preciable extent at lower flow rates. This finding gives rise to the interesting observation that, for constant-surface pellets, the system is, in a sense, more "homogeneous" at lower agitation intensities. Determination of solvent flow patterns in the dissolution chambers at different flow rates would aid in the selection of proper flow rates for any particular system. Such studies, using the method described by Withey and Bowker (7), are in progress in these laboratories.

Beaker Method—In a previous publication (5) dealing with tablet formulations, the three-bladed stirrer (50 r.p.m.) method of agitation resulted in a faster dissolution rate than the rotating basket method (100 r.p.m.). Yet the nomogram in Fig. 10 shows that the three-bladed stirrer, even at 200 r.p.m., produced a slower dissolution rate than the rotating basket at 100 r.p.m. The following explanation emphasizes the inherent difficulties associated with the beaker system. When working with disintegrating tablets, the granules fall out of the basket and are then subject to lower (actual) agitation intensities beause they are not in close proximity to the basket. This problem is compounded by the fact that the basic design of the basket makes it a poor stirring device for the solvent. The three-bladed stirrer was designed to agitate and therefore provided greater agitation than did the rotating basket in the tablet formulation experiments, especially after disintegration took place. However, with the nondisintegrating pellet the solid remains in the basket and is continuously subjected to the recorded rotational speed. Furthermore, in these experiments, the pellet was in the stationary basket well removed from the three-bladed stirrer; thus the agitation intensity near the pellet was considerably less than that near the blades. With the USP disintegration apparatus, the dissolution of the pellet was undoubtedly slowed by positioning it on the bottom of the beaker.

These results indicate that, with the beaker method, unwanted variations are likely, depending on the nature of the dissolving solid (disintegrating or nondisintegrating) and the particular conditions of the experiment (placement of the solid in relation to the stirrer, *etc.*). In addition, the "constant" stirring does not yield a constant (effective) agitation intensity throughout experiments with disintegrating tablets; the agitation near the intact tablet is quite different from that near disintegrated particles dispersed throughout the medium.

Comparison of Methods—The inherent deficiencies of the beaker method are essentially absent with the flow method. First, after defining the cell size, the only variable under nonturbulent flow conditions is the flow rate. Even under turbulent flow conditions, the problems seen with the pellet are reduced with disintegrating tablets, since the granules are usually small enough to circulate throughout the dissolution chamber.

Second, in light of the importance of low agitation intensities, it is encouraging to see (Fig. 10) that flow rates of less than 10 ml./min. with the 25-mm. cell yield agitation intensities lower than those provided by the three-bladed stirrer at 50 r.p.m. The inherent advantages of the flow method are emphasized by the fact that the lower flow rates needed for more laminar flow are most likely to yield meaningful *in vitro–in vivo* correlations.

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Evaluation of Tablet Breaking Strength Testers

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Abstract ☐ The objective of this study was to determine the relative merits of various tablet hardness testers now used along with one new tester, the Heberlein (Tester A). The Instron Tension-Compression machine (Tester B) was used as the standard machine to which all comparisons were made. A force washer was calibrated using the Instron machine, and the identical force washer anvil setup was used on various air-operated testers for comparative measurements. The air-operated testers studied were the Strong-Cobb (Tester C1) and three modified Strong-Cobb testers (Testers C2, C3, and C4). At an Instron breaking load of 6.00 kg., Testers C2, C3, and C4 gave scale readings (kilograms per square inch) of 9.60, 9.53, and 10.2, while Tester C1 gave a reading of 10.8. Tester A results were 10–15% higher than those of Tester C1 when the units of comparison were Strong-Cobb units. The kilogram scale on Tester A gave values about 10% higher than those of Tester B. A review of the current literature on this subject is given together with a theoretical analysis of tablet breaking. From the results obtained, it is apparent that there are distinct advantages to using a hardness tester with a mechanical drive rather than a pneumatic type, because more uniform force application rates may be achieved and there is less maintenance work and less need for calibration checks.

Keyphrases ☐ Tablets, strength—evaluation and comparison of six testers, theoretical aspects of tablet breaking ☐ Strength, tablets—evaluation and comparison of six testers, theoretical aspects of tablet breaking ☐ Hardness testers for tablets—mechanical *versus* pneumatic driven, theoretical aspects of tablet breaking, calibration method for force response

The determination of tablet breaking strength (tablet hardness test) has become an important measurement in the formulation and manufacture of compressed tablets. During formulation, breaking strength is determined along with friability and disintegration–dissolution measurements since these factors are often inter-

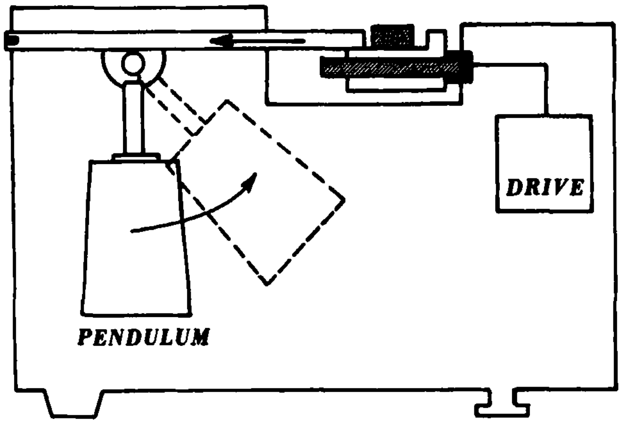

Figure 1—*Operating principle of the Heberlein (Tester A) hardness tester. (See text for description.)*

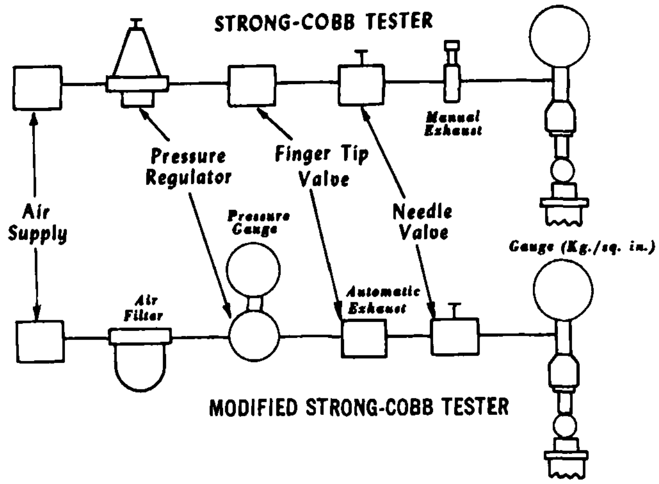

Figure 3—*Diagrammatic representation of air-operated hardness testers. (See text for description.)*

related. Generally, a manufacturing formula contains a breaking strength specification. A specified range of breaking strength indicates that factors such as disintegration, chewability, and friability (which, in turn, is related to packaging and handling properties) are all within acceptable limits. Since measurement of breaking strength is simpler and less time consuming than testing friability and disintegration, it has become a common control procedure in tablet manufacturing.

