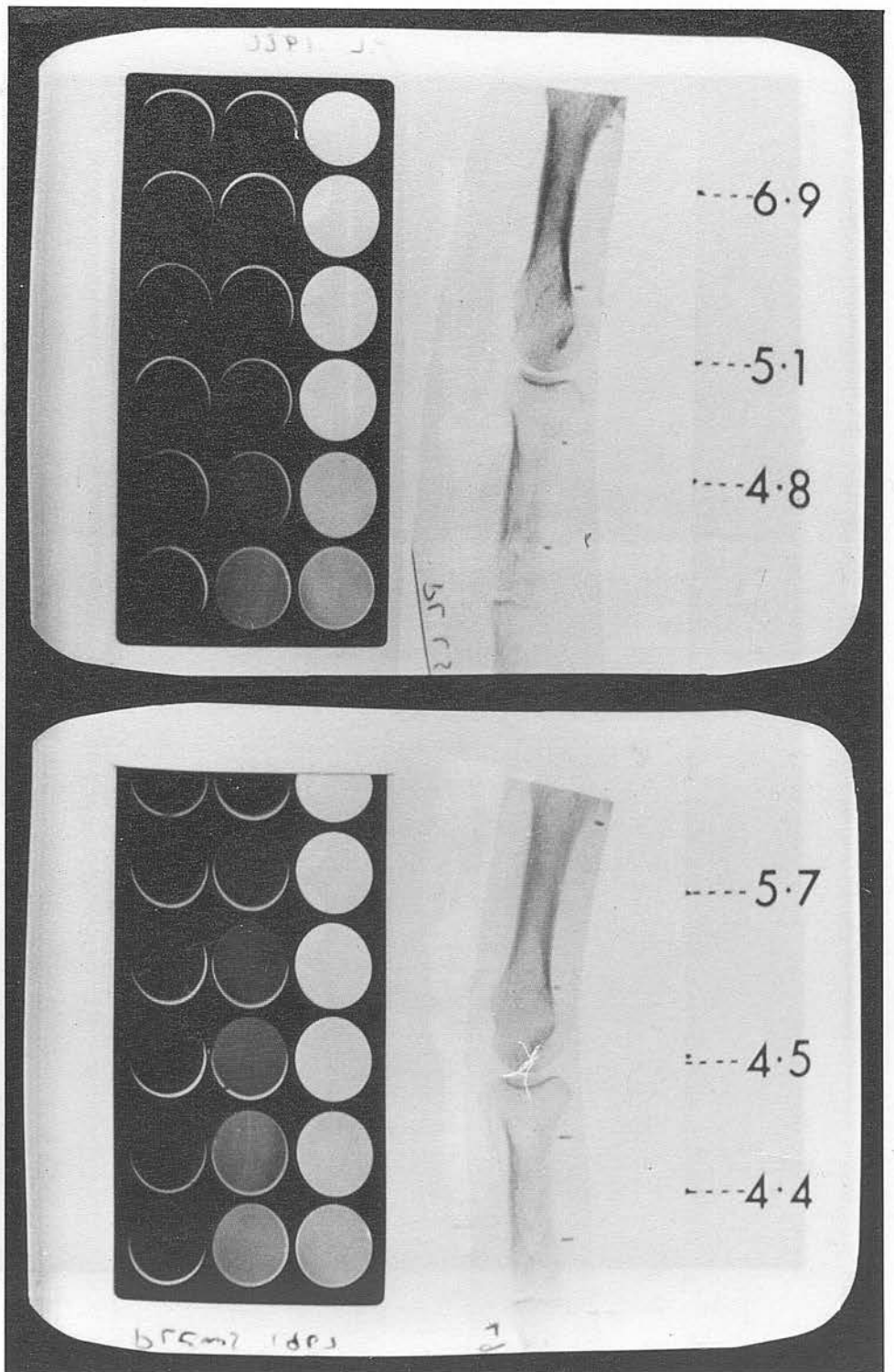


FIGURE 38

ALL THREE FIELDS LOSE BONE



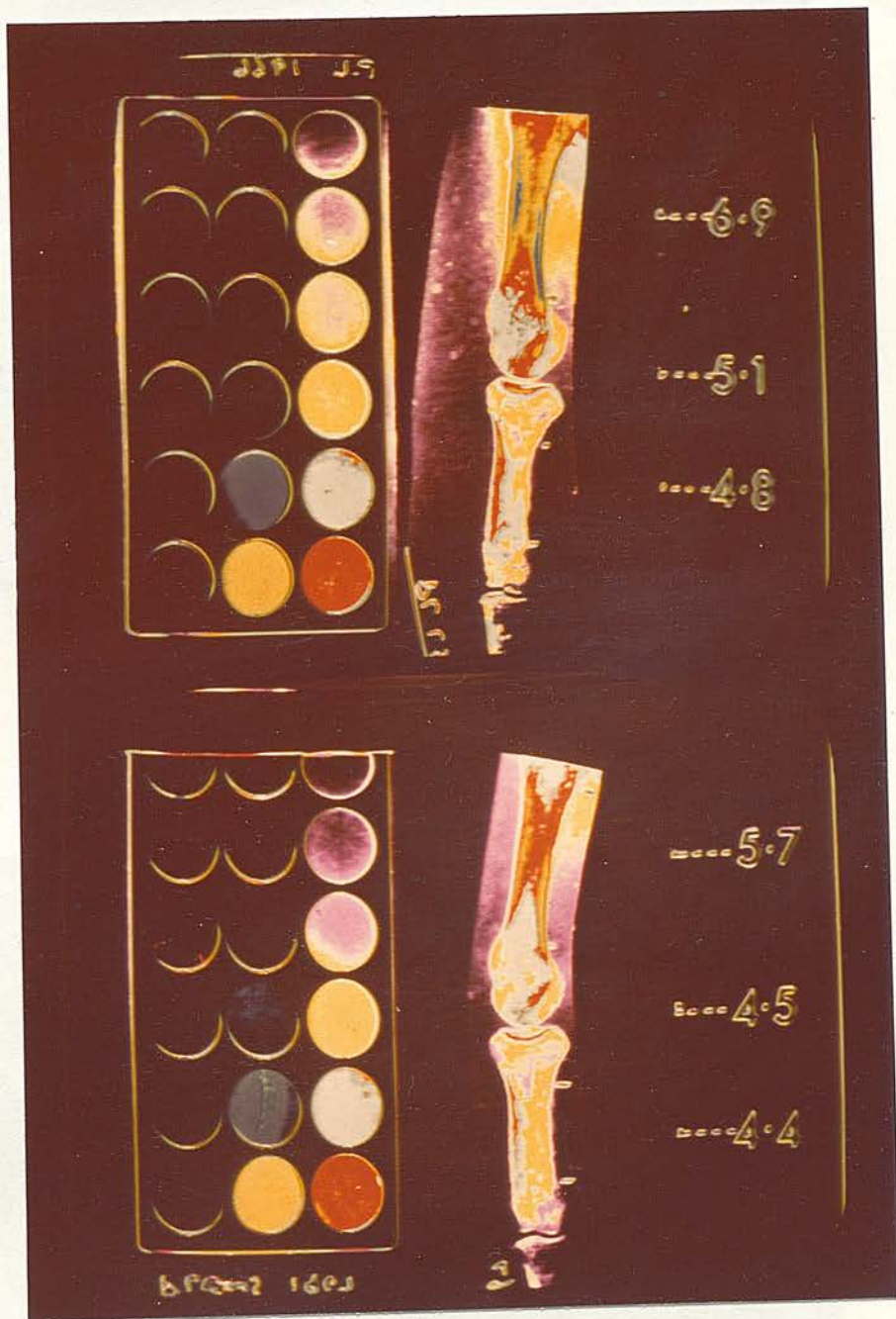


FIGURE 39

(for explanation see text)

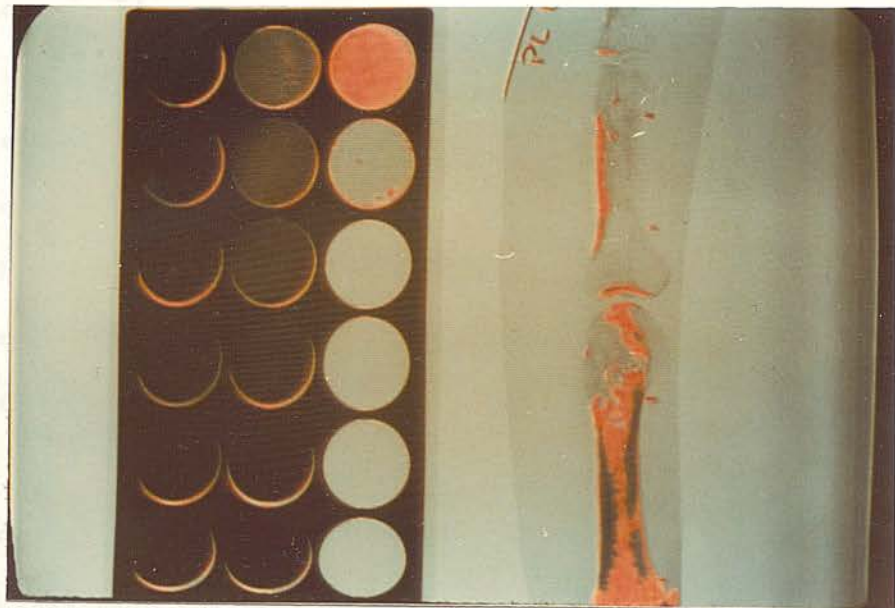


FIGURE 40

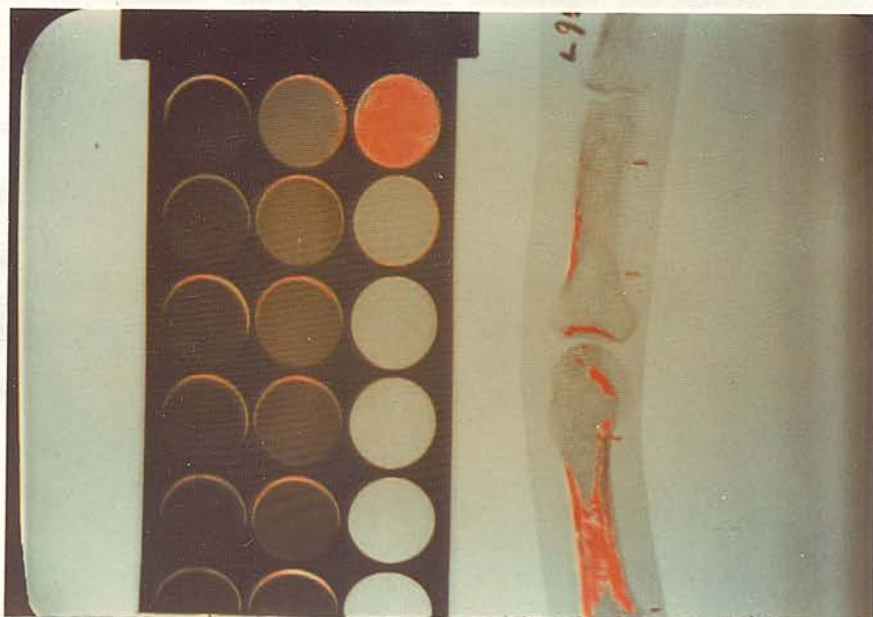


FIGURE 41

(for explanation see text)

Typical of the second type of bone density change is the patient's results shown in Figure 42. This is another double exposure picture, the upper screen showing the initial situation and the lower one the situation a year later. The metacarpal and proximal phalanx have both lost density - 6.7 to 6.3 and 4.8 to 4.3 mm. ivory respectively. However, the joint has increased in density from 4.7 to 5.3 and has occurred because the joint has begun to sublux and therefore overlap. Figure 43 shows the colour television analysis of this same digit. Here it is more difficult to interpret what has happened to the different density zones because the colours have been tuned to different steps from one year to the next. However, it is clear that a reduction in density has occurred for a year later blue, and the other colours, have to be set a step lower on the wedge before that density zone is visualised in the bone.

