

A HAND GRIP DYNOGRAPH AND WEIGHING MACHINE : TWIN APPLICATION OF A SIMPLE PRINCIPLE*

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Summary: A hand grip dynograph and weighing machine have been developed by applying the relationship 'force/area=pressure'. Force is applied to a relatively constant area provided by the partially inflated bladder taken from the compression cuff of a sphygmomanometer. Under such circumstances, the rise in pressure is proportional to the force applied, and after calibration, the pressure reading can be used to deduce the force. Thus the force, be it in the form of hand grip strength, or in the form of body weight, can be measured.

The maximum isometric hand grip tension measured by the reported device and a standard instrument are well correlated ($r = 0.86$). The relative load isometric endurance tests performed on the two instruments do not compare favourably ($r = 0.23$). The estimations of body weight performed on the device described here and a standard machine are very closely related ($r = 0.98$).

The devices are simple, sturdy and inexpensive. Their applications are discussed.

Key words: new technique
force area pressure relationship
simple weighing machine
sphygmomanometer
hand grip dynograph
isometric tension

INTRODUCTION

The present report describes two inexpensive devices built from wood, but which may also be made from any other suitable material. Used in conjunction with a sphygmomanometer, they are capable of measuring hand grip tension and body weight respectively. The former is a parameter which finds frequent application in work physiology; the latter is an important parameter with wide ranging applications in medical research as well as practice.

OPERATING PRINCIPLE

The devices are based on the simple physical relationship between force and pressure, viz force/area = pressure. If area is constant, pressure is directly proportional to the force.

A relatively constant area has been provided by a partially inflated leakproof flat rubber bladder taken from the compression cuff of a sphygmomanometer. Force is applied

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by the hand grip or the weight of the individual. The rise in pressure is noted on a mercury manometer. If the instrument has been previously calibrated, the rise in pressure can be used to find the force which was instrumental in producing it.

DESCRIPTION

1. *Handgrip dynograph :*

The device basically consists of two rectangular slabs of wood between which a bladder taken from sphygmomanometer cuff can be placed (Fig. 1). The upper slab can move up and down along a fixed track so that the distance between the two slabs can be altered. There is an arrangement for bringing the two slabs closer to each other by hand grip force. Whenever an attempt is made to bring the two slabs closer, the bladder placed between them gets compressed. The rise in pressure within the bladder is transmitted to the mercury manometer. The mercury manometer may be equipped with a float to which a writing device may be fixed for getting a kymographic record.

2. *Weighing machine :*

Though based on the same principle as the dynograph, its construction has to be adapted to its application (Fig. 2). The arrangement for obtaining a written record may be eliminated; therefore, the wooden device together with an ordinary sphygmomanometer can serve the purpose.

OPERATION

1. *Hand grip dynograph :*

The cloth covering the compression cuff may be removed to expose the rubber bladder. Inflate it partly with air by pumping the inflation bulb-5-6 times vigorously. Besides the number of times the bulb is pumped, the quantity of air pumped in may be roughly estimated also from the distance by which the two slabs get separated. Because of the tilt produced in the upper slab by the convexity of the inflated bladder, the extent of separation may not be the same at all the four corners of the device. Therefore, a scale may be fixed at each corner, and the average of the four distances may be taken. The degree of inflation deserves consideration because it affects the calibration. It is convenient and desirable to keep the inflation constant from day to day at an optimal level. Though inflation bulbs are provided with air release valves, it is safer to clamp the rubber tube to prevent escape of air from the bladder.

Alternatively, the bladder and the tubes connecting it to the manometer may be filled with water. All air is squeezed out of the bladder. The inflation bulb is submerged under water in a graduated 1000 ml beaker, and is pumped in that position. It starts

sucking water from the beaker and pushes it into the bag and the associated system of tubes and manometer. Expel all air from the system via the side tube in the manometer. Any water that is also expelled in the process should be collected in a small beaker and returned to the graduated beaker. After all the air has been expelled, clamp the side tube, and fill some more water into the bag. As in case of air, it is safer to clamp the rubber tube to prevent escape of water from the bag. The level of water left behind in the 1000 ml beaker tells the quantity of water filling the system. The water found suitable for operating the instrument usually fills the system at subatmospheric pressure. Regardless of how much this pressure is, it provides the reference level for the rise in pressure produced by the application of force to the device.

Place the rubber bladder at the appropriate position in the device if it was not done before filling the system.