DISCUSSION

Various instruments have been used over the years to measure tablet breaking strength. The most popular ones are the Strong-Cobb, hand and air operated, and the Monsanto. The Pfizer and Erweka testers are also frequently used in this country. The fact that various instruments are used attests to some dissatisfaction among users. One problem with the use of hardness testers is the question of operator variability. On those testers where mechanical force is applied by hand, operator variability can be a significant factor in the results obtained. Another factor that causes suspicion on the part of users is the lack of adequate or even recommended calibration procedures for ensuring the accuracy of testers. However, Brook and Marshall (1) described a calibration procedure for various testers using a piezo-electric force transducer.

Specific deficiencies in the Strong-Cobb, Monsanto, Pfizer, and Erweka testers were pointed out by Brook and Marshall (1) and Ritschel *et al.* (2). The Strong-Cobb tester records breaking strength as air pressure in kilograms per square inch rather than as a compressional load. Therefore, its scale values cannot be directly compared to other testers that have force scales. The Strong-Cobb instrument needs frequent checking and calibration, because the air cylinder gets dirty easily and this interferes with plunger movement. Also, the needle valve sometimes needs adjustment so that the load is applied at a uniform rate. Ritschel *et al.* (2) reported an initial delay in the registration of pressure for this tester. Brook and Marshall (1) demonstrated that three new Monsanto testers agreed fairly well in reproducibility among instruments, but two older instruments gave significantly higher readings and this was attributed to fatigued springs. However, Ritschel *et al.* reported that two older instruments of the same kind gave lower readings and questioned the initial uniformity of springs in testers when they are produced. The Pfizer tester was tested by both groups of researchers, and Ritschel *et al.* reported that their results did not conform to those of Brook and Marshall. Spring fatigue and manufacturing variations were again mentioned as factors. Significant operation variability was found when using the Pfizer tester and was believed to be caused by a variable rate of load application. The Erweka tester presumably eliminates operator effects, since it is mechanically driven; but it has been shown that significant large zero errors can occur (1). Ritschel *et al.* (2) found a surprisingly large operator variation for the Erweka tester.

A number of other testers have been employed to a lesser extent; these are the Dynstat (3), the DBT (2), and a Dillon force gauge setup (4). A new instrument, the Heberlein (Figs. 1 and 2) became available in this country in 1970. Both hand- and motor-operated versions are available. This instrument provides a horizontal mounting surface for the tablet. The right side of the instrument contains a horizontal shaft and rectangular anvil which contacts the tablet during operation. The left-hand side of the instrument also has an anvil and shaft. The shaft is connected by a gear to a pendulum weight inside the instrument housing. When in operation, the pendulum is displaced until the tablet breaks. The degree of displacement of the pendulum is recorded on a scaled dial on the front of the instrument. This dial is calibrated in kilograms and Strong-Cobb units. The instrument calibration can be simply checked by mount-

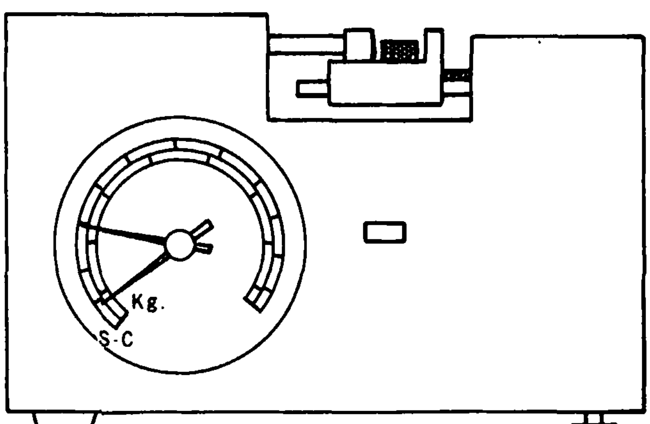

Figure 2—*Schematic diagram of Tester A hardness tester. (See text for description.)*

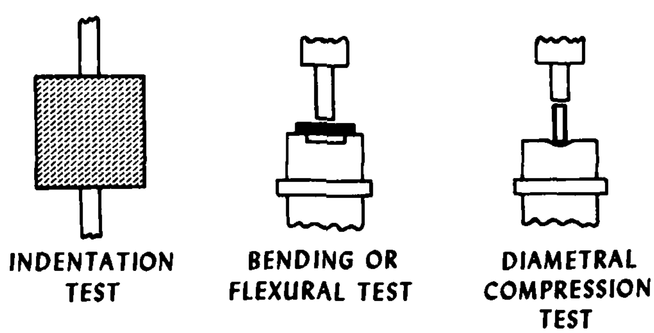

Figure 4—*Methods of determining the breaking strength of brittle materials. (See text for description.)*

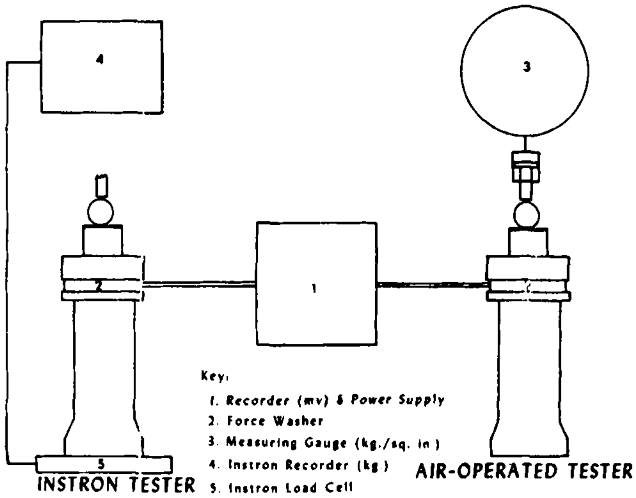

Figure 5—*Schematic view of the method for comparing force washer response to Tester B and air-operated testers. (See text for description.)*

ing a weight over a pulley and attaching it to a screw which fits into the left-hand shaft connected to the pendulum. The results obtained from the hand-operated and motor-driven units do not agree (2).