In order to examine the joint more closely, the quantity of red on its own can be studied. Here red occupies the same step position from one year to the next. Figure 44 shows the quantity of red in the joint initially and from Figure 45 it can be seen that red is much increased a year later as the joint has subluxed.

Table 18 summarises the results of paired T tests in the three fields examined in the 10 patients.

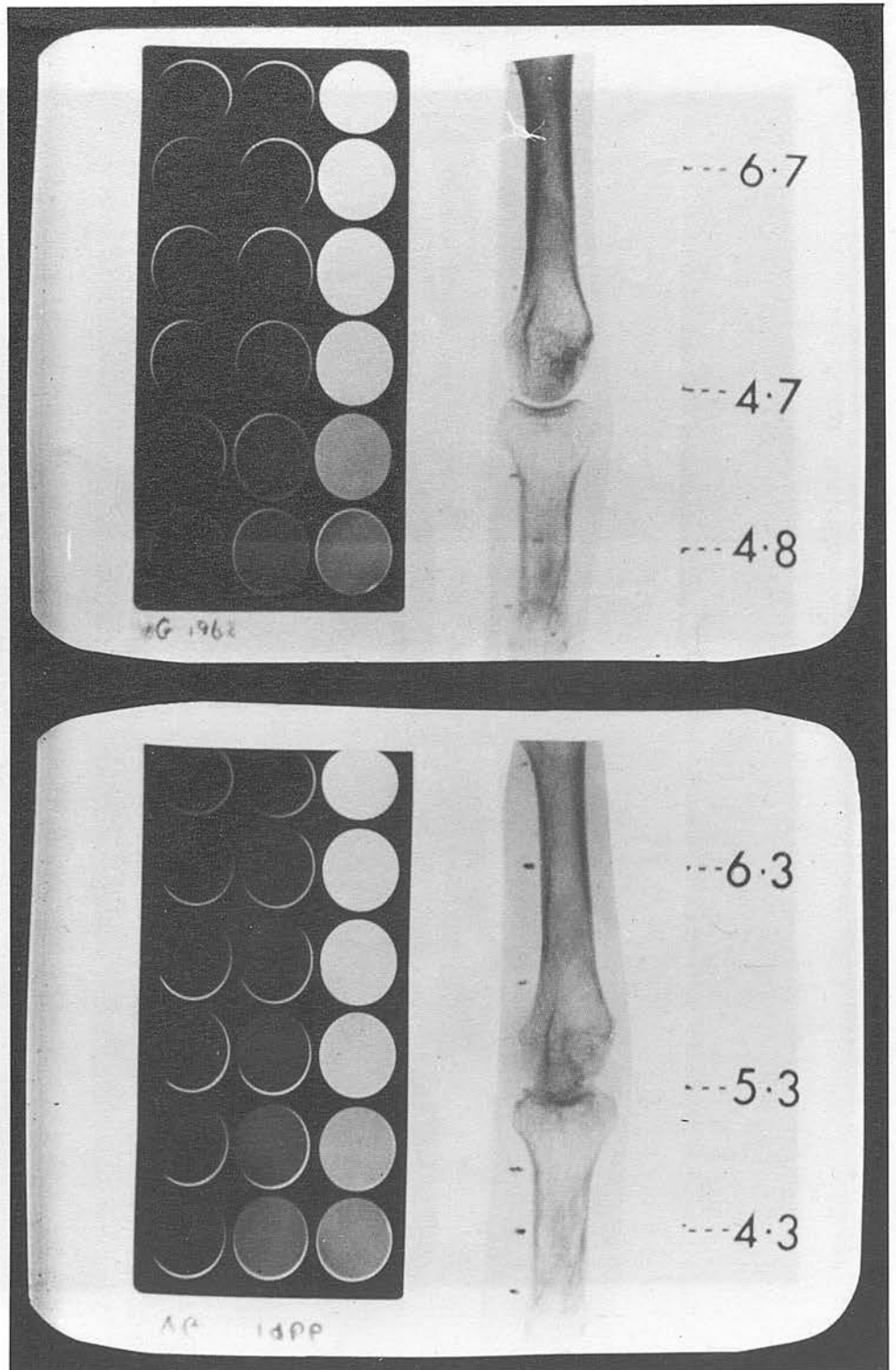


FIGURE 42

THE JOINT INCREASES IN DENSITY



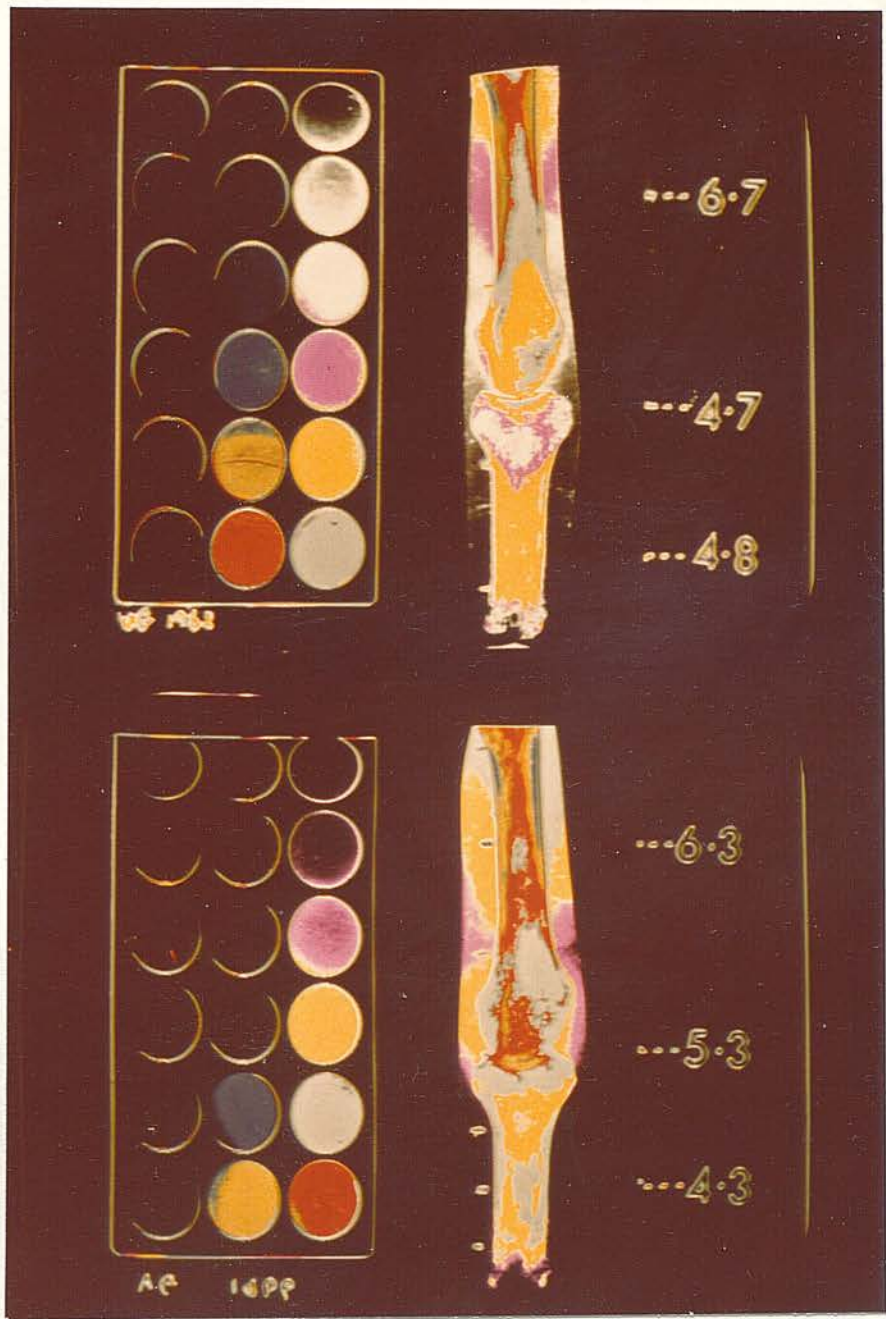


FIGURE 43

(for explanation see text)

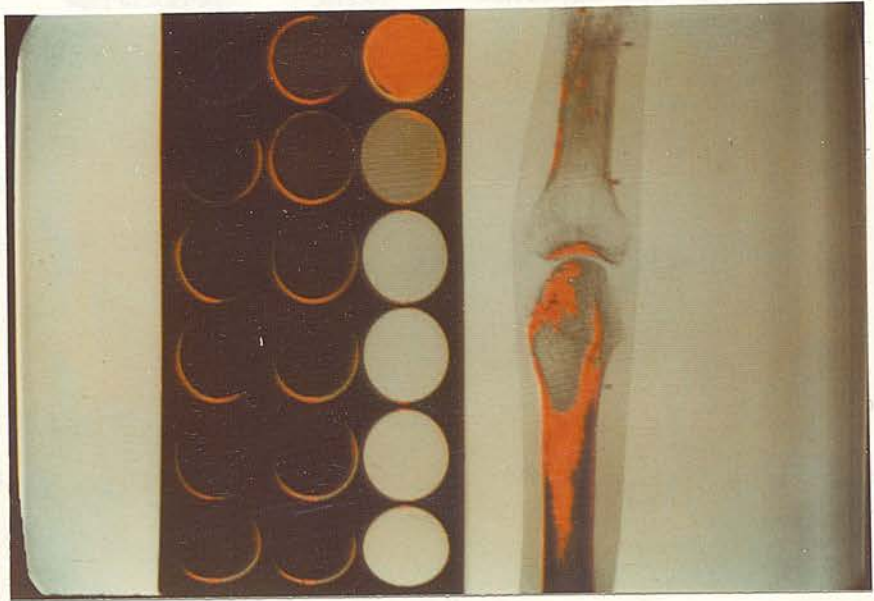


FIGURE 44

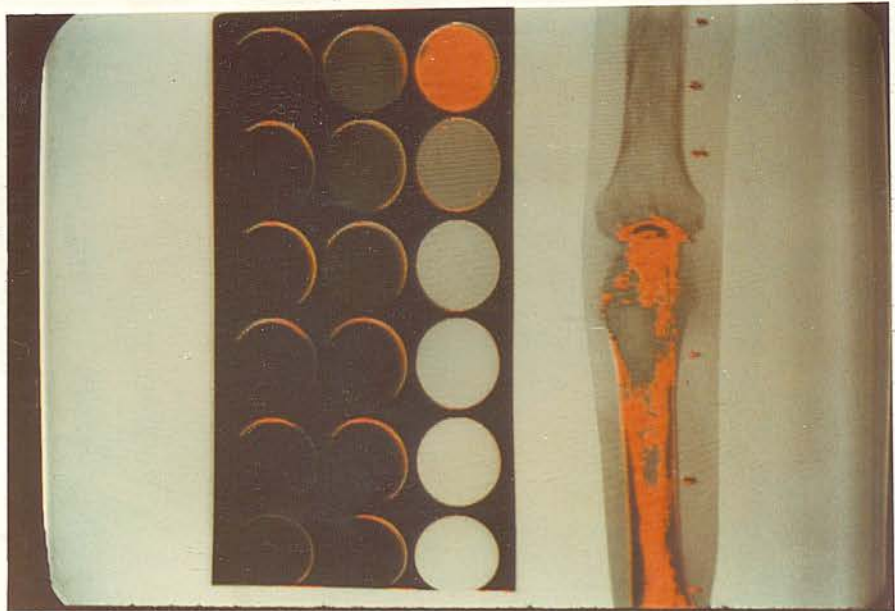


FIGURE 45

(for explanation see text)