Calibrate the device by placing over it, serially, weights ranging from 0-50 kg at a regular interval in ascending order. Note the pressure corresponding to each weight. Start reducing the weights in the same sequence and note the pressures. The mean of the two readings corresponding to each weight may be taken as the reading corresponding to the weight. The relationship may be plotted graphically (Fig. 3 b and c).

Set up the arrangement for obtaining a written record of the manometric readings. Let the subject apply the force of his hand grip to it while the kymograph is moving at slow speed (Fig. 1-d; and Fig. 3-a). Three precautions are important to get accurate readings :—

(i) If the device is lying on the table while the force is being applied, there is tendency to lean over the instrument. This leads to a part of the body weight being added to the force of the hand grip, thereby giving a false high reading. It has been found that the best way to eliminate this error is to ask the subject to lift up the device and then apply the force.

(ii) The force should be applied by placing the hand around the central 'shaved' portion on the rods c and d (Fig. 1). The farther away from the centre is the force applied, less is the rise in pressure registered.

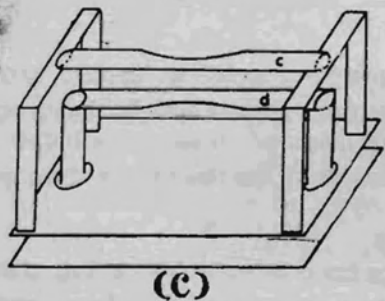
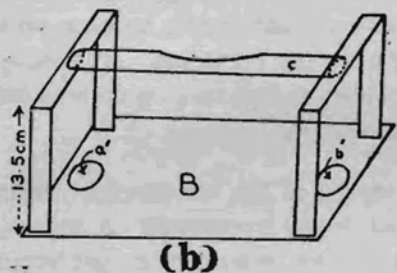
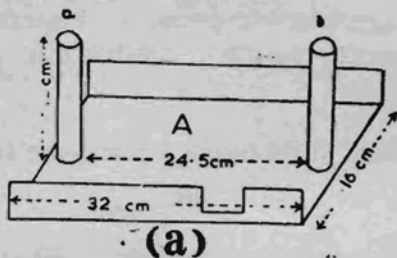
(iii) The technique of applying force is important. Let the force mount to the maximum level at a steady rate. Some rehearsal helps in learning the proper technique. Jerky application gives a false high reading, particularly if the bladder has been filled with air.

Two types of measurements may be made using the instrument (3).

(i) *Maximum isometric hand grip tension :*

Let the subject take two readings at one minute interval. The higher reading of the two gives the maximum tension.

Alternatively, let the subject take three readings with one minute interval between consecutive readings. The mean of the two greatest (4) or the two closest readings (6) gives the maximum tension.



(d)

Fig. 1: HAND GRIP DYNAMOGRAPH (a)-(c). Schematic diagrams showing the assembly.

- (a): Slab A, with a boundary along the long sides to hold the rubber bladder and two cylindrical rods a and b, fixed perpendicular to it.
- (b): Slab B, with holes a' and b' corresponding to the rods a and b in slab A.
- (c): Slab B has been slipped over slab A. A cylindrical rod d connecting a and b has been fixed. So long as this rod is there, slab B can slide up and down, but cannot be completely detached from slab A. Rods c and d have been shaved a little in the middle to make the palmar grasp comfortable. Hand grip pressure is applied around the region in an attempt to bring c and d closer. As a result, a bladder placed between A and B gets compressed. The boundaries on slab A which restrain the bladder have been omitted in the interest of clarity.

The measurements indicated are suitable for the bladder usually supplied with a sphygmomanometer for adults. When slabs A and B are in contact, rods c and d also just touch each other.

- (d): Finished device in operation.

(ii) *Relative load isometric endurance test :*

Calculate 60, 70 or 80% of the maximum hand grip tension of which the subject is capable. Let the subject maintain the calculated tension with a fluctuation of less than $\pm 2\%$ (5) for the maximum duration he is capable of. The duration gives the endurance time. The subject should be exhorted to continue the effort to the point of absolute and should be told the importance of maintaining steady tension. It is helpful if an interrupted horizontal line is drawn before hand on the recording paper to indicate to the subject the level at which he has to maintain the tension. The length of this line should be considerably longer than the expected endurance time, because it has been seen that the subject often terminates the effort at the end of the line. By the same token, a long line is an incentive for maximal endurance.