The Strong-Cobb and modified Strong-Cobb testers operate on the same mechanical principle and resemble each other in appearance. However, the modified Strong-Cobb tester has several features not supplied with the Strong-Cobb tester (Fig. 3). It includes an air filter in the apparatus to ensure clean air to the instrument. Both instruments have pressure regulators, but the modified Strong-Cobb tester has a pressure gauge to allow for adjustment of air pressure to the tester. Another difference is the kind of needle valve used on the two testers. The Strong-Cobb tester is adjustable by means of a handle at the back of the instrument. The modified Strong-Cobb tester has a more sensitive needle valve which is adjusted with a screwdriver during calibration. The function of these valves is to provide a certain rate of pressure application. Moreover, the Strong-Cobb tester has a manual exhaust while the modified Strong-Cobb tester has an automatic exhaust. An automatic exhaust releases the air pressure when the tablet breaks. The piston of the Strong-Cobb tester plunges to the anvil when a tablet breaks and the pressure must be relieved manually.

Instructions for the Strong-Cobb tester indicate that an in-line air filter should be used. Also, the pressure regulator is set by the factory to supply 27.2 kg. (60 lb.) of pressure. The instructions suggest that the needle valve be adjusted for various-sized tablets, giving a slow rate of load application for soft tablets and a higher rate to the harder tablets.

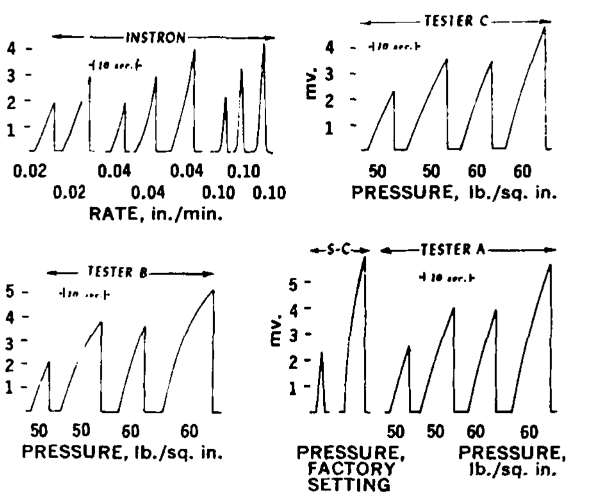

Figure 6—*Response of various hardness testers to 1.59-cm. steel slugs. (See text for description.)*

Table I—Calibration of the Force Washer Using the Tester B Machine

Run	Response Curve[a]	Correlation Coefficient	Predicted Load at 2.0 mv.
Day 1	kg. = 0.059 + 2.94 mv.	1.00	5.94
Day 2	kg. = 0.059 + 2.94 mv.	1.00	5.94
Day 3	kg. = −0.053 + 3.10 mv.	1.00	6.15
Day 4	kg. = −0.018 + 3.10 mv.	1.00	6.00

[a] Includes data for three sizes of steel slugs and three rates of load application.

The modified Strong-Cobb tester is checked for calibration routinely by the maintenance shop. Calibrations are made using a spring tester and gauge, which is checked for accuracy using a deadweight tester. The tester is adjusted for rate using the needle valve to give a scale reading of 15 in 10 sec. at 22.7 kg. (50 lb.) of air pressure. Before this calibration, the freedom of piston movement must be checked. Dust particles that enter the cylinder body on exhausting will retard free movement of the plunger or cause leakage around the neoprene cylinder washer. Testers should periodically be dismantled and cleaned. The plunger should be lubricated periodically to ensure free movement.

THEORY OF TABLET BREAKING STRENGTH

Many papers have appeared on the evaluation of tablet hardness testers, but only a few papers have treated the theory of tablet breaking strength tests (5, 6). The following discussion is included to give a basic view of tablet breaking strength.

The testing of tablet crushing strength is more fundamentally known as the determination of *breaking load.* Breaking load is one means of measuring the *tensile strength* of brittle materials. Various methods of tensile strength testing were described in detail by Berenbaum and Brodie (7) and by Earnshaw and Smith (8). The three kinds of tensile strength testing described by these authors are the *indentation test*, the *bending* or *flexural test*, and the *diametral compression test* (Fig. 4).

The principle of the indentation test is to compress a cubic specimen on opposite sides using a pair of flat-ended indenters (Fig. 4). When a material fails under tension, a vertical crack appears, whereas failure of shear strength results in a large number of irregular broken pieces. The values for tensile strength and shear strength can be determined using the indentation test by altering the thickness of the sample and the diameter of the indenter. For the indentation test to measure breaking load under tension, the shear strength of a material should be at least four times the tensile strength.

An alternative to direct tensile strength measurement is the bending or flexural test (Fig. 4). In this test the specimen is supported at several points, and a load is applied from above which causes the sample to break. This test was criticized by Rudnick *et al.* (9) because of nonuniform stress distribution, which in practice gives results that are considerably in excess of true tensile strength. The bending test was adapted to the Strong-Cobb tester by Endicott *et al.* (10) and to the Erweka tester by Delonca *et al.* (11). This type of measurement was shown to give smaller and more precise results.

A third method, the diametral compression test (Fig. 4), is the most accepted method of measuring tensile strength. In this test a

Table II—Summary of Correlation Results Obtained from Running Tablets and Steel Slugs on Tester B and Monitoring with the Force Washer[a]

Specimen	Response Curve
Tablets	mv. = 0.047 + 0.354 kg.
Slugs	mv. = −0.007 + 0.330 kg.
Tablets	kg. = −0.117 + 2.816 mv.
Slugs	kg. = −0.012 + 3.024 mv.

[a] Includes data for three sizes of steel slugs and three tablet sizes, each made at two compression force levels, and tested at three rates of load application on Tester B.