Table 18

Bone Density Loss in the Rheumatoid Hand

|                                     | METACARPAL | JOINT   | PROXIMAL PHALANX |
|-------------------------------------|------------|---------|------------------|
| INITIAL MEAN<br>mm. ivory           | 6.5        | 5.0     | 4.6              |
| MEAN ONE YEAR<br>LATER<br>mm. ivory | 5.7        | 4.4     | 4.1              |
| T                                   | 7.1        | 6.3     | 8.1              |
| P                                   | < 0.001    | < 0.001 | < 0.001          |

In each of the three fields examined from one year to the next - metacarpal, metacarpophalangeal joint and proximal phalanx - there has been a significant reduction in bone density.



e) The Effect of Synovectomy of the Metacarpophalangeal Joint on Bone Density and Hand Function

The values of flexion force, pinch force and bone density recorded on the 15 digits whose metacarpophalangeal joints underwent synovectomy were subjected to statistical analysis. This was in the form of paired T tests for each of the three parameters measured.

Table 19 shows the results of the paired T test analysis on the values obtained one year before and immediately before synovectomy.

Table 19

Flexion Force, Pinch Force, and Bone Density

The Preoperative Year

|               |                      |       |           |
|---------------|----------------------|-------|-----------|
| FLEXION FORCE | One Year Preop. Mean | 2.59  | Kg. force |
|               | Immediately " "      | 2.12  | " "       |
|               | T                    | 4.72  |           |
|               | P <                  | 0.001 |           |
| PINCH FORCE   | One Year Preop. Mean | 5.10  | Kg. force |
|               | Immediately " "      | 3.83  | " "       |
|               | T                    | 3.57  |           |
|               | P <                  | 0.003 |           |
| BONE DENSITY  | One Year Preop. Mean | 6.58  | mm. ivory |
|               | Immediately " "      | 5.29  | " "       |
|               | T                    | 4.96  |           |
|               | P <                  | 0.001 |           |

Statistically significant reductions have therefore occurred in flexion force, pinch force, and bone density over the year

preceeding synovectomy.

Table 20 shows the results of the paired T test analysis on the results obtained just before synovectomy and one year post-operatively.

Table 20

Flexion Force, Pinch Force, and Bone Density

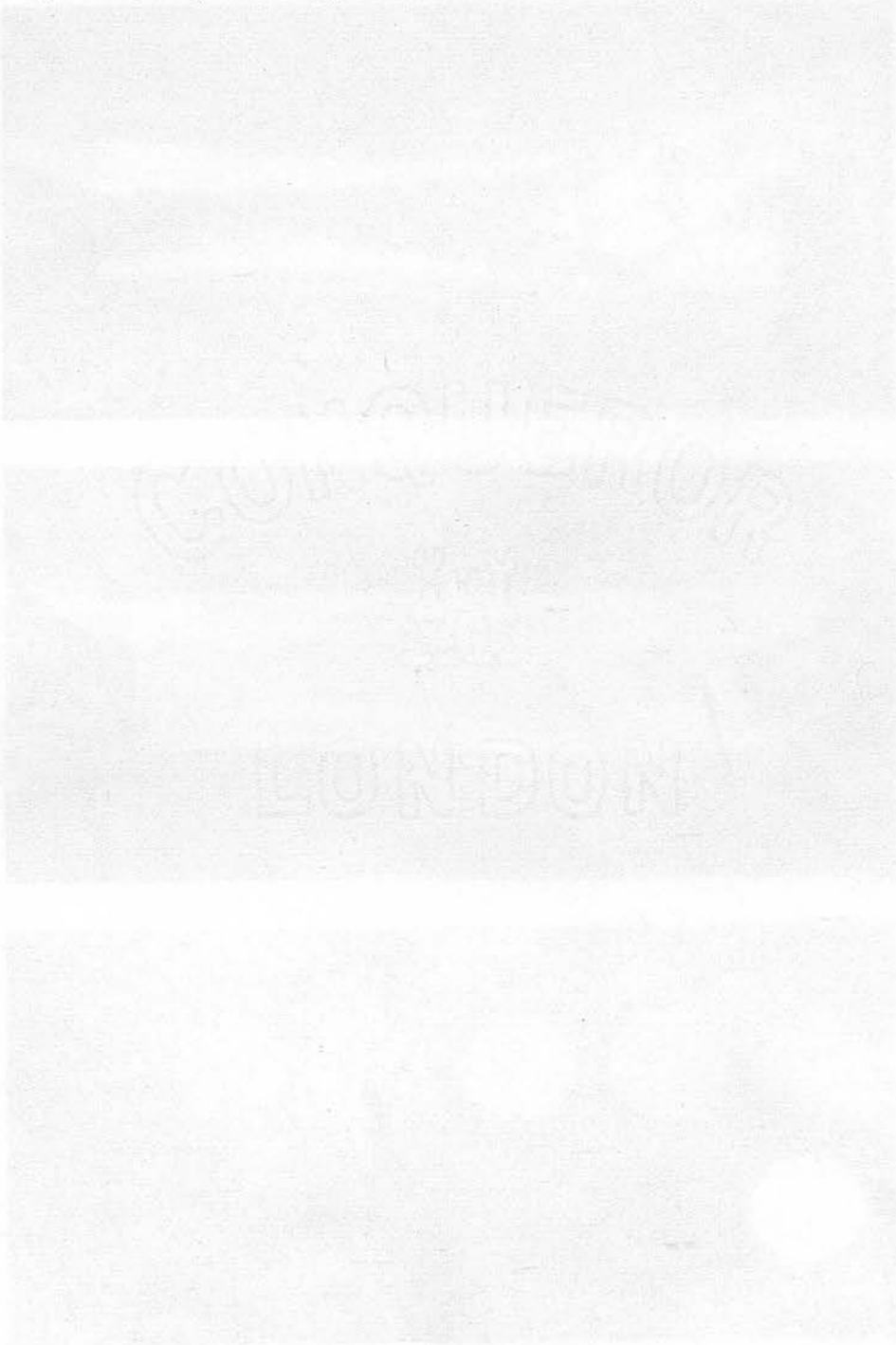
The Postoperative Year

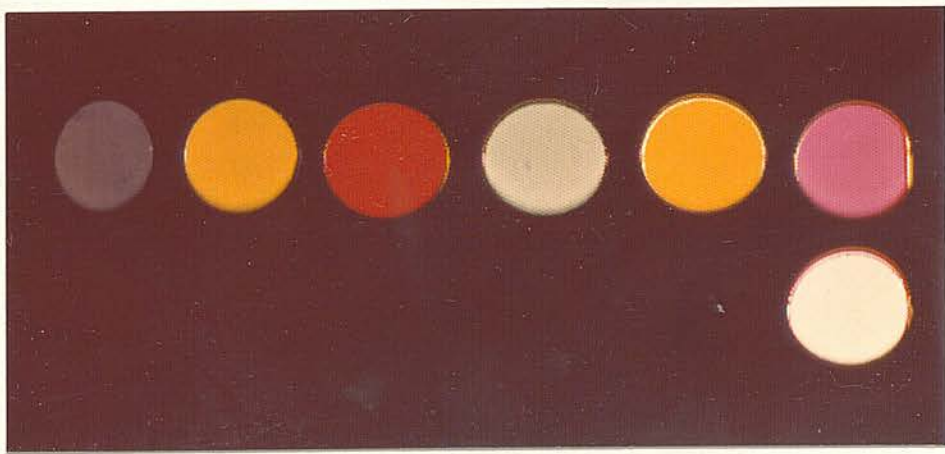
|               |                         |       |           |   |
|---------------|-------------------------|-------|-----------|---|
| FLEXION FORCE | Immediately Preop. Mean | 2.12  | Kg. force |   |
|               | One Year Postop. "      | 2.56  | "         | " |
|               | T                       | 5.14  |           |   |
|               | P <                     | 0.001 |           |   |
| PINCH FORCE   | Immediately Perop. Mean | 3.83  | Kg. force |   |
|               | One Year Postop. "      | 4.27  | "         | " |
|               | T                       |       |           |   |
|               | P <                     | 0.001 |           |   |
| BONE DENSITY  | Immediately Preop, Mean | 5.29  | mm. ivory |   |
|               | One Year Postop. Mean   | 6.29  | "         | " |
|               | T                       | 4.55  |           |   |
|               | P <                     | 0.001 |           |   |

Statistically significant increases have therefore occurred in flexion force, pinch force and bone density over the year following surgery.

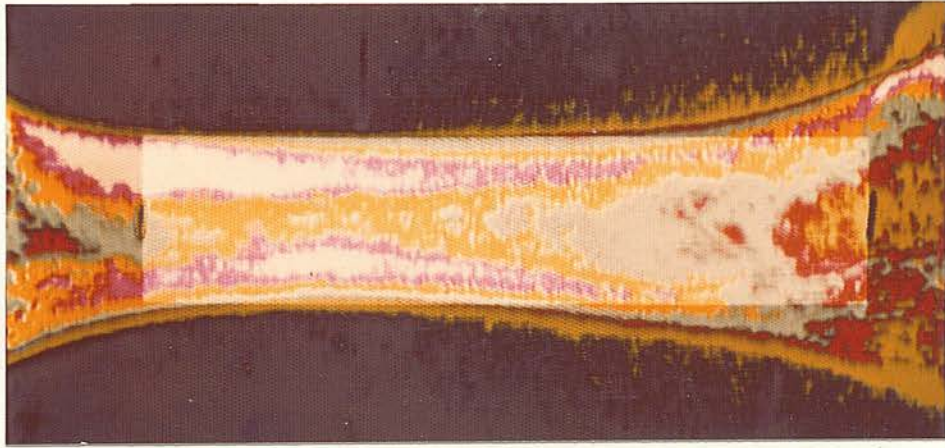
Colour television image analysis not only provides a numerical result for bone density. It also provides a seven-colour contour map of the bone examined. Figure 46 shows an example of what happens to the contour maps before and after surgery. A, shows the colours set on the steps of the wedge and this setting remains constant for this

analysis. B, shows the metacarpal shaft one year before surgery, comprising cyan and yellow with streaks of magenta and white. C, shows the situation just before surgery. Here much of the cyan and yellow has been replaced by red, a colour representative of a lower density. The position one year after surgery is shown in D, Here the picture has reverted towards the patterns seen in B, one year before surgery. Most of the red has been displaced by cyan and yellow, representing an increase in density..