2. *Weighing machine :*

Place the compression cuff of a sphygmomanometer at the appropriate place in the device. Inflate it to an optimum extent with air. Calibrate it in the range of 0-80 kg in the same way as described for the dynograph (Fig. 4). The calibration curve may be converted into a table for ready reference (Table I). Let the individual to be weighed

TABLE I: Ready Reckoner for the Weighing Machine.

| Pressure (mmHg) | Weight (kg) | Pressure (mmHg) | Weight (kg) |
|--------------------|----------------|--------------------|----------------|
| 5 | 1.4 | 120 | 37.6 |
| 10 | 2.7 | 125 | 39.5 |
| 15 | 4.1 | 130 | 41.3 |
| 20 | 5.4 | 135 | 43.5 |
| 25 | 6.8 | 140 | 45.4 |
| 30 | 8.2 | 145 | 47.2 |
| 35 | 9.5 | 150 | 49.0 |
| 40 | 11.3 | 155 | 50.8 |
| 45 | 12.7 | 160 | 52.6 |
| 50 | 14.5 | 165 | 54.9 |
| 55 | 15.9 | 170 | 56.7 |
| 60 | 17.7 | 175 | 59.0 |
| 65 | 19.5 | 180 | 60.8 |
| 70 | 20.9 | 185 | 62.6 |
| 75 | 22.7 | 190 | 65.3 |
| 80 | 24.5 | 195 | 67.1 |
| 85 | 25.9 | 200 | 69.4 |
| 90 | 27.7 | 205 | 71.8 |
| 95 | 29.5 | 210 | 74.4 |
| 100 | 30.8 | 215 | 76.7 |
| 105 | 32.7 | 220 | 79.4 |
| 110 | 34.5 | 225 | 81.7 |
| 115 | 36.3 | | |

stand on the device (Fig. 2). Considerable fluctuation in the manometric reading would be noticed while the subject tries to balance himself on a somewhat unstable surface. Note the highest reading achieved. Deduce the weight of the individual using the calibration.

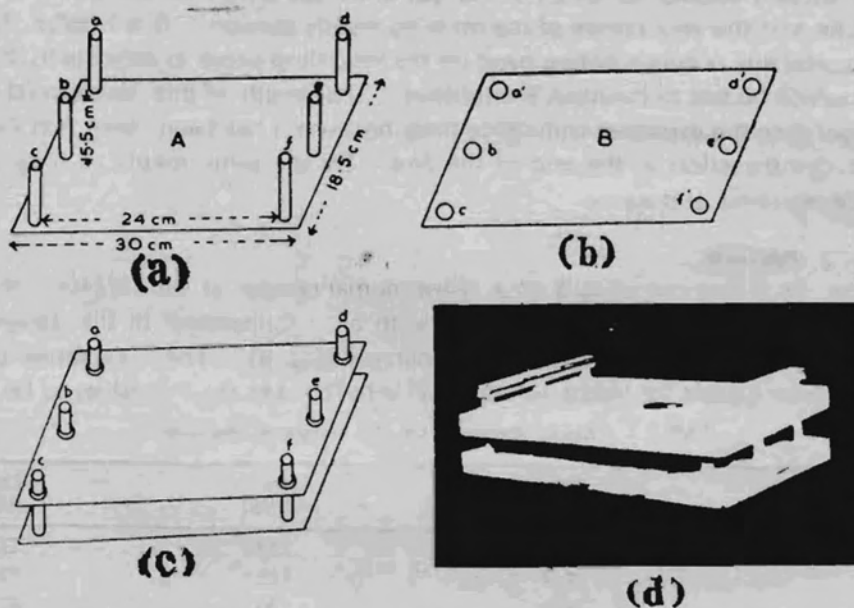


Fig. 2: WEIGHING MACHINE. (a)-(c) Schematic diagrams showing the assembly.

(a): Slab A, with six cylindrical rods, a-f, fixed perpendicular to it.

(b): Slab B with six holes, a'-f', corresponding to the rods a-f in slab A.

(c): Slab B has been slipped over slab A. After slipping it, two additional rods may be fixed—one connecting, a, b and c; and another connecting, d, e and f. These rods, seen in the photograph (d), have been omitted here in the interest of clarity. They provide much needed stability to rods a-f and also reduce the device to one unit. If an individual stands on slab B, a bladder placed between A and B gets compressed.

The measurements indicated are suitable for the bladder usually supplied with a sphygmomanometer for adults.

(d): Finished device.