Table III—Response of the C Type Testers Using a Steel Slug and Tablet and Monitoring with the Force Washer[a]

Tester[b]	Specimen	Response Curve[c]	Correlation Coefficient	Predicted Scale Reading at 2.5 mv.[d]
C1	Steel slug	S.R. = 0.77 + 4.05 mv.	1.00	10.90
C1	Tablet	S.R. = 0.88 + 4.11 mv.	0.96	11.16
C2	Steel slug	S.R. = 0.16 + 3.76 mv.	1.00	9.56
C2	Tablet	S.R. = 0.01 + 4.22 mv.	0.98	10.56
C3	Steel slug	S.R. = 1.11 + 3.75 mv.	1.00	10.48
C3	Tablet	S.R. = 1.12 + 3.57 mv.	0.99	10.05
C4	Steel slug	S.R. = 0.92 + 3.89 mv.	1.00	10.65
C4	Tablet	S.R. = 1.96 + 3.50 mv.	1.00	10.71

[a] Response curves of the 1.59-cm. slug were generated from 32 measurements on each tester. Response curves of tablets were generated from 20 or 30 measurements on each tester. [b] See text for designation of tester. [c] S.R. = scale reading in kilograms per square inch. [d] Calculated from equation under response curve column.

right circular cylinder, disk, or tablet is compressed between platens in contact with the edges of the sample. A uniform tensile stress occurs across the diametral plane joining the two lines of contact of the specimens and platens. The tensile strength is directly proportional to load, and its magnitude is given by the equation (5):

$$\sigma_x = \frac{2P}{\pi DT} \qquad \text{(Eq. 1)}$$

where σ_x is the tensile strength, P is the applied load, D is the diameter, and T is the thickness of the specimen.

Both tensile and compressive stresses exist along the loaded diameter of a tablet under test. Compressive and shear stresses vary along the loaded diameter and are maximal at the points of contact. Use of Eq. 1 is contingent principally on a vertical break as previously described. Another precaution in the determination of tensile strength by the diametral compression test is to minimize the area of contact between the platen and the specimen. The smaller contact area reduces the compressive and shear stresses in regions near the applied load where they are greatest and where the specimen will most likely break in tension. Fell and Newton (5) demonstrated the use of soft padding material between the tablet and the platen in testing the strength of various lactose tablets. This was necessary to obtain breakage of tablets in tension only and thus provide more reproducible results.

A multiobjective study of three tablet hardness testers was undertaken to determine their relative merits and shortcomings as routine instruments. The testers studied were: (*a*) the air-operated Strong-Cobb tester, (*b*) three modified Strong-Cobb testers containing some upgraded components to improve their performance[1], and (*c*) the electrically operated Heberlein tester which is a constant-speed motorized unit. The objectives were: (*a*) to determine if all three kinds of instruments give the same crushing strength readings, (*b*) to determine the accuracy and precision of the testers, and (*c*) to obtain a method of calibration for the testers.

EXPERIMENTAL

Equipment—The Instron Tension-Compression machine, model TM (Tester B), was used as the standard machine to which comparisons of the three testers were made. The anvils of the Strong-Cobb tester (Tester C1) and the modified Strong-Cobb testers (Testers C2, C3, and C4) are easily removed and can be used as mounting supports for the specimens being tested on Tester B. A force

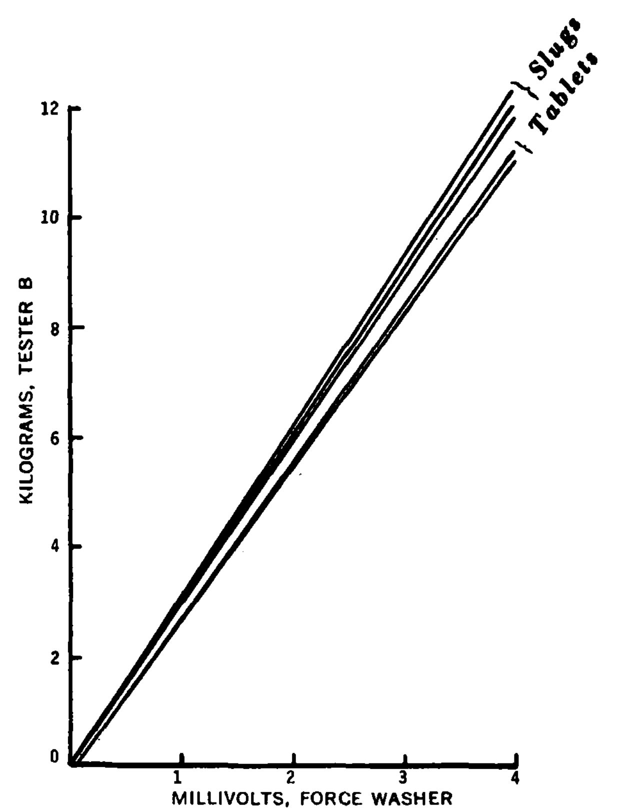

Figure 7—*Comparison of Tester B force response to force washer, 1.59-cm. steel slug and 1.59-cm. tablet.*

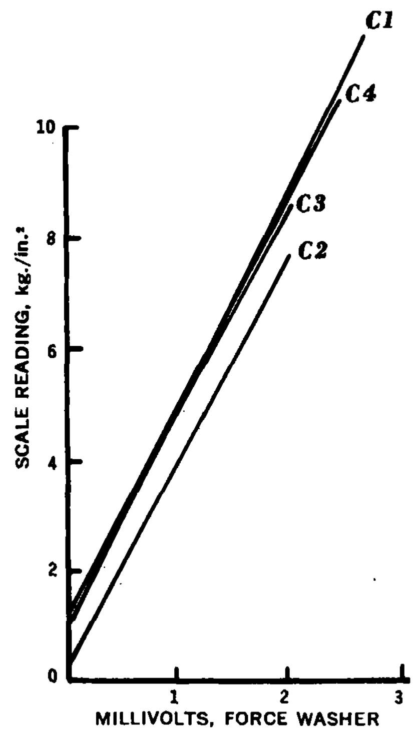

Figure 8—*Response of various air-operated hardness testers using steel slugs.*

[1] These testers are made by the maintenance shop, Warner-Lambert Co., Morris Plains, N. J.