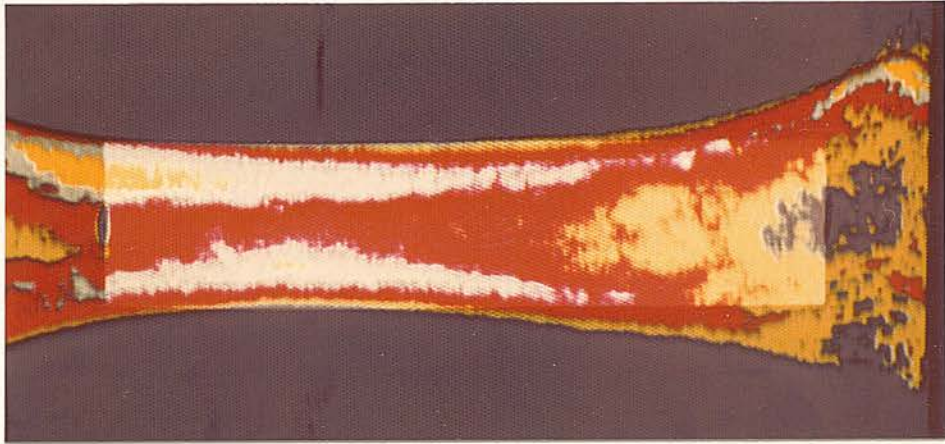




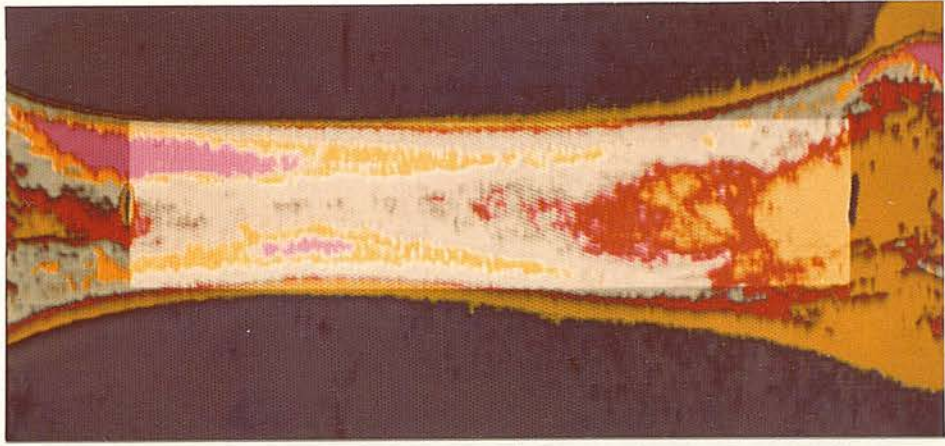
A



B



C



D

FIGURE 46

(for explanation see text)



PART III - DISCUSSION

The Need for a More Systematic Approach to the Study of Language

The subject of language has been the focus of a wide variety of studies and theories. It is important to have as much information as possible about the nature of language and its development. In various programs of research, many workers have attempted to describe language (Savage, 1966; Hockett, 1968; Chomsky, 1965, 1977) and have found it difficult to quantify. The only subjective assessment which can be made is that of value in the comprehensive program of research on the nature of certain everyday tasks.

Objective methods of research in the study of language have been developed. Their development is due to the work of many workers (Savage, 1966; Hockett, 1968; Chomsky, 1965, 1977) and the need of workers in the field.

**PART IV - DISCUSSION**

None of these methods are completely objective in the sense that they are not completely free of the influence of the researcher's own assumptions and purposes.

Blaschke's (1968) study of the development of language in children is an example of a study which is not completely objective. The study is based on the observation of children in a natural setting. The study is not completely free of the influence of the researcher's own assumptions and purposes.

## PART IV - DISCUSSION

### The Need for Satisfactory Methods of Assessing Hand Function

The search for satisfactory methods of assessing hand function has occupied many workers in this field. While it is important to have as much information about the hand as possible before a treatment programme is devised, many present day assessment methods (Savage, 1966; Ansell, 1969; Holt et al, 1972) are reviewed and found to lack definition and precision and are difficult to quantify. The only subjective assessment method that has been shown to be of value is the comprehensive proforma about the patient's performance of certain everyday tasks (Nicolle, 1972).

Objective methods of assessment are numerous but lack of faith in many of them is evidenced by the fact that most authorities base their assessment of function on measurement of grip strength (Wright, 1959; Savage, 1966; Swanson, 1968) and measurement of the range of motion of the involved joints (Flatt, 1969; Swanson, 1972; Nicolle, 1972). None of these authorities has, however, been able to use these two parameters as more than superficial standards for assessment purposes.

Rheumatoid arthritis is a multifocal disease and rheumatologists are able to assess the efficacy of their therapy along the broader lines of haematological investigations (Savage, 1966; Hart et al, 1972). Because the hand surgeon commonly deals with individual digits, the concept of the assessment of hand function at the digital level has been introduced. For this purpose, the author has described new instruments, the Cybernometer and the Torquemeter.

Hand Function and Bone Density

Much evidence exists that there is a relationship between muscle function and bone density (Nilsson, 1966; Hodgkinson et al, 1967; Whedon et al, 1967; Donaldson et al, 1970; Tulloh et al, 1963; Hunt et al, 1965; Mack, 1972). These investigations showed loss of function paralleling loss of bone density, and it is generally not considered today that osteoporosis is a process which can be reversed (Doyle, 1972). Furthermore, the only study of function and bone density in the rheumatoid hand (Virtama et al, 1968) was an investigation into another hypodynamic state, that of diminishing hand function, and involved many inaccuracies.

However with the introduction of an accurate instrument, the cybernometer, to measure function in individual digits, and a new, more accurate and rapid method of measuring bone density, the Colour Television Image Analyser, the pathway has been opened, not only for the accurate investigation of the hypodynamic state, but also to examine the possibility of reversing the disuse osteoporosis in the rheumatoid hand by the surgical improvement of hand function.



"New Lamps for Old"

The Cybernometer, designed by the author and built in the Royal Postgraduate Medical School engineering laboratory, fulfils the present day need to express hand function at digital level in terms of absolute units of force. There is no method for the accurate assessment of individual finger flexion force nor for the assessment of that of pinch, yet many surgical procedures are carried out specifically to improve such functions.

The apparatus is of simple design based on the movement of the simply-loaded uniform cantilever which conforms with Hooke's Law. It has certain built-in advantages being light, portable, reliable and accurate. The presence of the red light excludes any error in measuring flexion force by calling the examiner's attention to any undue flexion occurring at the metacarpophalangeal joint. In addition, it is simple to calibrate and ease of operation makes it most suitable for non-technical staff in physiotherapy and occupational therapy departments.

The Torquemeter, again designed by the author and built at Hammersmith, has enabled torque to be investigated in the metacarpophalangeal joints of the rheumatoid patient, before and after corrective surgery. The instrument is perfectly elastic and, by pivot, any digit of either hand can be investigated throughout its range. Like the Cybernometer it is light, portable, and easy to operate making it suitable for use by ancillary staff. One of its great advantages is that the rheumatoid digit, no matter how deformed, can still be studied as the resultant torque is independent of the position of the finger on the horizontal side-arm.

The Colour Television Image Analyser has added a new dimension to the measurement of bone density and to the investigation of a hand function - bone density relationship. Other methods of determining bone density have been reviewed, and colour television image analysis found to be the most accurate (coefficient of variation  $< 1\%$ ). The technical difficulties associated with densitometry (Doyle, 1965) tend not to apply with this new technique. Non-uniformity of Xray beam is corrected by the radiograph being taken under constant conditions, voltage clamped, by the same qualified radiographer. The ivory step wedge (Bywaters, 1948) ideally suits the range of densities in the bones of the hand, and interference from soft tissues is negligible in the fingers provided the soft tissue width of the digit does not vary from one examination to the next (Doyle, 1972). This eliminates the rather tedious necessity of immersing the hand in water to remove the contribution to density that the soft tissues make. The electronically controlled inset window allows concentration upon certain bone areas, while the equipment itself provides not only a measure of bone density in mm. of ivory, but also a seven colour density-contour map which can be easily photographed from the television screen so that density distribution changes can be compared from one examination to the next.

### The Normal Hand

Experiments have been carried out on the normal hand with the cybernometer in order to investigate normal hand function before turning to the pathological. From the statistical analysis performed on the data obtained certain inferences may be drawn. There is a significant difference between the strengths of the different fingers of a normal hand, the index and middle fingers being much stronger than the ring and little fingers. This latter observation lends support to Capener's view (1956) that the thumb, index and middle fingers form a 'dynamic tripod of prehension'. That pinch force is considerably greater than flexion force for a given digit emphasises the important contribution to hand function provided by the thumb. The fingers of the dominant hand are stronger than their non-dominant counterparts and this observation is of functional importance for, while few authorities would doubt the better dexterity of the dominant hand, none has, until now, demonstrated superior strength at the digital level. A day-to-day variation in hand function exists and also some variation in pinch and flexion force in the course of a single day. That no significant change occurs in grip strength confirms the work by Wright (1959) who showed that the period from 9 a.m. to 4 p.m. forms the substantial part of a plateau in the diurnal variation of grip strength. The grip strength of the hand and the pinch force of its individual digits are significantly correlated in both dominant and non-dominant hands, reflecting, perhaps, the similar nature of execution of these two hand functions.

The concept of a relationship existing between hand function and bone density has already been introduced. That the disuse osteoporosis in the rheumatoid hand might be reversed by the surgical

improvement of hand function raised the possibility of a pre-existing function - density relationship in the normal hand. The results of an investigation into this possibility confirms that a positive relationship is present at digital level. Area Index and pinch force are positively related. That Dimensionless Ratio is unrelated to function is not surprising on consideration that this parameter is independent of bone size. That a correlation does not exist concerning flexion force may be accounted for by the fact that pinch, being the more important and strong hand function, can reflect itself in the density of the bones of the individual digits, while flexion, being a lesser function, cannot.

As the metacarpophalangeal joint moves from full extension through flexion, torque at this joint gradually falls in the normal hand. The resistance to joint motion comprises contributions from all nearby soft tissues - skin, tendons, joint capsule and synovial membrane. It is the synovium whose proliferation so characterises the early pathological changes in rheumatoid disease, and a base-line has now been established, the pattern of torque fade in the normal hand, as a comparison for torque studies in the rheumatoid hand before and after metacarpophalangeal joint synovectomy.