PERFORMANCE

1. Handgrip dynamograph :

(i) *Force-pressure relationship* : The calibration curves (Fig. 3) show that the relationship is nearly linear. How degree of inflation affects the curve, and pros and cons of using air or water, are discussed later. In the assembly tested, it was found that the most dependable curve was obtained when the system was filled with 250 ml water.

(ii) *Correlation* : The instrument reported here was compared with a hand grip dynamometer (Jetter and Scheerer, Germany). Fortysix observations were made on

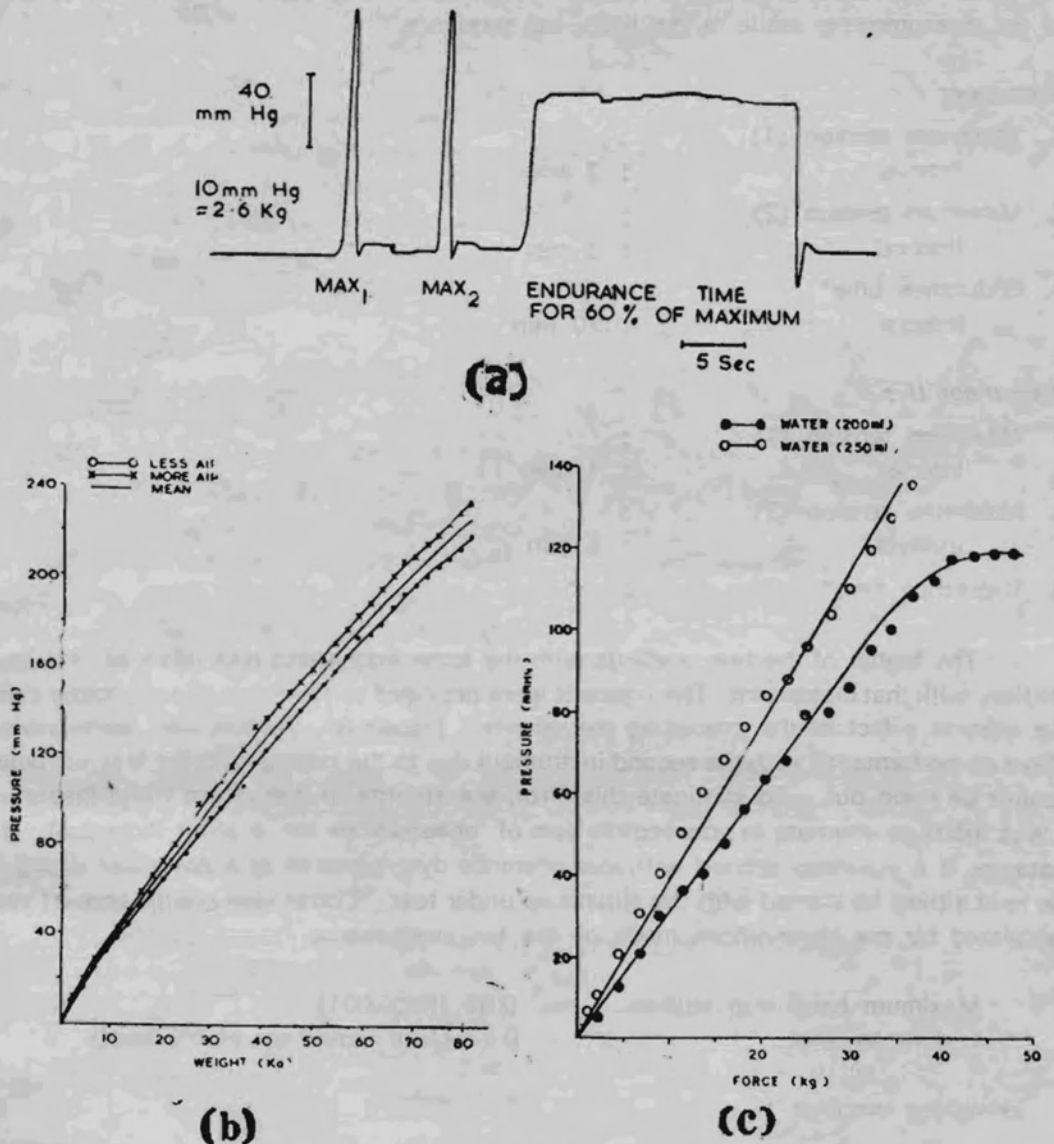


Fig. 3 : (a) : A sample record taken with handgrip dynamograph.
(b) and (c) : Calibration curves of handgrip dynamograph. Using them, a pressure reading may be used to deduce the force acting on the device.
(b). Bladder filled with air. The distances '1.3cm' and '2.2 cm' indicate the degree of separation of the two slabs continuing the device, and are related to the degree of inflation of the bladder.
(c) : Bladder filled with water. The volumes '220 ml' and '250 ml' indicate the amount of water filling the bladder and the associated tubes.
The points plotted do not correspond to whole numbers on the 'force' scale because the weights used were in pounds, while the scale has been expressed in kilograms.