Table IV—Comparison of Breaking Strength Obtained from Tester B to the C Type Testers

Instrument[a]	Correlation Analysis	Breaking Load, kg., at Scale Reading of 10.0	Scale Reading at Breaking Load of 6.00 kg.
C1	kg. (Tester B) = −0.08 + 0.562 × (scale reading)	5.54	10.8
C2	kg. (Tester B) = 0.28 + 0.596 × (scale reading)	6.24	9.60
C3	kg. (Tester B) = −0.32 + 0.663 × (scale reading)	6.31	9.53
C4	kg. (Tester B) = −0.55 + 0.644 × (scale reading)	5.89	10.2

[a] See text for instrument designations. [b] Data illustrated in Fig. 9.

washer[2] was obtained and mounted on the anvil as illustrated in Fig. 5. The force washer was the full wheatstone bridge type, having a maximum load capacity of 27.2 kg. (60 lb.). It was activated by a 6-v. power supply[3], and its output was recorded in millivolts on a strip-chart recorder[4]. A steel plunger having the same diameter as is used on Testers C1, C2, C3, and C4 was made for use with the Tester B machine. Specimens were mounted as illustrated in Fig. 5, and an Instron force reading as well as a force washer reading was obtained simultaneously. In this way, the force washer was calibrated and could be used as a secondary standard when the entire anvil assembly was used with the type C testers.

Materials—Stainless steel slugs, having 1.59-cm. (0.63-in.), 1.11-cm. (0.43-in.), and 0.71-cm. (0.28-in.) diameters, were made to use as artificial tablets for the comparison of instruments. Tablets of the same diameter were also made, consisting of 64.5% spray-dried lactose, 35% microcrystalline cellulose, and 0.5% magnesium stearate. A number of tablets were made as uniform as possible by

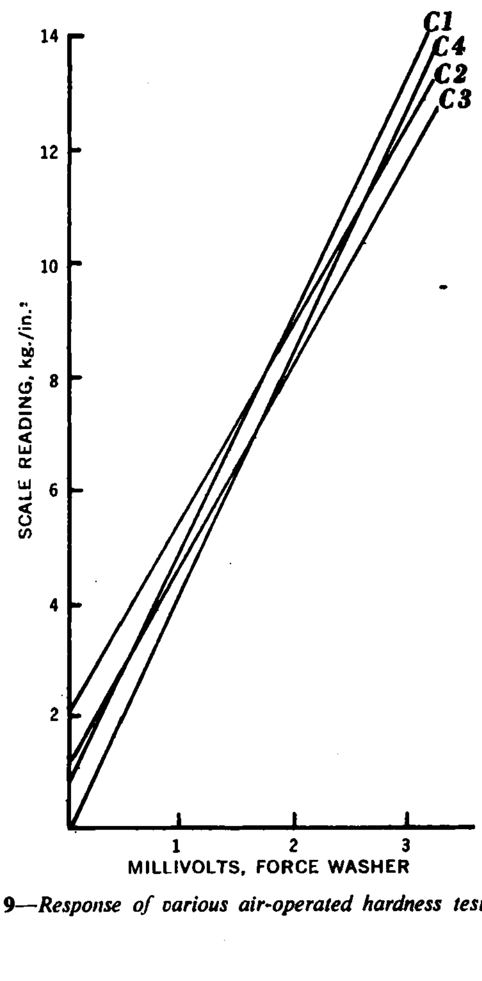

Figure 9—*Response of various air-operated hardness testers using tablets.*

[2] Model 1200B, Houston Scientific Industries, Inc., Houston, TX 77018
[3] Model 801C, Hewlett-Packard, Paramus, NJ 07652
[4] Electronic 19, Honeywell Industrial Division, Fort Washington, PA 19034

weighing the correct quantity of granulation and compressing tablets on an Instron tester (model TT) using standard 1.91-cm. (0.75-in.) barrel diameter punches and a 3.02-cm. (1.19-in.) die. These tools were used in a special jig which serves as a holder for compression of a single tablet. Tablets of 1.59-cm. (0.63-in.) diameter weighed 1.15 g. and were compressed at 907, 1134, and 1361 kg. (2000, 2500, and 3000 lb.); tablets of 1.11-cm. (0.43-in.) diameter weighed 500 mg. and were compressed at 726 and 930 kg. (1600 and 2050 lb.); and tablets of 0.71-cm. (0.28-in.) diameter weighed 150 mg. and were compressed at 454 and 680 kg. (1000 and 1500 lb.). Tablets were stored in well-sealed glass bottles until ready for testing.

RESULTS

Response of Force Washer—The steel slugs were mounted on the anvil of type C testers and the assembly was then placed into position on the load cell of Tester B (Fig. 5). The assembly was centered under the plunger, which was attached to the upper platen of Tester B. Tester B and the strain-gauge recorder were zeroed before each run. Three rates were tested: 0.051, 0.102, and 0.254 cm./min. (0.02, 0.04, and 0.10 in./min.), and runs were made on 4 separate days.

The results of typical runs are illustrated in Fig. 6, which shows recordings obtained from the force washer. A series of correlation analyses was made from the data compiled from various force washer peak heights *versus* the load value from Tester B. No significant differences were found for the three sized slugs or the three rates used. Table I summarizes the calibration curve data for 4 separate days, in which each day includes all slug sizes and all rates of load application. At a 2.0-mv. (about 6.01-kg.) reading, the predicted load on various days varied by no more than 3.5% with a high degree of correlation.

The same experiment was repeated using tablets of different sizes and made with various compression forces. Tester B load readings were again compared to the millivolt output of the force washer, and the results of the correlation analysis indicate that the rate of load application, tablet size, and compression force used to make the tablets were not significant factors in the results obtained. The pooled results from both tablets and slugs are given in Table II.