### The Rheumatoid Hand

Much is still not known about the aetiology, pathogenesis, and prognosis of rheumatoid disease as it affects the hand. Because of this uncertainty it has become increasingly more necessary for hand surgeons to evaluate their results in a critical manner. A retrospective study of over 100 metacarpophalangeal joint synovectomies (Nicolle et al, 1971) has shown the prophylactic value of surgery. Lack of precise criteria, however, by which the relative merits of surgery can be judged, has made the therapeutic value of synovectomy more difficult to determine. Apart from measurement of range of joint motion and measurement of grip strength there is a distinct lack of meaningful criteria in the assessment of the results of prosthetic joint replacement in the rheumatoid hand. Because of this, the two most recent reports on the value of artificial finger joints (Swanson, 1972; Nicolle and Calnan, 1972) provide no useful parameters on which can be based sound statistical evaluation methods. The ability to measure flexion and pinch forces of individual digits has provided the necessary parameters for statistical assessment not only of the results of surgery but also of the relationship between function and bone density in the rheumatoid hand.

### Cybernometer v. Dynamometer

As an introduction to investigations into the clinical situation, a comparison was carried out of the relative merits of cybernometer and pneumatic dynamometer using 16 rheumatoid patients. In each case, the cybernometer either highlighted weakness in a hand not revealed by grip strength measurement, or focussed attention on the weakened digit responsible for the difference in grip strengths of the two hands. Furthermore, in each case there was radiological evidence of disease



in that digit. Measurement of grip strength is therefore not only of limited value but may in fact be misleading, while assessment at digital level can be seen to be of specific value.

#### Testing the Value of Surgery with the Cybernometer

A total of 51 patients were assessed with the cybernometer just before and again six months after surgery. 47 of the 51 patients underwent either metacarpophalangeal joint synovectomy, metacarpophalangeal joint replacement, or proximal interphalangeal joint synovectomy. The fingers assessed fell into two interesting groups, those which underwent surgery, and those belonging to the hands operated upon but which did not undergo surgery themselves. Paired T tests were performed on these two groups for each of the three types of operation. Significant improvement in terms of function was demonstrated for each operation. Not only was function improved in the digits which underwent operation but also in those which did not, presumably, due to the overall improvement in hand function which operation has provided. That synovectomy practised for prophylactic purposes can achieve in addition a significant functional improvement is of great importance to the hand surgeon who before had little to offer his patient in terms of rapid results. It can be foreseen that synovectomy might enjoy the new title of 'therapeutic' as well as 'prophylactic'.

Prosthetic replacement of the metacarpophalangeal joint of the rheumatoid hand is, perhaps, the greatest advance in rheumatoid hand surgery this decade. It is comforting that statistically significant improvement in hand function in a prospective study accompanies an operation of such increasing vogue.



Testing the Value of Surgery with the Torquemeter

As the normal metacarpophalangeal joint passes from extension to flexion, torque has been seen to fade gradually and unimpressively, while torque in the joint involved with rheumatoid synovitis falls dramatically after only a few degrees of flexion. All neighbouring soft tissues contribute a resistance to joint movement but it can be seen in the rheumatoid patient that by far the greatest contribution comes from the diseased synovium for, after radical synovectomy, the pattern of torque fade closely approximates that of the normal unaffected digit. By measuring torque at the metacarpophalangeal joint before and after synovectomy, the contribution to joint resistance that the diseased synovium makes can therefore be quantified and the efficacy of surgery determined.

The remaining 4 patients had a variety of different procedures which could not be analysed in a statistical manner. However, an example of synovectomy of flexor tendons in the palm shows that function can be improved as early as three months after operation. The importance of a good functional thumb has been demonstrated previously in that pinch force is considerably greater than flexion force for a given digit. A patient whose thumb metacarpophalangeal joint was fused serves as further evidence of the importance of having a firm pillar against which the pulps of the digits can pinch.

Statistical studies can therefore be performed to investigate the value of surgery in the rheumatoid hand, due to the concept of assessment at digital level by accurate measurement of the forces of the individual digits. In turn the instrument designed to assess these digits, the cybernometer, proves its flexibility in the clinical situation.

Bone Density Loss in the Rheumatoid Hand

Disuse osteoporosis in the hands of patients suffering from rheumatoid disease has been briefly and inaccurately studied (Virtama et al, 1968), while none of the present methods of measuring bone density (Doyle, 1965) achieves the degrees of accuracy of Colour Television Image Analysis. That a significant loss of bone density occurs in rheumatoid hands has never until now been shown. Metacarpal and proximal phalanx lose a considerable quantity of bone in one year, in some patients as much as 50%. Overall loss of bone from the metacarpophalangeal joint is considerably less because some joints increase in density as volar subluxation occurs. However, two patterns of bone density loss can be separated, the early stage of disease and the later stage. In the former all three fields lose bone - metacarpal, joint, and proximal phalanx, while in the latter the two bones lose density but the joint increases in density. Colour Television Image Analysis not only provides an attractive colour contour map but also provides a numerical result on which can be based a statistical analysis.

It has been demonstrated that the relationship between bone density and disease activity in the rheumatoid hand.

The Effect of Synovectomy of the Metacarpophalangeal Joint on  
Bone Density and Hand Function

The function of the human hand and the density of its individual bones have been shown to be positively related in the hypodynamic state. This study on how surgery can affect bone density and hand function shows that this relationship continues into the hyperdynamic situation. Statistically significant reductions in flexion force, pinch force and bone density are shown to occur over the year preceding surgery, and equally significant increases in the year following operation. Here the value of the seven-colour contour map is demonstrated, for the picture one year after surgery closely resembles that of the year before operation. A numerical result and a contour map are therefore both clearly of help in the assessment of bone density. The osteoporosis occurring in association with rheumatoid disease of the hands is not generally accepted as being reversible, but here evidence is presented to the contrary. Not only has colour television image analysis made bone density measurements both accurate and rapid, it has been responsible for the statement that osteoporosis can be reversed and, with the cybernometer and torque-meter, a positive relationship between function and bone density exists in the rheumatoid hand.

CONCLUSION

Evidence has been presented which strongly supports the concept of assessment of hand function at the digital level, Surgery of the rheumatoid hand assessed in this manner has been subjected to strict statistical analysis and the results clearly favour surgical intervention. These results can only be judged on the short term evidence available but would suggest for the author's methods of assessing hand function, a favourable long term prospect as well.

Hand function and bone density are demonstrated to be positively related in both the hypodynamic and hyperdynamic situations. In this investigation Colour Television Image Analysis proved itself to be the most accurate method of bone density measurement in present use.

While these initial investigations must be followed by long term studies, at present in progress at the Royal Postgraduate Medical School, they present hope for the patient and inspiration to rheumatologist and hand surgeon in their continuing serch.

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**THE ASSESSMENT OF HAND FUNCTION**

**Part 1—Measurement of Individual Digits**

R. A. DICKSON and F. V. NICOLLE, London

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## THE ASSESSMENT OF HAND FUNCTION

### Part 1—Measurement of Individual Digits

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#### INTRODUCTION

*“There is a natural inclination to put a figure on any measurement, but unless it is accurate this should be resisted.”* (Savage, 1966)

While some progress has been made in the assessment of the hand at the neurological level (Moberg, 1958; Moberg, 1968), little has been done at the mechanical level.

When Bywaters in 1949 described rheumatoid arthritis as an “Unwieldy nosological hodge-podge”, he could also have applied this phrase to the methods of assessment of the rheumatoid hand, and he would find no reason, nearly a quarter of a century later, to revise his opinion. In that same year, however, an effort was made to assemble therapeutic criteria in rheumatoid disease (Steinbrocker, 1949). This classification of functional capacity was graded from class 1, “Complete function” to class IV “Incapacitated”. We must all admit that little of relevance has since been added. The hand surgeon can claim little success with his results if they are only based upon the subjective impressions of both himself and the patient, unless he can show improved function based upon sound objective methods of assessment. However, we must first ascertain what function is particularly important to an individual patient and what improvement is likely (Savage, 1966; Holt, 1969; Ansell, 1969; Hart, 1972; Nicolle, 1972). It is possible, nevertheless, to design objective methods of assessment to suit a particular problem.

#### METHODS OF ASSESSMENT—HISTORICAL REVIEW

*“We have got to measure these things eventually.”* (Welbourn, 1969)

The methods of assessment in common use are shown in Table 1.

TABLE 1  
METHODS OF ASSESSMENT

| <i>Subjective</i>   | <i>Objective</i>                        | <i>Laboratory</i>                     |
|---------------------|---|---------------------------------------|
| Patient's views     | Clinical appraisal                      | Haemoglobin                           |
| Everyday tasks      | X-ray                                   | Sedimentation Rate                    |
| Special functions   | Photography                             | Serum Iron                            |
| Pain grades         | Cinematography                          | Rheumatoid factor                     |
| Functional capacity | Pinch ability                           | Rose Waaler                           |
| Cosmetic appearance | Arc of motion, hand span,<br>flexor lag | Sheep Cell Agglutination              |
|                     | Grip strength                           | 17 hydroxycorticosteroids in<br>urine |
|                     | Joint size                              |                                       |
|                     | Articular index                         |                                       |
|                     | Cuff dolorimeter                        |                                       |
|                     | Duration of morning stiffness           |                                       |
|                     | Thermography                            |                                       |
|                     | Technesium clearance                    |                                       |

### Subjective

A suitable proforma cataloguing the patient's views, his performance of everyday tasks, his predominantly important functions and special disabilities is commonly recommended (Savage, 1966; Ansell, 1969; Holt, 1972); yet no general agreement has been reached as to the exact size and content of such a method of documentation. The adoption of a universally acceptable method would facilitate a degree of control and reciprocity in results published from different centres. A comprehensive proforma has recently been suggested and been shown to be of value in assessing the results of prosthetic joint replacement, Table 2 (Nicolle, 1972). Its use is of value while no suitable objective methods exist.

Methods of grading pain in response to treatment have been suggested, including three pain grades or the number of analgesics required to relieve pain (Savage, 1966). It seems unlikely that grading of such a subjective impression can be of any real quantitative value.

Some authorities believe that "The best cosmetic hand is also the best functional hand". This may well be the case but lack of evidence precludes cosmesis as more than a superficial standard for assessment.

TABLE 2  
LIST OF DAY TO DAY FUNCTIONS

|            |                  |                    |                    |
|------------|------------------|--------------------|--------------------|
| Occupation | Tying shoe laces | Picking up coins   | Holding hair brush |
| Hobbies    | Shaving          | Holding glasses    | Sewing             |
| Driving    | Doing up buttons | Cooking utensils   | Scissors           |
| Eating     | Dressing         | Housework          | Knitting           |
| Writing    | Door handles     | Washing up/laundry |                    |

### Objective

#### General methods

*"The clinical appraisal of the rheumatoid hand is an integral part of its assessment."* (Flatt, 1969)

In the timing of operative treatment the progress of the disease has been usefully divided into three stages (Barron, 1969):—the early stage of "Proliferation", the intermediate stage of "Soft tissue destruction" and the late stage of "Skeletal collapse"—while clinical appraisal of the suitability of operative treatment has been based on specific anatomical structures (Holt, 1969).