11 volunteers. Five volunteers supplied 6 sets of observations each, the rest could not complete the series and therefore, provided fewer sets. One set of observations consisted of six measurements made in the following sequence.

Instrument I :

- | | | |
|------------------------|---|--------|
| 1. Maximum tension (1) | : | |
| Interval | : | 1 min |
| 2. Maximum tension (2) | : | |
| Interval | : | 5 min |
| 3. Endurance time* | : | |
| Interval | : | 10 min |

Instrument II :

- | | | |
|------------------------|---|-------|
| 4. Maximum tension (1) | : | |
| Interval | : | 1 min |
| 5. Maximum tension (2) | : | |
| Interval | : | 5 min |
| 6. Endurance time* | : | |

The higher of the two readings with the same instrument was taken as maximum tension with that instrument. The intervals were provided to minimise to a negligible extent the adverse effect of the preceding manoeuvre. In spite of the intervals, some adverse effect on performance with the second instrument due to the testing with the first instrument cannot be ruled out. To eliminate this error, the identity of instrument I and instrument II was made to alternate in consecutive sets of observations on a given individual. For instance, if a volunteer started with the reference dynamometer at a particular sitting, at the next sitting he started with the substitute under test. Correlation coefficients (r) were calculated for the observations made on the two instruments.

Maximum hand grip tension $r = 0.86$ ($P < 0.001$)

Endurance time $r = 0.23$ (Not significant at 5% level)

2. *Weighing machine :*

(i) *Calibration :* The calibration curves were found to be nearly linear as in the case of the dynamograph (Fig. 4).

* Endurance time was measured for 80% of the maximum tension in case of the reference instrument. But it was found that 80% of the maximum tension could be maintained with the substitute under test only for such short periods of time that the readings were unreliable. Therefore the fraction was lowered to 60% in case of the substitute.

(ii) *Correlation* : The fabrication reported here was compared with a standard weighing machine (Avery, India). Fifty individuals ranging from 37.6 to 78.6 kg in weight were weighed using both the devices and the correlation determined. The correlation coefficient (r) was found to be 0.98 ($P < 0.001$).

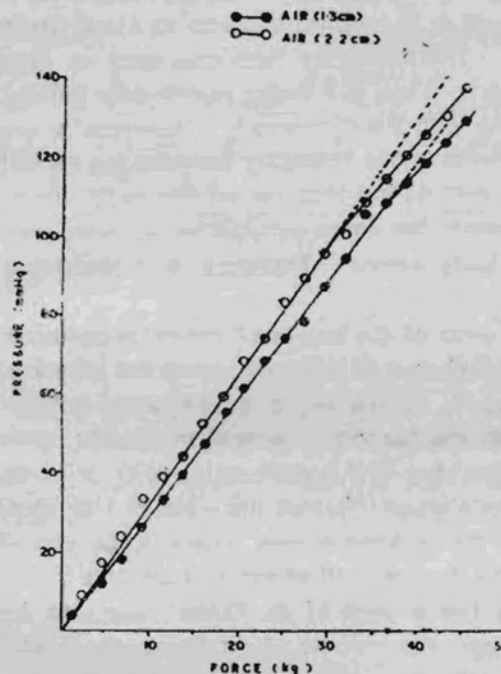


Fig. 4 : Calibration curves of weighing machine with two different quantities of air filling the bladder. Since the gap between the two curves is narrow, a line indicating the mean of the two has been drawn. The mean line was used to construct Table 1. This compromise is preferable to any pretence to being precise because of the difficulty associated with accurate quantification of air filling the bladder.