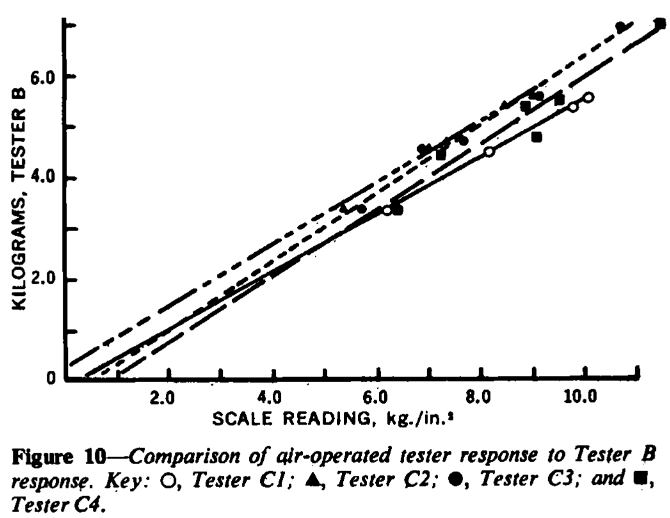

Figure 10—*Comparison of air-operated tester response to Tester B response. Key:* O, *Tester C1;* ▲, *Tester C2;* ●, *Tester C3; and* ■, *Tester C4.*

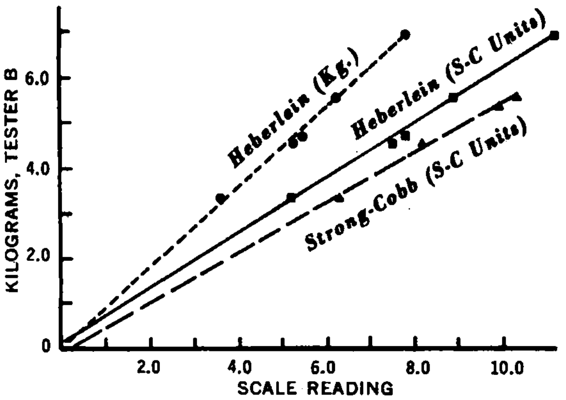

Figure 11—*Comparison of breaking strength of Testers B, C1, and A.*

Table V—Comparison of Breaking Strength Obtained from Tester B to Testers C1 and A

Instrument	Correlation Analysis	
Tester A	kg. (Tester B) =	0.05 + 0.624 × (scale reading in Strong-Cobb units)
Tester A	kg. (Tester B) =	0.01 + 0.901 × (scale reading in kg.)
Tester C1	kg. (Tester B) =	−0.08 + 0.562 × (scale reading)

The results for both steel slugs and tablets are illustrated in Fig. 7. Although the results from each experiment were linear, the force washer response for these two different materials was somewhat divergent. A possible explanation for this result is that the tablets were more resilient than the steel slugs. However, the main objective of this part of the experimentation was to prove good linearity and reproducibility in the force washer response. Having achieved excellent working characteristics on the anvil-force washer combination, the same setup could be used to evaluate the operating characteristics of the C type hardness testers.

Response of the C Type Testers Using a Steel Slug and Tablets—Testers C1, C2, C3, and C4 were tested for response using a 1.59-cm. steel slug and the various tablets described in the *Experimental* section. The same anvil-force washer assembly was used as described for the Tester B machine. The hardness testers were used in the normal fashion, and both the force washer readings and the instrument gauge readings were recorded. These results are illustrated in Figs. 8 and 9; the correlation analysis is given in Table III.

These results indicate good linearity in response for both specimens on all testers. For the slug, similar slopes were obtained for Testers C1, C2, and C3, but Tester C1 gave a somewhat higher slope. Positive intercepts were obtained for all testers, but Tester C2 had a much lower intercept than the other testers. These intercept data contrast with the results for Tester B, which were nearly zero for both tablets and slugs.

The results obtained for tablets were similar to those obtained for slugs, but there was less agreement between slopes of the various testers. Tester C2 had a lower intercept for tablets than the other three testers and this compares to the results obtained for slugs. For testers having intercepts which were significantly different from zero, no simple conversion factor to a kilogram force measurement can be given. For Tester C2, whose intercept was practically zero, a conversion factor of scale reading to kilograms is about 0.66. This factor is derived from the results of the Tester B response curve for tablets in Table II. Brook and Marshall (1) reported a conversion factor of 0.728 for the Strong-Cobb hardness tester, and Strong-Cobb claims a theoretical factor of 0.78 based on a 2.54-cm. (1-in.) cylinder area of the piston drive. The high positive intercepts for three of the testers indicate that a higher than expected loading is occurring early in the run or that significant curvature exists in the early portion of the response curve. No readings were obtained

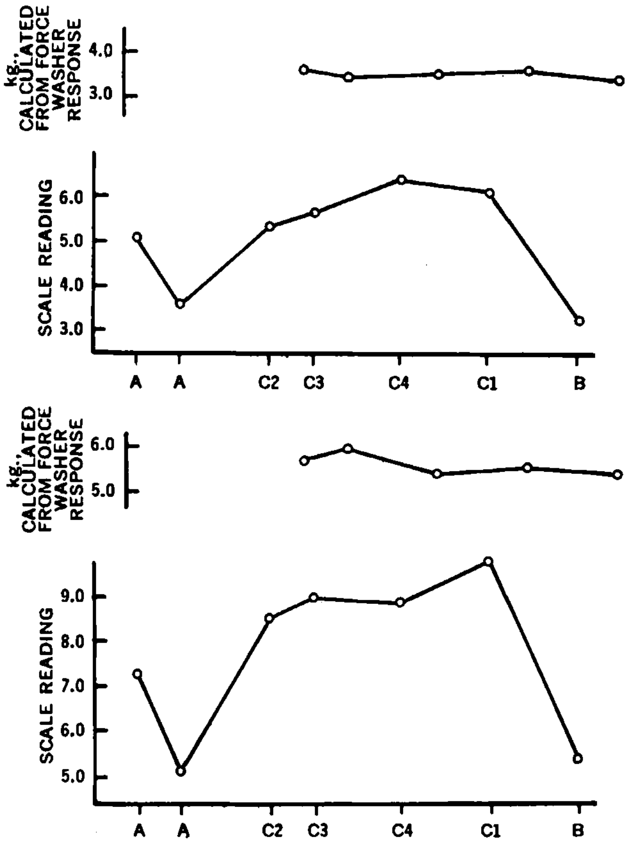

Figure 12—*Overall comparison of tester response, 0.71-cm. tablet. Upper curve is for 454-kg. compression force, and lower curve is for 680-kg. compression force. Units for Tester A are kilograms per square inch and kilograms (left to right); units for Testers C1, C2, C3, and C4 (air-operated testers) are kilograms per square inch; and units for Tester B are kilograms.*