Radiological assessment is at least as important as the clinical assessment and the appropriate views are essential (Swanson, 1968; Ansell, 1969). These include anterior, posterior, lateral, oblique, tangential and "ball-catching" views. Lateral views of individual joints as well as the thumb may be necessary. These authors also recommended the use of a selection of photographs to document the state of the hand, but such photographs tell little about function. Photographs must include radial, ulnar, palmar, dorsal and axial views, with the hand both flexed and extended.

#### Measurement

Joint tenderness has been measured using an "Articular index" (Ritchie, 1968) and this measurement has been recommended as one of the best six measurements in rheumatoid arthritis (Hart, 1972). The minimal stimulus needed to produce pain has also been measured, using a cuff dolorimeter (Hawkins, 1966). Neither method has gained widespread acceptance due to the very varied nature of tenderness as a response to painful stimuli.



Measurement of the duration of morning stiffness has been suggested as a "Therapeutic index" (Savage, 1966; Hart, 1972). Also measurement of joint size using gauges and graded sizes of jewellers' rings enjoys some degree of vogue (Savage, 1966; Boardman, 1967; Hart, 1972). A considerable degree of error is admitted in the latter method due to difficulty in finding exactly the same point for each measurement. Moreover, there is no information to prove that the degree of disease is proportional to joint size, except perhaps in the acute proliferative exacerbation. In fact progress through Barron's three stages of the disease may well be accompanied by a reduction in joint size. However, joint size has some value as an index in the measurement of the anti-inflammatory response to salicylate treatment in rheumatoid disease (Boardman, 1967).

Thermography and technesium clearance using the pyroscan and bolometer have been added to the list of methods of assessment (Cosh, 1966) but these have not been widely used.

Measurement of the ability to pinch as demonstrated by picking up coins, screwing lids on jars, and putting pegs in boards, has been graded (Ansell, 1969), and is a step along the road to adequate functional assessment and these simple tests are routine in many centres and occupational therapy departments. Although such tests can be adapted to suit the best needs of the patient, they lack precision, are difficult to quantify, except by measuring the accomplishment time (Greeneid, 1968), and the results vary with the enthusiasm and practice of both patient and therapist.

By far the commonest two objective methods of assessing function in the rheumatoid hand are firstly the measurement of the arc of motion of the joints, and secondly the grip strength of the hand. Most authorities give high priority to the measurement of the range of motion of joints. Savage found this measurement difficult, but stressed that the ability to close the hands was most important to the housewife. Ansell also measured the inability fully to extend the fingers recorded in centimetres, with the hand held flat on the table. Measurement of active and passive arcs of motion has been used in diagnosis and assessment of treatment, in preference to grip strength because the presence of pain and its relief with treatment biased the latter method (Wissinger, 1971). The presence or absence of pain should not preclude grip strength as a measure of improvement since post-operative pain relief is surely as much a success for the operation as relief of flexor lag. The restoration of a functional range of movement has been given first priority in the requirements of successful joint replacement (Flatt, 1969), yet in the assessment of the results of such operative treatment (Flatt, 1967) an average range of metacarpophalangeal joint movement post-operatively of 25% was reported without any pre-operative levels being included for comparison. However in the same report pre- and post-operative pinch strength measurements did demonstrate post-operative improvement. In a more recent report on the results of flexible implant resection arthroplasty (Swanson, 1972), a post-operative range of movement of 66.1 degrees was stated but without any pre-operative values for comparison, despite the necessity of pre-operative comparison levels having been stressed by that author (Swanson, 1968). The pre- and post-operative measurements of the range of motion after prosthetic joint replacement have been reported, in another recent study, and significant improvement was demonstrated (Nicolle, 1972).

Measurement of the strength of grip of the hand (Wright, 1959; Savage, 1966; Swanson, 1968) is probably the only quantitative measure of the function of the hand in common use today. It has undoubted advantages in that it is inexpensive, and simple to operate and can also be used in physiotherapy departments. It may have a use in the assessment of the disease process, at an early stage in its



development, in response to various forms of medical treatment (Boardman, 1967), and is widely used as a therapeutic criterion in hand surgery. However control and reciprocity in results from different centres suffer from the absence of any form of standardisation. In one instance (Ansell, 1969) the bag is to be inflated to 20mm.Hg., while another (Savage, 1966) the bag must be six inches by six inches and inflated to 30mm.Hg., while yet another (Swanson, 1968) the bag must have a diameter of two inches and be inflated to 50mm.Hg. One authority suggests that the bag be squeezed once (Boardman, 1967), while another (Nicolle, 1972) derives the mean of three successive measurements.

It must be borne in mind that to be of any value the pneumatic dynamometer must be squeezed with the whole hand, with the wrist, forearm, elbow and shoulder in a constant position. A period of familiarity between patient and instrument is necessary and at least three readings should be taken so that a mean can be derived. Furthermore measurements should be made at the same time of day (Wright, 1959). Despite all this a coefficient of variation of about 25% at best is obtained. Electrical and mechanical dynamometers (Swanson, 1968) do reduce the error.

### Laboratory

Measurement of Erythrocyte Sedimentation Rate, Haemoglobin Concentration, Rheumatoid factor, the Rose-Waaler and Sheep Cell agglutination tests, and the seventeen hydrocorticosteroids in urine are all used as indices of progress of rheumatoid disease (Savage, 1966; Hart, 1972). While of value to the general rheumatologist such tests are of little assessment value to hand surgeons.

#### CONCEPT OF ASSESSMENT AT THE DIGITAL LEVEL

*"When the hand loses the function of effective pinch, as it may do in rheumatoid disease, then it has lost 80% of its value." (Arden, 1970)*

The fact that the hand comprises amongst other things four fingers and a thumb seems to have escaped the attention of most workers in this field. Because only one digit may be operated upon or indeed, affected by disease, the concept of the measurement of individual digital function becomes a necessity. Measurement of grip strength, a measure of the function of the hand as one integrated unit, is not valid due to the asymmetry in the manner in which the disease process strikes the units of the hand and in the programme of surgical treatment. Table 3 shows the distribution among the digits of the operations performed on the hand for rheumatoid disease at the Hammersmith Hospital over the past year. The thumb was involved in thirteen operations, the index finger thirty-six, the middle finger thirty-eight, the ring finger thirty-nine, and the little finger twenty-four. However, one digit was operated on forty-six times, two digits eighteen times, three digits eight times, and four digits eleven times. From this table it can therefore be seen that it is more than three times commoner for two or less digits to be operated upon at one time. To assess the function in these hands adequately at the digital level a new instrument was developed.

TABLE 3  
ANALYSIS OF OPERATIONS ON RHEUMATOID HANDS PERFORMED AT  
HAMMERSMITH HOSPITAL IN ONE YEAR (1971-1972)

|                                 |             |             |              |            |              |
|---------------------------------|-------------|-------------|--------------|------------|--------------|
| No. of operations on each digit | Thumb<br>13 | Index<br>36 | Middle<br>38 | Ring<br>39 | Little<br>24 |
| No. of digits at each operation | 1<br>46     | 2<br>18     | 3<br>8       | 4<br>11    | 5<br>0       |

### THE CYBERNOMETER

This instrument measures the force of flexion of a digit and its force of pinch. Details of its design, method of assessment, assessment of normal hand function, and examples of the functional improvement in the rheumatoid hand following surgery have already been described (Dickson and Calnan, 1972 (a) and (b)). While it is recognised that better dexterity exists in the dominant hand, it has not been shown that the individual digital forces of the dominant hand are significantly stronger than their non-dominant counterparts. Obviously this may well be a causative factor for the preponderance of disease in the joints of the dominant hand. The index and middle fingers are significantly stronger than the ring and little fingers and this fact supports the concept of Capener (1956) that the thumb, index and middle fingers form a dynamic tripod of prehension.

Fig. 1 shows the instrument in use measuring the force of flexion of a digit. Measurement of this force has proved particularly valuable in the assessment of digital disease. Table 4 shows the result following synovectomy of the flexor tendons in the palm of a patient with rheumatoid disease. Only the flexor tendons of the middle and ring fingers were involved in the proliferative synovitis and these digits show an increase in flexion force of 71% and 48% respectively only three months after surgery. The index and little fingers although not operated upon, show slight increases in force presumably due to the improvement in overall hand function which synovectomy has provided.

Fig. 2 shows measurement of the pinch force of a digit. In addition to the obvious value of precise measurement of this most important hand function the degree of disability in the thumb in rheumatoid disease and its improvement after surgery can be readily quantified by measurement of pinch force. Table 5 shows

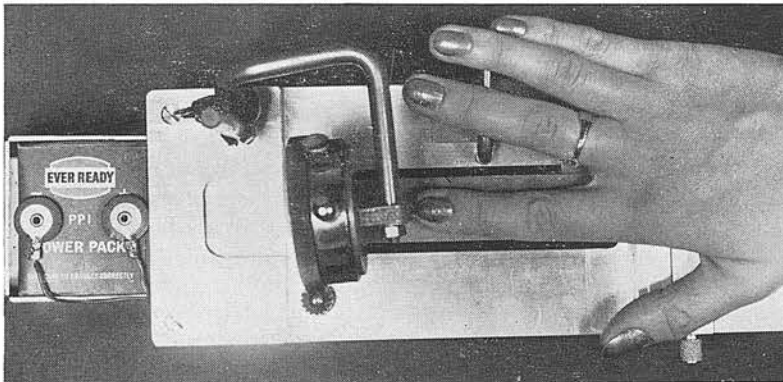


Fig. 1 The cybernometer in use measuring the force of finger flexion.

TABLE 4  
DIGITAL FLEXION FORCES BEFORE AND THREE MONTHS AFTER  
LONG FLEXOR TENDON SYNOVECTOMY

| Digit   | Index | Middle | Ring | Little |
|---------|-------|--------|------|--------|
| Preop.  | 3.2   | 2.1    | 2.3  | 3.0    |
| Postop. | 3.5   | 3.6    | 3.4  | 3.2    |

(Units are Kg. force)

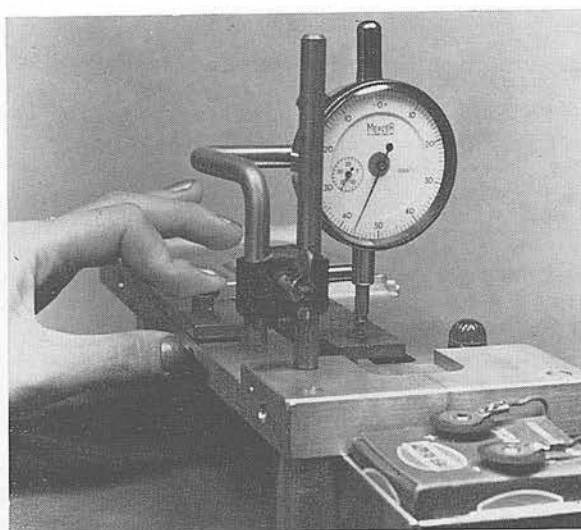


Fig. 2 The cybernometer in use measuring the force of pinch—reproduced by kind permission of the Editor, Biomedical Engineering.