DISCUSSION

The principle on which the devices reported here are based was thought of only after the first version of the first device had been fabricated. That the underlying principle really is 'force/area = pressure' was verified by the simple expedient of folding the bladder to half its area. On doing so, it was found that the rise in pressure produced by a given force was double that produced by it before the bladder was folded. This also suggests that if the weighing machine has to be used for infants and children, a smaller rubber bladder taken from a paediatric sphygmomanometer might provide better sensitivity. Further, for weighing infants, a concave platform may be fixed to the

The rubber bladder may be filled with air or water. Air is more convenient to fill, but its quantity pumped in cannot be accurately quantified easily. The most serious disadvantage of using air is that when handgrip force is applied, the manometric reading shows repeated oscillations before settling at the final level. Therefore, when maximal pressure has to be measured by applying a single brief push, false high readings are obtained. On the other hand, though water is a little messy to handle, its volume can be accurately quantified easily. Moreover, a water filled bag acts as a well loaded system with a suitably low frequency response. Therefore, the response even to single brief applications of force is not very oscillatory, while still being reasonably faithful. Therefore, water was found more suitable for use with the dynograph. However, in case of the weighing machine, damping of the response is not necessary because the individual stands on the appliance for at least 15 sec and during that period the oscillations subside. Moreover, in clinical practice or field work, the same sphygmomanometer may be used for measuring blood pressure as well as body weight. Therefore, air is preferable for the purpose.

The degree of inflation of the bag is of critical importance. Because of its effect on the area of the bladder exposed to the force, more the inflation more steep is the force pressure curve (Figs. 3 and 4). If the bag is grossly under-inflated, after the force exceeds a certain limit, the fluid in the bladder is almost maximally compressed, and the force-pressure curve becomes flat (Fig. 3-d bottom right, '200 ml'). Since progressive increase in force flattens the bag, for a given inflation, the curve is less steep for larger forces (Figs. 3 and 4). The curves for the air filled system appear to be less affected by the degree of inflation than the curves for the water filled system (compare Fig.3b and Fig.4 with Fig.3c). The reason appears to be that in case of air, Boyle's law also becomes operative. With progressive increase in force, the volume of air filling the bladder decreases, leading to an inversely proportional change in the pressure irrespective of the area of the bladder compressed.

The maximum hand grip tension measured by the fabricated dynograph correlates extremely well ($r = 0.86$) with that measured by one of the standard instruments for the purpose. But the endurance periods measured by the two instruments are very poorly correlated ($r = 0.23$). The explanation appears to be that the standard instrument available causes pain if pressed for a long time. Therefore, the endurance period measured by it reflects the threshold for pain rather than true muscle fatigue. This impression was further confirmed by a few observations on the reference dynamometer wherein an attempt was made to maintain less tension - i.e. 60% or 70% of the maximal tension. The endurance period was still found to be essentially the same. On the other hand, the dynograph described here can be comfortably pressed for a long time, and the limiting factor for exerting sustained tension is truly the muscle fatigue. That is why there is considerable individual variation in the endurance period, as also variation within the same individual, as would be expected in any parameter which measures some aspect of human performance. In

addition to this advantage, the device also has the advantage that it provides a constant, convenient and prominent feed back to the subject about any fluctuations in sustained pressure. This enables the subject to monitor his effort and alter it suitably to keep it constant. It also gives a permanent written record unlike the reference instrument. Further, it can be assembled from equipment available in every physiology laboratory with the mere addition of the wooden device which would cost next to nothing.

In general, it was found that the endurance period for a given individual increased gradually at every session, thus displaying the effect of practice.

Although the device described here is for handgrip tension, its design can be adapted for measurement of the strength of other muscle groups also.

The body weights measured by the fabrication reported here, and a standard weighing machine, are extremely well correlated ($r = 0.98$), thereby indicating the reliability of the fabrication.

APPLICATION

1. *Handgrip dynograph :*

Maximum isometric tension and isometric endurance are important parameters of physical performance. The dynograph may be used wherever these parameters have to be measured for research or teaching.

2. *Weighing machine :*

(i) *Clinical practice :* Many rural centres and practitioners possess a sphygmomanometer, but not a weighing machine. By procuring the wooden fabrication described here, they can use the sphygmomanometer to measure the body weight as well. If adopted commercially, the wooden attachment and calibration tables may be supplied along with the sphygmomanometer. In fact, it can be supplied also as a direct reading instrument. On one side of the manometer may be fixed the usual *mm* scale, and on the other an appropriate *kg* scale.

(ii) *Field work :* Many surveys involve going from place to place, sometimes on foot. In such cases, the weight and volume of the equipment assume considerable importance. In surveys where blood pressure and body weight need to be measured, a mercury or aneroid sphygmomanometer may be supplemented with the light weight, unbreakable attachment described here.

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