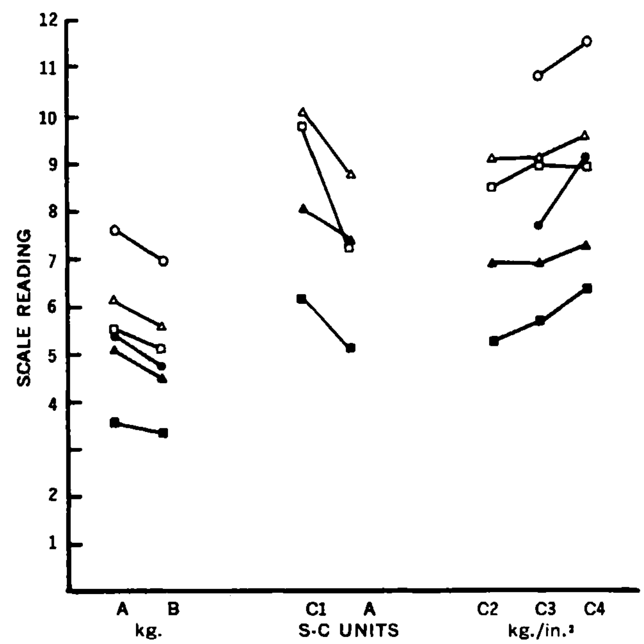

Figure 13—*Comparison of overall average results for various tablet sizes. Key:* ○, *1.59-cm. tablet, 1361-kg. compression force;* ●, *1.59-cm. tablet, 907-kg. compression force;* △, *1.11-cm. tablet, 930-kg. compression force;* ▲, *1.11-cm. tablet, 726-kg. compression force;* □, *0.71-cm. tablet, 680-kg. compression force; and* ■, *0.71-cm. tablet, 454-kg. compression force. (Tester A = Heberlein, Tester B = Instron, and Testers C1, C2, C3, and C4 = air-operated testers. See text for description.)*

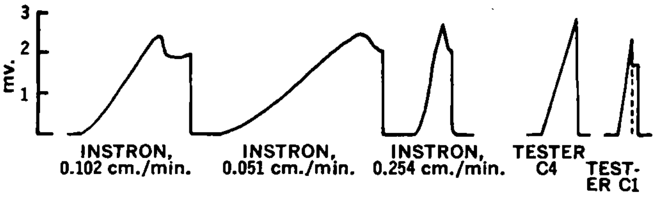

Figure 14—*Comparison of the rates of force application for tablets. Tester C4 = a modified Strong-Cobb tester, and Tester C1 = Strong-Cobb tester.*

below a scale reading of 4, which would have indicated whether initial loading or a curvature existed. A high initial loading would indicate some frictional forces in the instrument must be overcome before reaching linearity.

Calculated tester scale readings from the response curves listed in Table III indicate that a 2.5-mv. force washer loading (6.92 kg. equivalent from Tester B tablet response curve) gives readings of 11.2, 10.6, 10.1, and 10.7 for Testers C1, C2, C3, and C4, respectively. These data indicate that significant variations can occur between the same instruments when actually breaking tablets. Figure 3 indicates that the response slopes are more uniform with slugs than with tablets (Fig. 9). The individual tester response to tablets is dependent on both its intercept and slope.

Comparison of C Type Tester Response to Tester B Response—The results obtained from breaking random samples of the various, specially prepared tablets on the Tester B machine and the C type testers were compared as illustrated in Fig. 10. From this curve, the correlation of breaking strength in kilograms to scale readings can also be determined, and these comparisons are given in Table IV. A similar comparison could be made by combining response equations for the Tester B machine and the C type testers since a millivolt response was obtained for each.

The instruments are variable in response, as noted by the different slopes and intercepts for each tester. The data in general indicate that one conversion factor is not valid for conversion of scale reading to breaking load in kilograms. Table IV gives an example of the calculated load for a scale reading of 10.0 for each tester. The calculated scale reading for a 6.00-kg. breaking load is also given in the same table. Among the modified C type testers, a calculated range of 9.53–10.2 is obtained in scale readings. The Tester C1 calculated scale reading for a 6.00-kg. load is 10.8, which is significantly higher than the modified testers. The modified testers were calibrated by the previously mentioned procedure just prior to this work, and Tester C1 was new and used according to the instructions supplied. The reason for nonagreement between testers was not readily apparent during the testing.

Comparison of Tester C1 and Tester A Response to Tester B Response—Figure 11 illustrates the results obtained from breaking the specially prepared tablets on the Tester B machine *versus* the scale reading obtained from tablets broken on Testers C1 and A. The correlation analysis of Tester B breaking strength to the tester scale readings is given in Table V.

In comparing breaking strengths of tablets between Testers A and C1, it was found that the former tester gives significantly higher results and that these could be 10–15% greater than Tester C1, depending on the hardness range considered. The usually assumed "scale factor" of 0.78 (scale reading to kilograms) for Tester C1 does not compare favorably with the slope of 0.624 obtained for Tester A.

The kilogram scale on Tester A is about 10% higher than the actual breaking load determined on Tester B. A very small intercept was obtained for this correlation, indicating that a scale factor of 0.90 would be fairly accurate in converting Tester A breaking load in kilograms to Tester B breaking load in kilograms.

Overall Comparison of Tester Response—Overall comparisons between testers are illustrated in Fig. 12 for 0.71-cm. diameter tablets. The lower curve presents the scale reading from each instrument and illustrates the variability that can be expected by breaking tablets that are prepared in the most uniform method possible. In general, the results for Testers A and B in kilograms breaking load are significantly lower than the readings of other testers whose scales are in kilograms per square inch. Modified Testers C2 and C3 usually gave somewhat lower readings than Tester C4. Also, results of Tester C1 were higher than those of Testers C2, C3, and C4.

The upper curves in Fig. 12 illustrate the actual breaking load.