TABLE 5  
DIGITAL PINCH FORCES BEFORE AND THREE MONTHS AFTER FUSION  
OF THE METACARPOPHALANGEAL JOINT OF THE THUMB

| Digit   | Index | Middle | Ring | Little |
|---------|-------|--------|------|--------|
| Preop.  | 4.0   | 4.5    | 3.7  | 2.9    |
| Postop. | 6.1   | 6.0    | 5.7  | 4.1    |

(Units are Kg. force)

the result following fusion of the metacarpophalangeal joint of the thumb of a patient with rheumatoid disease. Pre-operatively the thumb is unable to provide a sufficiently firm pillar against which the pulps of the digits can pinch. Three months after fusion of the thumb there is a 50% improvement in function.

Objective assessment at the digital level has demonstrated significant improvement in individual finger function six months after metacarpophalangeal joint synovectomy or prosthetic joint replacement (Calnan-Nicolle prosthesis) (Dickson, 1972 (b)). However we have now been able to show that improvement occurs much earlier than generally recognised. Table 6 is an example of such a functional improvement. All four metacarpophalangeal joints were replaced and all four digits show an increase in pinch force after only six weeks.

TABLE 6  
DIGITAL PINCH FORCES BEFORE AND SIX WEEKS AFTER PROSTHETIC  
JOINT REPLACEMENT (CALNAN-NICOLLE PROSTHESIS)

| Digit   | Index | Middle | Ring | Little |
|---------|-------|--------|------|--------|
| Preop.  | 1.2   | 1.4    | 1.1  | 0.9    |
| Postop. | 1.5   | 1.5    | 1.25 | 1.05   |

(All four metacarpophalangeal joints were replaced)  
(Units are Kg. force)

A clinical trial of the efficacy of the cybernometer versus the dynamometer in the assessment of hand function has already been performed (Dickson, 1972 (c)). A total of thirty-two rheumatoid hands were analysed using both instruments. It was concluded that the cybernometer could highlight a weakness in a hand not revealed by grip strength measurement alone and specify the offending digit. Furthermore simultaneous radiological examination confirmed this observation by showing joint disease in that digit, confirming the superiority of measurement at digital level.

### CONCLUSION

Until now the assessment of hand function has been based largely on speculation and hypothesis. Objective measurement of function at the digital level is essential for the proper assessment of hand function and will be to the greater benefit of both patient and surgeon.

### SUMMARY

Little is yet known about function, disease, and the efficacy of surgery in the rheumatoid hand. Subjective assessment methods have been reviewed but found to lack definition and precision and are difficult to quantify. The concept of the objective assessment of hand function at the digital level is emphasised and the value of cybernometer\* measurements before and after corrective hand surgery is clearly demonstrated. Only by measuring the forces of the individual digits can the function of the hand be shown to improve in a quantitative fashion to the greater benefit of both patient and surgeon.

Parts 2 and 3 of this study will be published in subsequent issues of *The Hand*.

\*The cybernometer is not yet commercially available but a limited number can be supplied at cost by the authors.

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There has been no method for the accurate assessment of the flexion and grip forces of individual fingers, yet many surgical operations are carried out to improve these functions. This paper describes a new, simple device which does measure these forces. It has been used to provide an objective assessment of improvement in finger forces in the hands of rheumatoid patients undergoing synovectomy or the substitution of artificial finger joints.

# A Device for Measuring the Force of the Digits of the Hand

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THE TWO MAIN functions of the hand are grip and pinch. The latter is the more important. In 1959 Wright<sup>1</sup> described a method for measuring grip force using a pneumatic dynamometer. This is in fact a partially inflated bag attached to a sphygmomanometer, such as is used for recording blood pressure. The hand grips the bag and squeezes it so that the height of the column of mercury displaced may be read from the millimetre scale. The mean of three successive readings is recorded as the mean grip strength of that hand.

However, grip is a relatively crude function and it is the force of pinch which makes the human hand so useful. Indeed Arden, Harrison and Ansell<sup>2</sup> stated that when the hand loses the function of effective pinch, as it may do in rheumatoid arthritis, it has lost 80% of its value.

There is no method for the accurate assessment of individual finger flexion force nor for the assessment of that of pinch, yet many surgical operations are carried out specifically to improve such functions. The present paper describes a new and simple device, the "digital cybernometer", to measure just these forces. Examples of the use of the device to assess improvement following surgery of the hand are given in the appendix.

## The apparatus

The cybernometer (Fig. 1) comprises a base of aluminium (A) which secures a cantilever of mild steel (B) fixed at its origin only. The cantilever is perforated centrally every one centimetre of its length, by small holes which house the central pin of a small brass button (C). The most proximal perforation is at the origin and this accommodates a small brass switch (D) operating a red light (E)

from batteries (F). In addition, the cantilever has a small lateral projection (G) similarly perforated, and the aluminium base is grooved vertically beneath it. The aluminium base also secures a measuring clock (height gauge) (H) whose recording arm (I) rests upon the distal free end of the cantilever. A swivel arm (J) protects the lateral projection from the other digits when the one under test presses the cantilever.

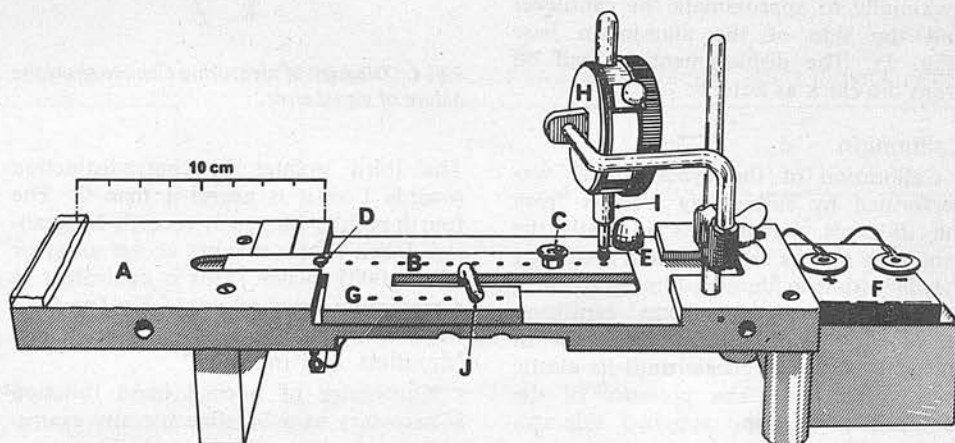


Fig. 1. The digital cybernometer, side view. For explanation see text.



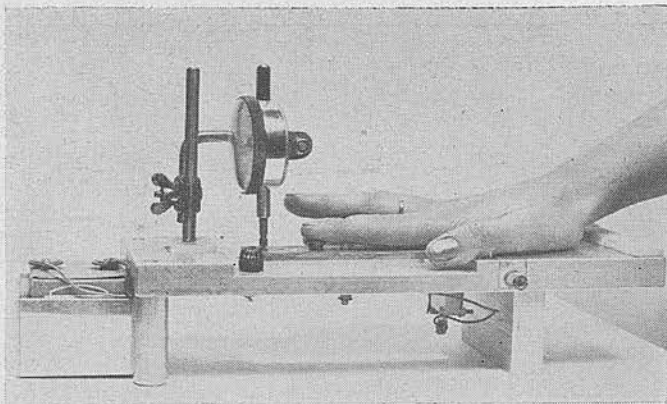


Fig. 2. The digital cybernometer in use measuring the force of finger flexion.

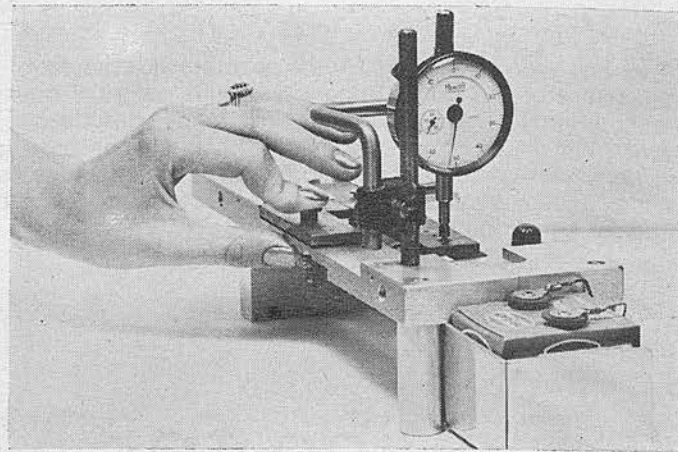


Fig. 3. The digital cybernometer in use measuring the force of pinch.

### The apparatus in use

In order to determine the force of flexion of a digit, the palm of the hand rests upon the aluminium base, the metacarpal head rests upon the light switch at the origin of the cantilever, and the pulp of the finger rests in the small brass button which has been seated in one of the perforations of the cantilever, according to the length of the finger (Fig. 2). Maximal force is then applied to the cantilever by the finger tip of the subject while the metacarpal head depresses the light switch. Any undue flexion occurring at the metacarpal-phalangeal joint will then become readily apparent to the observer, the light going out at once. The displacement of the cantilever is then read off from the measuring clock.

In order to determine the force of pinch, the brass button is inserted into one of the perforations on the cantilever's lateral projection, the pulp of the digit is placed in the depression of the button and the thumb in the groove vertically beneath it. The subject then attempts maximally to approximate the cantilever and the side of the aluminium base (Fig. 3). The displacement is read off from the clock as before.

### Calibration

Calibration of the cybernometer was performed by suspending weights from the different perforations in both the cantilever and its side-arm, and recording the deflection in thousandths of an inch. The simply-loaded uniform cantilever behaves according to Hooke's Law in that it is perfectly elastic until its elastic limit is reached. The presence of the perforations and the attached side-arm renders the cantilever theoretically non-uniform. However, the calibration graphs for both cantilever and side-arm are straight lines, weight being directly pro-

portional to deflection, and therefore for practical purposes the cantilever remains uniform and Hookean.

### Error

The only error in the system is that associated with the measuring clock. Considering the various positions of the pointer in Fig. 4, the first pointer obviously records 0. Accepting recordings in whole numbers only, the second pointer also records 0 in that it is nearer 0 than 1.

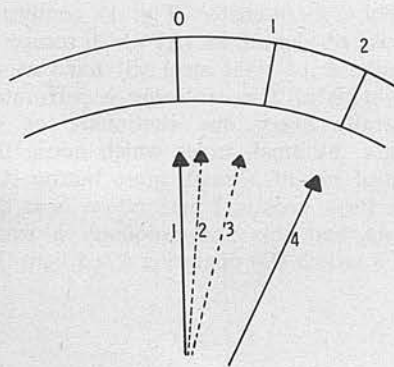


Fig. 4. Diagram of measuring clock to show the nature of visual error.

The third pointer in contradistinction records 1 as it is nearer 1 than 0. The fourth pointer obviously records 2. Readings taken in this manner accept an error of  $\pm 0.0005$  inches. This is equivalent to a maximum error of  $\pm 0.15$  Kg force\*.

### Materials and method

Knowledge of normal hand function is necessary as a baseline for any examination of the pathological. Therefore, using the calibrated cybernometer in con-

\*1 Kg force is equivalent to 9.804 Newtons

junction with the pneumatic dynamometer mentioned earlier, the answers to five basic questions about hand function were sought.