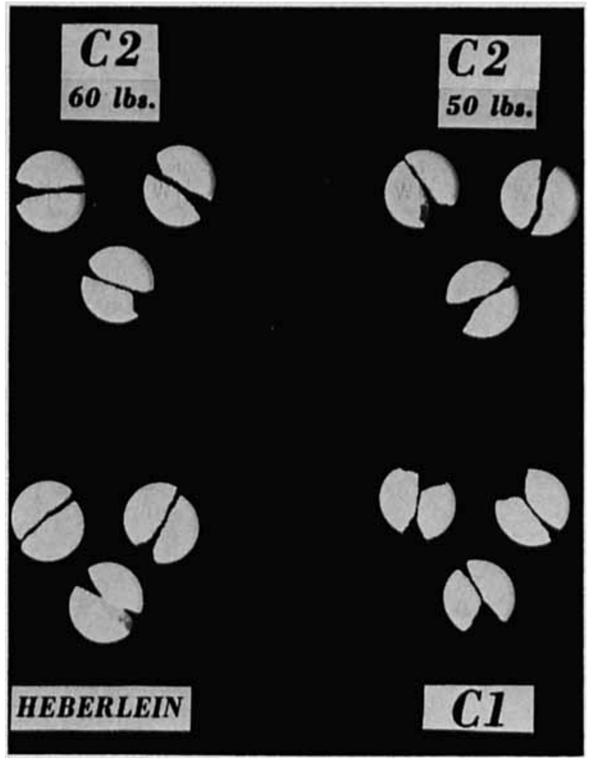

Figure 15—*Typical broken tablet fragments. Key: top, modified Tester C2 at 27.2 kg. (60 lb.) (left) and 22.7 kg. (50 lb.) (right) operating pressure; bottom, Tester A and Tester C1.*

The data for the air-operated testers were obtained by measurement of force washer response. The equation used for this calculation was given in Table II and is repeated here:

$$\text{kg.} = -0.117 + 2.816\ \text{mv.} \qquad \text{(Eq. 2)}$$

Under ideal working conditions for the testers, a relatively flat curve for breaking load would be expected. It has been shown that the force washer response was not significantly affected by using different sizes of tablets made at two compression force levels.

To illustrate the trends in the various testers, overall average scale readings were plotted for all tablets in Fig. 13. These data show that on the average the Tester A results in a kilogram breaking load consistently higher than Tester B. A comparison of Testers C1 and A indicates that higher values are obtained from Tester C1 and that these differences range from 0.8 to 1.6 units. Inspection of the results of modified Testers C2, C3, and C4 indicates that Tester C4 is 0.3–1.5 units higher in most instances.

Rate of Force Application—The force–response curve for the various testers was examined to determine whether this factor affected the breaking strength obtained. Figure 14 illustrates the type of force curves obtained for Tester B at three rates, for Tester C4, and for Tester C1. Tester B results indicate that a piston travel rate of 0.254 cm./min. approximates the rate of force application rate of Tester C4. Tester C1, however, applies force at a much faster rate, almost twice the rate of Tester C4 and Tester B. The rates of 0.102 and 0.051 cm./min. for Tester B are considerably slower than the rates obtained for any of the air-operated testers. The peak responses on the Tester B curve indicate the point of diametral cracking. Force level drops after cracking, but if the tablet remains in place the force level again rises, as seen for the 0.102-cm./min. rate (Fig. 14). The sharp drop is obtained on releasing the Tester B drive. The modified C type testers, in general, produce a diametral crack similar to Tester B, but several fragments may be formed. Typical broken tablet fragments are shown in Fig. 15. Of particular interest is the fact that the relatively fast rate of Tester C1 results in the shattering of the tablet. This fast rate is responsible for the more complex breakage of a tablet; *i.e.*, tablets are not broken in tension and this results in the higher scale reading results obtained for Tester C1.

A better understanding of the mode of force application can be seen in Fig. 6, which depicts curves obtained from the various testers with steel slugs. These slugs are rigid and are not penetrated by the plunger. This results in an increasing rate of force application when Tester B is used. The air-operated testers, on the other hand, give a decreasing rate of load application as load is increased. This occurs because of the buildup of pressure within the tester air cylinder to the point where it begins to approach the pressure level supplied to the tester. Sometimes hard tablets cannot be broken by using the air-operated testers, because of the limitation of force applied by these testers. Because of the change in the rate of load application of the air-operated testers at higher load levels, the constant-speed mechanical tester would be preferred. Figure 6 also points out the fact that variable rates are obtained for different air-operated testers and that this rate is not easily adjusted or controlled.

SUMMARY AND CONCLUSIONS

A suitable method of calibrating the force response of air-operated hardness testers was developed. The results obtained from various type C testers were variable and could be traced to inconsistencies between instruments such as variable rate of load application and variable friction in the piston. The Tester A instrument load scale (kilograms) gave values about 10% higher than were obtained in Tester B.

There are distinct advantages for using a mechanical tester such as Tester A:

1. More uniform force application may be achieved.
2. Less maintenance work is required.
3. There is less need for calibration checks.

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New *In Vitro* Disintegration and Dissolution Test Method for Tablets and Capsules

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Abstract □ An *in vitro* technique for testing the disintegration and dissolution of tablets and capsules was developed and evaluated. The apparatus consists of a beaker with a cylindrical well in the bottom into which is placed a platform containing the dosage form to be tested. Shallow cylindrical depressions in the platform are used to hold capsules snugly in a vertical position for testing while variously shaped depressions are used for tablets, depending on their size and shape. Comparisons between the official and the new method indicated that the official test does not differentiate between capsule formulations containing a hydrophobic lubricant. A phenylpropanolamine hydrochloride capsule formulated with a high level of magnesium stearate was shown to release drug more slowly *in vitro* and *in vivo*. The effects of capsule formulation factors such as type and level of lubricant and disintegrant as well as the presence of a surfactant were determined. It was found that the use of magnesium stearate and hydrogenated vegetable oil as lubricants significantly prolonged the *in vitro* disintegration time of hard gelatin capsules. Hard gelatin capsules also disintegrated more rapidly in artificial gastric fluid as compared to distilled water, and machine-filled capsules generally disintegrated more slowly than hand-filled capsules. Studies on tablets containing a slightly water-soluble drug indicated that the method of preparing the granulation has an important effect on the *in vitro* release of the drug.

Keyphrases □ Dissolution—method and equipment for tablets and capsules, compared to compendial method □ Tablet dissolution—method and equipment, compared to compendial method □ Capsule dissolution—method and equipment, effect of lubricant and disintegrant characteristics, surfactants, compared to compendial method □ Surfactant effect—dissolution of capsules, method, equipment □ Phenylpropanolamine hydrochloride capsule—dissolution characteristics, effect of formulation

Progress in *in vitro* dissolution technology of solid dosage forms resulted in the adoption of a specific apparatus and methodology by NF XIII and USP XVIII for testing drug availability from tablets and capsules. In addition, the basket-rack assembly is still recognized by the official compendia as a test method for the disintegration of tablets. No test method has ever been adopted for testing the disintegration of capsules. *In*