1. Is there a difference between the strengths of the fingers of a single hand?
2. Is there a difference between the strengths of the fingers of the dominant and non-dominant hands?
3. Is there a biological day-to-day variation in strength?
4. Is there a difference in strength during the course of a single day?
5. Finally, is there any correlation among flexion force, pinch force and grip strength?

Twenty healthy adult males, between the ages of 20 and 45, volunteered to have their hand function assessed in this manner.

The experiment was conducted in three parts. In experiment 1, three recordings of flexion force and three of pinch force for all the fingers, and three recordings of the grip strength of each hand, were made in random order at one sitting. In experiment 2, similar readings were taken, but at the same time on three separate days. In experiment 3, flexion force and pinch force of the index of both hands and the grip strength of each hand, three recordings of each, were measured hourly during the course of a working day.

A two-way analysis of variance with replication was then performed on the data obtained.

### Results and discussion

In this group the mean digital flexion force of the index finger (digit 2) was 4.6 Kg weight, the middle finger 4.4, ring finger 3.2 and the little finger 2.8 Kg weight, for the dominant hand. The forces for the non-dominant hand were

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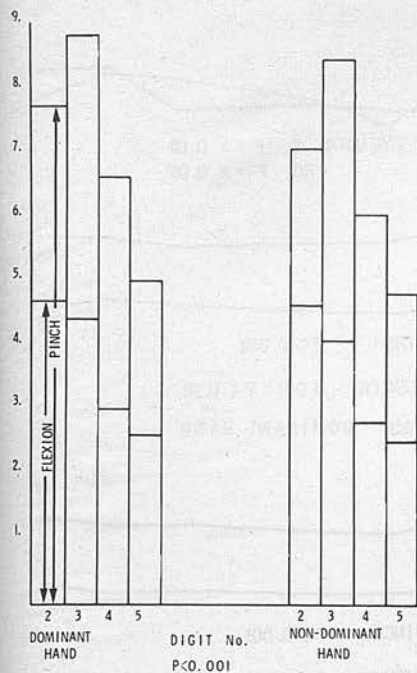


Fig. 5. Histogram to show mean force of flexion and pinch of the digits of each hand.

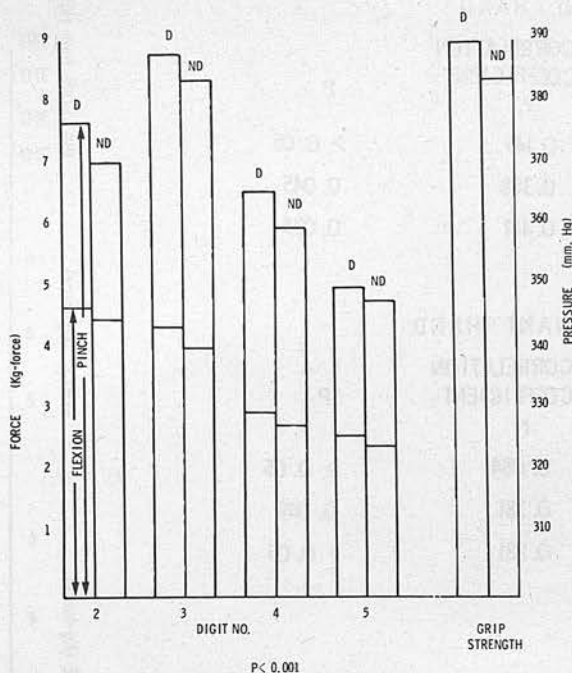


Fig. 6. Histogram to show the difference in forces between dominant (D) and non-dominant (ND) digits.

less. Pinch force was almost twice as great as flexion force for each finger.

Experiment 1

For force of flexion a significant difference at the 0.1% level of significance between the fingers was noted for both the dominant and the non-dominant hands; the index and middle fingers were stronger than the ring and little fingers (Fig. 5). This latter observation lends support to Capener's view<sup>3</sup> that the thumb, index and middle fingers form a dynamic tripod of prehension.

A significant difference between the fingers of both hands at the 0.1% significance level was also observed in pinch

force. The fingers of the dominant hand (D) were significantly stronger at the 0.1% level than those of the non-dominant hand (ND), in terms of flexion force and pinch force (Fig. 6).

The difference between the pressures of grip of the hands was significant at the 0.1% level, the dominant hand again being stronger than the non-dominant hand.

In the dominant hand, the correlation coefficients between grip strength and pinch force and between pinch force and flexion force were significant ( $P=0.045$  and  $0.035$ , respectively), but that between grip strength and flexion force was not significant ( $P>0.05$ ) (Fig. 7). In the non-

dominant hand the correlation coefficient between grip strength and pinch force was significant ( $P=0.049$ ), but not between pinch force and flexion force ( $P>0.005$ ).

Experiment 2

A significant difference at the 1% significance level was observed in the residual variation between experiments 1 and 2, indicating that the day-to-day variation was greater than the variation occurring at one sitting.

Experiment 3

A significant change at the 0.1% level in flexion force and pinch force of both hands was observed during the course of

TABLE 1: Flexion and pinch forces—synovectomy

| DIGIT                    |         | 2   | 3   | 4   | 5   |
|--------------------------|---------|-----|-----|-----|-----|
| Flexion force (Kg force) | Preop.  | 4.0 | 4.8 | 5.7 | 5.1 |
|                          | Postop. | 6.2 | 6.5 | 6.1 | 5.5 |
| Pinch force (Kg force)   | Preop.  | 6.1 | 6.9 | 8.0 | 7.2 |
|                          | Postop. | 8.1 | 9.3 | 8.5 | 7.9 |

Table 1. Digital forces of a patient before and six months after synovectomy. Only the second and third digits were operated on.

TABLE 2: Flexion and pinch forces—joint replacement

| DIGIT                    |         | 2    | 3    | 4    | 5   |
|--------------------------|---------|------|------|------|-----|
| Flexion force (Kg force) | Preop.  | 1.7  | 1.4  | 1.0  | 0.7 |
|                          | Postop. | 2.2  | 1.7  | 1.35 | 1.0 |
| Pinch force (Kg force)   | Preop.  | 4.85 | 3.1  | 0    | 0   |
|                          | Postop. | 5.2  | 3.45 | 1.15 | 0.9 |

Table 2. Digital forces in a patient before and six months after joint replacement. The metacarpophalangeal joints of all four fingers were replaced

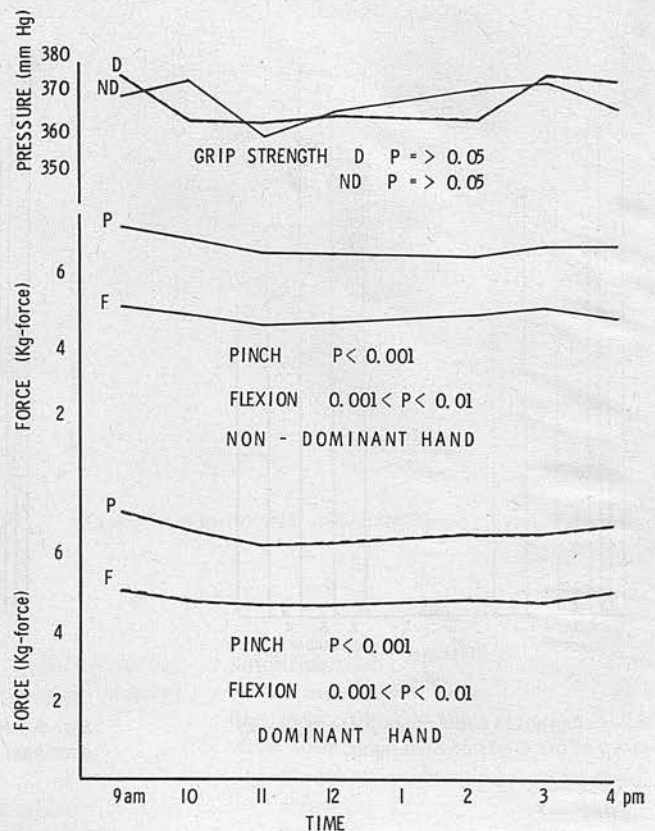


| DOMINANT HAND           |                               |        |
|-------------------------|-------------------------------|--------|
| VARIABLES               | CORRELATION COEFFICIENT<br>r. | P      |
| Grip strength : Flexion | 0.145                         | > 0.05 |
| Grip strength : Pinch   | 0.388                         | 0.045  |
| Pinch : Flexion         | 0.414                         | 0.035  |

| NON-DOMINANT HAND       |                               |        |
|-------------------------|-------------------------------|--------|
| VARIABLES               | CORRELATION COEFFICIENT<br>r. | P      |
| Grip strength : Flexion | 0.084                         | > 0.05 |
| Grip strength : Pinch   | 0.381                         | 0.049  |
| Pinch : Flexion         | 0.281                         | > 0.05 |

Fig. 7 (above). Table to show correlation among grip strength, flexion and pinch.

Fig. 8 (right). Graph to show variation in grip strength, flexion force and pinch during a working day.



a working day, but no significant change ( $P > 0.05$ ) was observed in grip strength (Fig. 8). The latter observation on grip strength confirms the work by Wright<sup>1</sup>, who showed that the period from 9 a.m. to 4 p.m. forms the substantial part of a plateau in the diurnal variation of grip strength.

#### Summary and conclusions

Wright<sup>4</sup> has pointed out the continuing need for quantitative assessment of the hand in the rheumatoid patient, and has devised instruments for this purpose.

Likewise, in hand surgery a knowledge of finger function in terms of absolute units of force is necessary. The digital cybernometer is thus presented as a light, portable, reliable and accurate device for assessing individual finger function, which is also simple to calibrate and to operate.

A statistical analysis has been performed on the results of experiments to assess individual finger function using the cybernometer, and the following inferences may be drawn: there is a significant difference between the strengths of the different fingers of a normal hand. The force of pinch is greater than the force of flexion of a digit. The fingers of the dominant hand are stronger than their non-dominant counterparts. A day-

to-day variation in hand function exists and also some variation in the course of a single day. Finally, there is some degree of correlation among the individual hand functions—grip, pinch and flexion.

#### Appendix: The Rheumatoid Patient

The joint most frequently operated upon in the rheumatoid hand is the metacarpophalangeal joint, and the most common operations are synovectomy (removal of the diseased lining of the joint) and joint replacement (removal of the diseased joint and its replacement by a synthetic substitute).

So far, thirty patients have been assessed before and 6 months after these operations using the cybernometer. In every case a significant increase in digital forces was measured. Typical of the improvement seen following synovectomy is the patient whose results are shown in Table 1. Here only the 2nd and 3rd digits were operated upon and there has been an increase of up to 50% in flexion and pinch forces. The 4th and 5th digits, while not actually operated upon, exhibit a slight increase in forces due to the overall improvement of hand function provided by the operation.

Table 2 shows the results obtained with one patient following joint replace-

ment. Here all four digits have had their metacarpophalangeal joints replaced and all four digits show considerable improvement six months post-operatively. In particular, the 4th and 5th digits now have a sizeable pinch force, whereas before the operation the patient was unable to pinch at all.

The cybernometer has thus provided unique information in the assessment of the rheumatoid hand—objective evidence that hand function improves following corrective hand surgery.

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